SOKOINE UNIVERSITY OF AGRICULTURE

DIRECTORATE OF POSTGRADUATE STUDIES, RESEARCH, TECHNOLOGY TRANSFER AND CONSULTANCY

# Proceedings of the 2nd SUA Scientific Conference on *Research and Technological Innovations Towards Transformation of Lower Middle Income Countries* held at the SUA Edward Moringe Campus, Morogoro-Tanzania from 25th to 26th May 2021

**Edited by:**
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Prof. E.D. Karimuribo
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ISSN 0856-664X

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**June, 2022**

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# Preface

We are privileged to publish the Proceedings of the 2nd SUA Scientific Conference on *'Research and Technological Innovations Towards Transformation of Lower Middle Income Countries'*. The conference was organised by Sokoine University of Agriculture (SUA) to commemorate and honour the life and legacy of the late Hon. Edward Moringe Sokoine, the former Prime Minister of the United Republic of Tanzania which was held from 25th to 26th May 2021 at the SUA Edward Moringe Campus grounds. The proceedings is an output of this scientific conference which serves as a platform to share the knowledge, innovations, solutions, and findings generated by researchers based at SUA as well as those from other national and international partner and collaborating institutions outside SUA.

The Proceedings is organised to cover major sub-themes of the conference namely: Agricultural innovations for enhanced food security and economic growth; Pests, diseases and innovative control strategies for improving food security and health; Policy Framework, Economic Transformation and Quality Livelihoods; Contribution of Forestry, Wildlife Management and Tourism towards economic development; Public Engagement in Research and Innovation for Sustainable Economic Transformation.

We take this opportunity to thank all contributors, from within and outside SUA, who made efforts to prepare high quality articles published in this proceedings. We appreciate support received from Senate Research and Publication Committee members, the Conference organizing committee, Editors of SUA-hosted journals; Tanzania Journal of Agricultural Sciences (Prof. C.N. Nyaruhucha) and the coordination team led by Prof. J.J. Kashaigili, Dr. A.W. Mwanri, Dr. Doreen Ndossi, Ms. R. Kiravu and Ms. L. Madalla during preparations of the proceedings. The Management of the Sokoine University of Agriculture is thanked for financial and materials support during organisation of the SUA scientific conference. We recognise generous support from different research projects during the conference.

I hope that you will find the proceedings to be a useful resource in terms of education and enrichment of your knowledge. Enjoy reading the proceedings!

Prof. E.D. Karimuribo
Director
Directorate of Postgraduate Studies, Research, Technology Transfer and Consultancy

# Identifying the Right Plants for Diverse Biocontrol Agents in Tropical Smallholder Bean Farming Systems

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**Abstract**

*Biocontrol agents such as predators, parasitoids and pathogens potentially regulate crop pests populations. The agents feed directly on the pests, oviposit in the pest body or cause disease in the pest. While biocontrol has become a commercial enterprise in temperate horticulture, there is much less information on the biocontrol agents present in smallholder agricultural systems in the tropics and little knowledge about the importance of plant diversity in supporting their biocontrol activities. A standardized botanical survey walk combined with observations of plant-insect interactions was conducted on field margin vegetation of 24 smallholder fields of common beans (Phaseolus vulgaris L.) in three elevation zones of a tropical ecosystem. Sweep nets were also used to capture the biocontrol agents and stored in 70% ethanol for detailed taxonomy where identification in the field was not possible. A wide range of biocontrol agents interacting with the field margin plants, particularly flowering forbs were revealed. The most preferred field margin plants were Ageratum conyzoides, Commelina benghalensis, Pennisetum purpureum, Panicum maximum and Tripsacum sp. The most common biocontrol agents found to interact with the field margin plants were spiders (Araneae), long-legged flies (Dolichopodidae), predatory and parasitic wasps (Ichneumonids and braconids), hoverflies (Syrphidae) and assassin bugs (Reduviidae). Preferences of the biocontrol agents to certain plant species were similar across all three zones, indicating the importance of such plants in terms of food resources, shelter or nesting sites. The preference of the biocontrol agents to some plant species indicates the need to identify the specific benefits of these species to the biocontrol agents to determine whether non-crop habitat manipulation might enhance natural pest regulation.*

***Keywords:*** Natural enemies, habitat manipulation, crop pest regulators, margin plants, tropical ecosystem.

## Introduction

Semi-natural habitats around tropical smallholder agricultural lands consist of diverse plants, useful in the provision of food resources, habitats, nesting sites and refuge sites to biocontrol agents. These agents may be predators, parasitoids or pathogens that are responsible for natural pest regulation. Some of the semi-natural habitats within the cropping landscapes that have been reported from various studies to be useful in enhancing biocontrol agents include field margins/hedgerows, woodland or shrubland and grassland (Holland *et al.,* 2017). Field margin vegetation is one of the common features around smallholder tropical farming systems responsible for enhancing populations of biocontrol agents. They can effectively promote more diverse biocontrol agent assemblages when there is also reduced pesticide use, tillage and enhanced crop cover compared with a conventionally managed crop (Vickery *et al.,* 2009). Field margin habitats provide food, nesting sites, overwintering sites, shelter and hosts to various predators and parasitoids which facilitates their enhanced biological control services in agro-ecosystems (Bianchi *et al.,* 2006; Gurr *et al.,* 2003; Landis *et al.,* 2000, Ramsden *et al.,* 2014). Many European nations and other developed countries have established these semi-natural habitats within the agricultural lands through agri-environment schemes to enhance biodiversity for various ecosystem services (Carvell *et al.,* 2007; Field *et al.,* 2007; Walker *et al.,* 2007; Scheper *et al.,* 2013). Non-crop habitats around croplands are more florally diverse, less disturbed and relatively permanent compared with the cropland. Generally, the presence of diverse plants within arable lands significantly influences the abundance and diversity of biocontrol agents regardless of the area of the non-crop habitat (Knapp & Řezáč, 2015; Pluess *et al.,* 2010; Jung *et al.,* 2008).

Biocontrol agents are enhanced by timely accessibility of prey as a food resource, floral resources as additional food, as well as shelter habitats and overwintering sites in case of disturbances (Ramsden *et al.,* 2014). Usually, biocontrol agents move from the field margin plants to the field crop during the growing season when there are abundant food resources and later back to the margin plants when the resources are scarce or due to agronomic disturbances (Girard *et al.,* 2011). Therefore, agricultural lands may be an unwelcoming environment for the biocontrol agents due to ecological simplification of the land with limited semi-natural habitats. Monoculture cropping systems together with the intensive application of agrochemicals in conventional farming are considered detrimental practices to many beneficial insects including the biocontrol agents in the field. The presence of semi-natural habitats within the agricultural lands provide suitable sites for the biocontrol agents and other beneficial insects to hide during farming disturbances like pesticide application, tillage, crop harvesting and other unfriendly farming practices. This highlights the importance of field margin plants in enhancing the population of the biocontrol agents where they act as refuge sites for the biocontrol agents to recolonize the cropland after disturbance.

Understanding the field margin plant species and various benefits provided by these features around arable fields is particularly important for their proper management. Some field margin plants are also reported to be the source of insect pests in the field through the provision of similar resources such as food and shelter. Drosophila suzukii and Stictococcus vayssierei are among the most reported pest species with several non-crop host plants along the field margin (Arnó *et al.,* 2016; Kenis *et al.,* 2016; Diepenbrock *et al.,* 2016; Tindo *et al.,* 2009). The information that a particular field margin plant may be more preferred by the insect pests is very useful for proper identification and management of the margin plants.

The smallholder agricultural lands of tropical ecosystems are largely heterogeneous and naturally surrounded by diverse field margin plants. However, these features around smallholder fields are highly used for feeding animals, as field boundary and sometimes for firewood (Elisante *et al.,* 2019) with limited research information on the role of these margin plants to the population of biocontrol agents. The intention of integrating agronomic and biodiversity objectives may widely be achieved through field margin establishment and management. Identification and maintenance of field margin plants within the smallholder tropical agricultural land is a potential measure towards enhancing the population of predators and parasitoids together with other beneficial insects. This study surveyed the field margin plant species available within the smallholder bean farming systems of tropical climate in Moshi rural district to evaluate the relationship between the margin plants and biocontrol agents. Specifically, the study focused on; i) identification of field margin plants in smallholder bean fields across elevation zones and ii) to assess the interaction between the biocontrol agents present in smallholder bean fields and the margin plants. The study sought to test the following hypothesis; i) The biocontrol agents in smallholder bean fields interact with the margin plants ii) Some field margin plants are more preferred by the biocontrol agents across elevation zones.

## Materials and Methods

### Study Sites

The study sites were located across three agricultural zones in Moshi rural district, Kilimanjaro region. The three zones were classified based on the elevation to understand the effect of elevation on field margin vegetation and their influence upon biocontrol agents for wider application in the tropical areas where zonation do exists (Bussmann, 2006; Seo *et al.,* 2008). The three elevation zones also differed in terms of climate, land use management and farming practices (Ensslin *et al.,* 2015; Soini, 2005), which may consequently influence the vegetation diversity and biocontrol agents present. The low zone was between 800 to 1000 m asl, the mid-zone was between 1001 to 1500 m asl and the high zone was between 1501 to 1800 m asl. The annual rainfall ranged between 600 to 2000 mm (increasing with elevation). In the high zone, the study sites comprised Mbahe village (3.23 ºS, 37.50 ºE) which is located in the Marangu Mangharibi ward. The mid-zone covered Mieresini village (3.33 ºS, 37.53 ºE) whereas the low zone covered Kilimo Makuyuni village (3.40 ºS, 37.55 ºE). All the sites were smallholder fields of common beans (*Phaseolus vulgaris*). The assessment was done under their normal farming practices but without pesticide application.

### Sampling design

The study involved 24 smallholder bean fields in all three elevation zones. In each zone, 8 bean fields were purposively sampled based on the size and length of the field margin vegetation. The length of the field margin vegetation chosen was at least 50 m.

### Data collection

Assessment of the specific interaction between the field margin plants and the biocontrol agents was done through a standardized survey walk where the bean field and the margin meet, along 50 m long. Constant observation of any biocontrol agent found on plants within 1m of the researcher was done for three hours, from 9.00 am to 12.00 noon, when the insects were more active (Montgomery *et al.,* 2021). Both the biocontrol agents and the plant species found interacting were recorded. The observed biocontrol agents were counted together as either visiting or feeding the plant or resting on it and it was not necessary for the biocontrol agent to be on the flower part. The insect identity and the plant with which it interacted were recorded in each case to identify the most preferred field margin plants by the biocontrol agents in each zone.

The biocontrol agents were captured using a sweep net and stored in 70% ethanol where identification in the field was uncertain. The margin plants found to interact with the biocontrol agents were collected for herbarium specimen where identification was impossible in the field. The collected biocontrol agents were identified based on morphological features at the life sciences laboratory, Nelson Mandela African Institution of Science and Technology (NM-AIST), Arusha, with further support from Tropical Pesticides Research Institute (TPRI), Arusha. The collected herbarium specimens were sent to TPRI and Royal Botanic Garden, Kew in the UK for identification.

### Data analysis

Network graphs were constructed from the collected data using the R program (R Core Team, 2018), version 3.5.1. Bipartite package (Dormann, *et al.,* 2008) was used to draw the networks via RStudio. To minimize complexity in the network graphs, only interactions that occurred more than 10 times between the biocontrol agents and the margin plants were included in the networks.

## Results

A total of 39 plant species (Table 1) were found interacting with different biocontrol groups for over 10 times (Figures 1, 2 and 3).

**Table 1: Surveyed field margin plant species in three elevation zones of Moshi rural district**

| Label | Plant species | Location |
|---|---|---|
| 1 | *Centella asiatica* | High and mid zones |
| 2 | *Oxalis corniculate* | High and mid zones |
| 3 | *Commelina benghalensis* | High, mid and low zones |
| 4 | *Drymaria cordata* | High zone |
| 5 | *Conyzae bonariensis* | High zone |
| 6 | *Asystasia mysorensis* | High and mid zones |
| 7 | *Ageratum conyzoides* | High, mid and high zones |
| 8 | *Richardia scabra* | High, mid and low zones |
| 9 | *Sporobus pyramidalis* | High zone |
| 10 | *Galingsoga parviflora* | High, mid and low zones |
| 11 | *Bidens fondosa* | High zone |
| 12 | *Bidens pilosa* | High and mid zones |
| 13 | *Cyperus rotundas* | High and low zones |
| 14 | *Persea americana* | High zone |
| 15 | *Tripsacum sp* | High zone |
| 16 | *Desmodium uncinatum* | Mid zone |
| 17 | *Digitaria velutina* | Mid and low zones |
| 18 | *Neonotonia wightii* | Mid and low zones |
| 19 | *Pennisetum purpureum* | Mid and low zones |
| 20 | *Senna spectabilis* | Mid zone |
| 21 | *Achyranthes aspera* | Mid zone |
| 22 | *Sida rhombifolia* | Mid and low zones |
| 23 | *Cynodon dactylon* | Mid zone |
| 24 | *Panicum maximum* | Mid and low zones |
| 25 | *Desmodium intortum* | Mid and low zones |
| 26 | *Hyparrhenia rufa* | Mid zone |
| 27 | *Amaranthus hybridus* | Mid zone |
| 28 | *Lantana camara* | Mid zone |
| 29 | *Emilia discifolia* | Mid zone |
| 30 | *Morus australis* | Low zone |
| 31 | *Thevetia peruviana* | Low zone |
| 32 | *Euphorbia heterophylla* | Low zone |
| 33 | *Tridax procumbens* | Low zone |
| 34 | *Leucas martinicensis* | Low zone |
| 35 | *Euphorbia hirta* | Low zone |
| 36 | *Indigofera trita* | Low zone |
| 37 | *Acacia tortilis* | Low zone |
| 38 | *Gynandropsis gynandra* | Low zone |
| 39 | *Launaea cornuta* | Low zone |

**Identified field margin plants supporting biocontrol agents in the high elevation zone (1501 to 1800 m asl)**

The biocontrol agents that were found to interact with the field margin plants more frequently in the high zone were spiders, long-legged flies, predatory wasps, parasitic wasps, hoverfly and tachinid fly (Fig. 1). Spiders were found to interact mostly with creeping plant species such as *C. benghalensis*, *D. cordata* and *C. asiatica* and few non-creeping plants like *A. conyzoides* and *C. bonariensis.* Long-legged flies highly interacted with Guatemala grass (*Tripsacum* sp.) while predatory and parasitic wasps were mostly interacting with A. conyzoides compared with other plant species. Similarly, hoverfly interacted more with A. conyzoides and to some extent with *D. cordata.* Lady beetle is one of the biocontrol agents that was observed to have very low interaction with the margin plants. Generally, the most preferred field margin plants to the biocontrol agents in the high zone were Tripsacum sp, *A. conyzoides* and *C. benghalensis*.

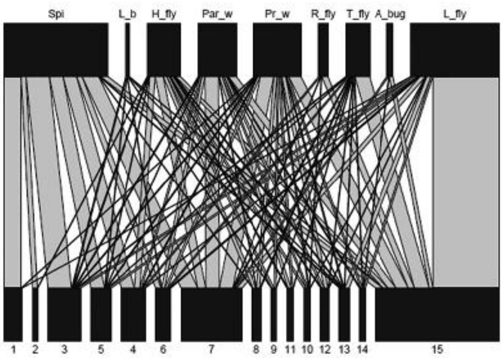


**Figure 1: Bipartite network graph between biocontrol agents and field margin plants in the high elevation zone in Northern Tanzania**

Each bar in the upper row represents biocontrol agents (Spi = spider, L_b = lady beetle, H_fly = hoverfly, Par_w = parasitoid wasps, Pr_w = predatory wasps, R_fly = robber fly. T_fly = tachinid fly, A_bug = assassin bug, L_fly = long-legged fly) and each numbered bar in the bottom row represents field margin plant species (Table 1). The width of the bars is proportional to the number of interactions.

**Identified field margin plants supporting biocontrol agents in the mid-elevation zone (1001 to 1500 m asl)**

In the mid zone, hoverflies, spiders and predatory and parasitoid wasps and assassin bugs were the most dominant biocontrol agents and were found to interact with several plant species. *A. mysorensis* was the most dominant species in the mid-zone but not attractive to biocontrol agents. Instead, similar preferences of the biocontrol agents toward certain plant species were observed in mid-zone as was found in the high zone. Spiders were most often interacting with *N. wightii* and *C. benghalensis,* which are mostly climbing and creeping plant species, respectively, compared with other plants. Predatory wasps were highly interacting with *A. conyzoides* as in high zone, followed by *B. pilosa* and *P. maximum*. Hoverfly and parasitic wasps had diverse interactions with several plant species including *B. pilosa* and *P. maximum*, while assassin bugs were more specific to *S. rhombifolia*. Long-legged flies were less abundant in mid-zone as compared with the high zone, thus their interaction with field margin plants in the mid-zone was not so strong (Fig. 2).

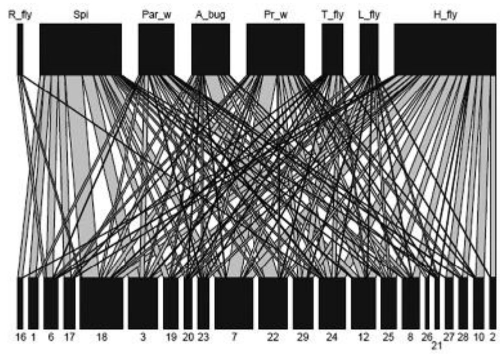


**Figure 2: Bipartite network graph between biocontrol agents and field margin plants in the mid-elevation zone in Northern Tanzania**

Each bar in the upper row represents natural enemies (R_fly = robber fly, spi = spider, Par_w = parasitoid wasps, A_bug = assassin bug, Pr_w = predatory wasps, T_fly = tachinid fly, L_fly = long-legged fly, H_fly = hoverfly) and each numbered bar in the bottom row represents field margin plant species (Table 1). The width of the bars is proportional to the number of interactions.

**Identified field margin plants supporting the biocontrol agents in the low elevation zone (800 to 1000 m asl)**

*Pennisetum purpureum*, *P. maximum*, *R. scabra*, *B. pilosa* and *E. heterophylla* were the common margin plants in the low zone (Fig. 3). The interactions between the biocontrol agents and the margin plants were so diverse compared with mid and high elevation zones due to the existence of less abundant but diverse weed species. *A. conyzoides* and *C. benghalensis* which were the most abundant weeds in high and mid-elevation zones were less abundant in low elevation zone. Hoverfly and predatory wasps were the most abundant biocontrol agents with a high preference for *E. heterophylla* and *B. pilosa*. Only a few long-legged flies were present in the low elevation zone with a high preference to *P. maximum* which is also a grass species as Guatemala grass which was the most preferred in the high zone. Other biocontrol agents were less abundant with no strong interaction with particular plant species.

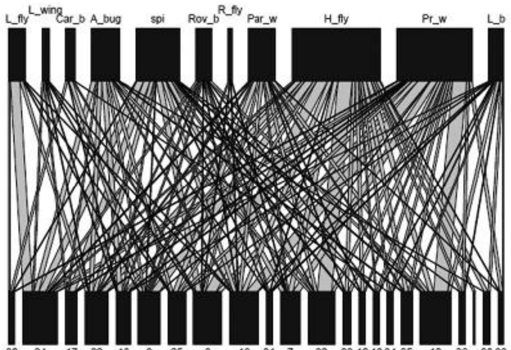


**Figure 3: Bipartite network graph between biocontrol agents and field margin plants in the low elevation zone in Northern Tanzania**

Each bar in the upper row represents biocontrol agents (L_fly = long-legged fly, L_wing = lacewing, Car_b = carabid beetle, A_bug = assassin bug, spi = spider, Rov_b = rove beetle, R_fly = robber fly, Par_w = parasitic wasps, H_fly = hoverfly, Pr_w = predatory wasps, L_b = lady beetle) and each numbered bar in the bottom row represents field margin plant species (Table 1). The width of the bars is proportional to the number of interactions.

**Discussion**

The biocontrol agents showed similar preferences to certain field margin plants across the three elevation zones. Predatory wasps, parasitic wasps and hoverflies were highly interacting with *A. conyzoides* in all three zones, justifying the importance of this plant to biocontrol agents regardless of elevation. Most creeping and climbing plants were found to support several ground-dwelling biocontrol agents due to their potential in providing microhabitats with increased vegetation complexity. *D. cordata* and *C. asiatica* both of which are creeping plant species are reported to harbour several biocontrol agents especially spiders (Mukti *et al.,* 2014; Sadof *et al.,* 2014; Withaningsih *et al.,* 2018) as also observed in the high zone. Likewise, in the -mid-elevation zone spiders were more interacting with *N. wightii* and *C. benghalensis* which are mostly climbing and creeping plant species, respectively, compared with other plants. These weed plant species are among the most reported plants of agricultural importance within the smallholder farming communities of Africa (Hillocks, 1998).

*A. conyzoides* is one of the known plant species with several floral visitors searching for pollen and nectar (Amaral *et al.,* 2013; Lin *et al.,* 1993; Ngongolo *et al.,* 2014), signifying its importance as a food resource to beneficial insects around agricultural land. A. conyzoides, and B. pilosa promote the survival and activities of predators (Amaral *et al.,* 2013). Assassin bugs were highly attracted by *S. rhombifolia*, and according to Cruz *et al.* (2013), it is among the spontaneous plants in agroecosystems that harbour predatory mites and other several species important in natural pest control. It can therefore be considered as a potential field margin plant for enhancing the beneficial insects within the smallholder farming systems. *Tripsacum* sp is a commonly known fodder plant in tropical countries including Tanzania due to its high nutritive values (Singh, 1999). The study reports an additional benefit of this plant to harbour biocontrol agents particularly long-legged flies in smallholder agricultural ecosystems.

Most of the field margin plants that show a strong interaction with the biocontrol agents have been reported by other studies to potentially enhance their population through the provision of alternative food resources, nesting sites and refuge sites. For example, *R. scabra* and other several margin plants are reported as useful in maximizing multiple ecological services (Olson & Wäckers, 2007). *Panicum* spp. and other grass species are highly used in the construction of beetle banks (Hopwood *et al.,* 2016) and as fodder for animals (Fernandes *et al.,* 2014). The study revealed additional benefits of these grass species in harbouring biocontrol agents around agricultural lands. Lady beetles were very abundant in the field but very few along the margin plants, and this is supported by Olson and Wäckers (2007) who also found the abundance of ladybeetle to increase from the margin towards the field centre. They are known to prefer floral resources only when their host insect pests, particularly the aphids are scarce (Hatt *et al.,* 2017; Lundgren, 2009).

The relative importance of field margin vegetation and other non-crop features in enhancing biocontrol activities around agricultural lands may vary dramatically due to several factors. The efficiency of the biocontrol agents in pest regulation is influenced by their dispersal ability between the margin plants and cropland (Fischer *et al.,* 2013), intraguild predation (Martin *et al.,* 2013) as well as the qualities of resources from the margin plants (Arnó *et al.,* 2016; Kenis *et al.,* 2016; Robinson *et al.,* 2002; Tindo *et al.,* 2009). Inconsistent responses of the biocontrol agents and insect pests to the surrounding landscape composition is also reported by Karp *et al.* (2018). This signifies the need for more studies to understand when habitat manipulation and management represent the win-win situation.

## Conclusion

Network analysis informs that many of the biocontrol agents interacts with diverse weed plants, including several species with pesticidal or medicinal properties (e.g. *A. conyzoides, Bidens* sp., *Tithonia diversifolia*, and Ocimum gratissimum). Other plants like C. benghalensis, *C. asiatica*, *T. luxum*, *P. purpureium*, *N. wightii, R. scabra* and *E. heterophyla* were also preferred by several predators and parasitoids. Many of these plants have a longer flowering season than the crop itself so play a role in supporting biocontrol communities, as well as conferring further ecosystem services. However, the promotion of these species should proceed with care and sensitivity as many are introduced exotics from other tropical biomes. Farmers should be encouraged to observe and identify the best field margin vegetation for enhancing the beneficial insects with proper field margin management practices to ensure a high population of beneficial insects within the cropland. Addressing all these will enable movement towards a more environmentally sustainable crop production system.

## Acknowledgements

The authors are grateful to the District Executive Director of Moshi rural District Council for granting the permission to conduct the research. Thanks to the agricultural extension officers and the smallholder farmers in Moshi rural district for their full participation in the study. The authors acknowledge the management of the Tropical Pesticides Research Institute (TPRI) for their kind support during the identification of plants and insects. This work was funded by Darwin Initiative grant (DI22-012) through Darwin Initiative project and McKnight Foundation grants through Charles Sturt University in Australia.

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# CoolBot Coldroom Technology Enhance Postharvest Quality and Shelf-life of Tomato (*Solanum lycopersicum* L.) Fruits

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**Abstract**

*Fruit and vegetable value chain actors in developing countries experience postharvest losses of 20 – 50% depending on the crop and management practices. One of the reasons for such loss is mentioned to be lack of affordable technologies to enhance produce storability during handling after harvest. Temperature management serves as the number one practice for extending shelf life of fresh produce. CoolBot is a device coupled to room air conditioner capable of dropping the room temperature to as low as 2°C. Storage rooms installed with the technology seem suitable for handling fresh fruits and vegetables over an extended period. Despite the awareness creation upon the value chain actors, they are yet skeptical of these technologies' performance and cost-effectiveness during utilization. Therefore, this study was designed to evaluate the performance and cost-effectiveness of two CoolBot Cold-rooms (CB-CR) independently, one set at temperature of 13±1°C and the other at 16±1°C, respectively. Tomato fruits of the variety Assila harvested at three maturity stages were used during the evaluation. A 2x3 factorial experiment arranged in a Completely Randomized Design (CRD) with two factors; storage condition (CB-CR at 13±1°C and CB-CR at 16±1°C) and Maturity stage (mature-green, breaker and light red) were used. Following 42 days of storage at pre-defined storage conditions, results indicated no significant interaction of maturity stage and storage condition among variables. However, external fruit colour change in terms of Lightness (L*), Chroma (C*), and Hue (H*), marketable fruits (%), soluble solid content (% Brix), titratable acidity (MeqL-1), weight loss (%) and firmness-compression (kg/mm2) varied with maturity stages. External fruit colour change from yellow yellow-green colour (L*C*h* = 57, 31.7, 110) to yellow yellow-red (L*h*C*= 39.7, 42.3, 43.0) was delayed more on mature green (MG) compared to other stages at both CB-CR (13±1°C and 16±1°C). Percentage marketable fruits was much higher on mature green fruits (84.83%), followed by Breakers (60.91%) and light red (48.58%). Based on electricity consumption, storage of tomato at CB-CR 16±1°C (160.2 KWh) was more beneficial than at CB-CR 13°C (272.7 KWh) due to less power consumption. It is therefore imperative to conclude that, more benefit can be realized when CB-CR storage is combined with the proper harvest maturity stage. Similarly, mapping of crop price change over season is required for proper storage timing using the technology throughout the year.*

***Keywords:*** CoolBot cold room, Post-harvest storage technologies, Tomato maturity stages, Storage temperature.

## Introduction

Fruits and vegetables are perishable but the percentage of their post-harvest losses are much higher in developing ranging from 20 to 50% than in developed countries from five (5) to 35% (Hailu and Derbew, 2015). Most developing countries including Tanzania, experience high post-harvest losses due to poor postharvest handling practices that are partly attributed to unavailability and high cost of the necessary infrastructures (MOA, 2019). Tomato is among fruit vegetable crops that suffer the highest postharvest losses during the peak production season. Such losses are associated with poor handling, inherent high temperature and low relative humidity to which the crop is exposed after harvest. Temperature management is considered as the major factor in maintaining quality and extending shelf life of fresh horticultural produce (Kader, 2002). Low temperatures reduce the rate of respiration and ethylene production, hence delay produce deterioration (Mutari and Debbie, 2011). Mechanical refrigeration has been used to provide optimal storage conditions for fresh produce. However, it is not economical and practically feasible among small-scale farmers in developing countries due to its high investment and running costs (Kader, 2004; Kitinoja and AlHassan, 2010; Kitinoja *et al.,* 2011; Singh *et al.,* 2017).

Cold storage facilities have been advocated to reduce postharvest losses and maintain the quality of fresh fruits and vegetables for small-scale farmers in Tanzania. Cold rooms have been established in export farms and airports in Tanzania to meet the quality and safety standards of the export commodities, including fresh fruits and vegetables. It is however established that; under optimally low storage temperature fruits and vegetables can be kept for an extended period with little change in quality. In addition to the reduced rate of respiration and ethylene production, optimal low storage temperature also reduces growth of latent infections on the produce (Din *et al.,* 2011). Availability and access to low-cost storage postharvest technologies have been improving among value-chain actors in developing countries but little is known about their cost-effectiveness and performance on key crops to enhance utilization. To improve postharvest handling and marketing of fresh fruits and vegetables, numerous market collection centres have been established at different places in the country. A few of the existing produce collection centres have cold rooms installed with mechanical cooling units to enhance storability and hence the marketing of fresh fruits and vegetables. Unfortunately, most of such cold rooms are not utilized due to high running costs.

Recently, a mini packing house with two cold storage rooms (CoolBot Cold-rooms) of 2.94 m x 2.35 m x 2.59 m each has been established at Sokoine University of Agriculture (SUA) to serve as a model for produce handling for small/ medium scale farmers. Each of the two cold rooms has the capacity of storing 144 stackable plastic crates of (H x L x W = 28.5 cm x 62 cm x 37 cm) with a carrying capacity of 300 tomato fruits/crate (≈28.5 kg/crate). CoolBot is an innovative device which when fitted to a digital air conditioner of specified brands can turn a well-insulated room into a walk-in produce cooler (Saran *et al.,* 2013; Majubwa *et al.,* 2019). CoolBot has three temperature sensors: the air conditioner's fins, the air conditioner's temperature sensor (heater) and the storage room. When coupled to an air conditioner, the device can trick and override the air conditioner in a well-insulated room and drop the air temperature to as low as 2$^{o}$C depending on the pre-set temperature (Saran *et al.,* 2013; Rivard *et al.* 2016; Majubwa *et al.,* 2019). In Tanzania, the cost of such walk-in cooler with well-insulated walls fabricated from an old marine shipping container was estimated at 4,150 USD and may as well vary with the country (Majubwa *et al.,* 2019).

CoolBot cold room has been found effective for storage of several horticultural produces. In India for instance, CoolBot cooler at 12 – 15$^{o}$C has been efficient in maintaining firmness, freshness, and marketability of tomato and okra over 21 days of storage (Huidrom *et al.,* 2016). In Ghana, CoolBot cold room has been found to be cost-effective compared to traditional storage shade during several months of onions storage (Saran *et al.,* 2012). CoolBot cold rooms are effective in retaining optimal temperatures but limited in maintaining an ideal range of relative humidity (RH) for storage of some fresh horticultural produce (Tolesa and Workneh, 2018). Adoption of this technology to Tanzania requires extensive research to validate its efficacy under local conditions. It has been established that overall effectiveness of any postharvest technology can vary with the crop, harvest maturity, season, storage duration, and region of application (Saran *et al.,* 2012). Nevertheless, there are limited studies on the performance of the model mini cold rooms, particularly on its ability to prolong shelf life and maintain the quality of key fresh fruits and vegetables and generate benefits for small-scale farmers and marketers selling the commodities in the local markets. This study establishes the comparative performance of the two CoolBot Cold-rooms (CB-CR at 13±1$^{o}$C and 16±1$^{o}$C) in terms of produce quality retention and cost-effectiveness for storage of tomato fruits harvested at mature green, breaker, and light-red maturity stages.

## Materials and Methods

### Plant materials and storage facility

Tomato fruits of the variety "Assila" were harvested on 21$^{st}$ Nov. 2019 from a leased farm at Mlali village, Mvomero district. The fruits were selectively harvested at three maturity stages (physiological maturity/mature green, breaker, and light red) (Table 1). Sorted fruits were packed into plastic crates, and transported to the mini packinghouse at Horticulture unit, Sokoine University of Agriculture (SUA), Morogoro for storage experiments. The cold rooms in the mini pack-house have two separate cold storage rooms with well-insulated walls. Each of the rooms is also fitted with a CoolBot coupled air conditioner (Fig. 1).

### Experimental design

A 2x3 factorial experiment arranged in a Completely Randomized Design (CRD) with two factors, storage conditions (CB-CR at 13±1$^{o}$C and CB-CR at 16±1$^{o}$C) and maturity stage (mature-green, breaker and light-red) were used. A total of 900 (approx. 85.5 kg) uniform and undamaged fruits per maturity stage were stored in each of the storage conditions in three replications. Three hundred (300) fruits (28.5 kg) were used per replicate, out of which 30 fruits were numbered and used for tracking colour change at three days interval until the 42nd day

**Table 1: Horticultural maturity indices for harvesting tomato fruits**

| S/N | Ripeness/harvesting stage | External color/appearance |
|---|---|---|
| 1. | Mature green | Fruit surface is completely green; the shade of green may vary from light to dark. |
| 2. | Breaker/turning | Breaker - There is a definite break in color from green to tannish-yellow, pink, or red on not more than 10% of the surface. |
| | | Turning - 10 to 30% of the surface is not green; in the aggregate, shows a definite change from green to tannish-yellow, pink, red, or a combination thereof |
| 3. | Light red | 60 to 90% of the surface is not green; in the aggregate, shows pinkish-red or red. |

***Source:*** Sargent and Moretti (2016)


**Figure 1: Wall insulation in a cold room (a) and a CoolBot mounted on an air conditioner in a cold room (b) at the Horticulture unit in SUA, Morogoro, Tanzania.**
***Source:*** Majubwa *et al.* (2019)

of storage. The percentage of marketable fruits and physiological weight loss per replicate was established at the 42nd day of storage when at least one treatment combination had 50% of the fruits unmarketable. At the 42nd day of storage, a total of 36 fruits were sampled per replicate for destructive measurements including firmness (puncture/compression force), soluble solid content (SSC), and titratable acidity (TA).

**Data collection**

***Fruit weight loss***

Fruit weight loss was measured according to Huidrom *et al.* (2016) using a digital kitchen scale (Ozeri, ZK 14-S) and percentage physiological weight loss (PWL) established as per equation 1.

$$PWL(\%) = \frac{Initial\ weight(g) - \text{Final weight(g)}}{Initial\ weight(g)} \times 100 \quad (1)$$

***Fruit colour change***

Fruit colour change was measured according to (Diaz-Mula *et al.,* 2012) using a Minolta Chroma meter (Chroma meter CR-400, Konica Minolta Inc., Japan) in the CIE colour space; Hue (h*), Chroma (C*), and Lightness (L*). Two measurements were taken per fruit one on each side along the fruit equator.

***Fruit firmness***

Fruit firmness in terms of compression and puncture force was measured using a hand-held pressure tester (FT 011, USA) mounted on a manual test stand (QA Supplies LLC, USA). The force (kg/mm2) required to compress the fruit to 10mm using a round-tip probe of 11 mm diameter was recorded. Similarly, the force required to puncture the puncture the fruit using a flat tip probe of 3.2 mm diameter was recorded. 2.3.4 Fruit soluble solid content and titratable acidity

Fruit SSC and TA were measured according to Huidrom et al. (2016). For SSC, 1ml of blended and well-filtered tomato fruit juice sample was added on a handheld digital refractometer (Antago PAL-1, Japan) and readings in percentage brix were recorded. The percent of dominant acid (citric acid) in tomato fruit was determined according to Rajwana et al. (2010) by pipetting 5ml of tomato juice into 50mls of distilled water and titrate against 0.1N NaOH to 8.2 pH using an automatic potentiometric titrator (HI 901, Hanna Instrument, USA). The percentage of dominant acid was then calculated based on equation 2.

$$Titratable\ acidity(\%) = \frac{0.1N\ NaOH\ used \times 0.064}{Volume\ of\ sample\ used} \times 100 \quad (2)$$

Where; N = normality

***Percentage marketable fruits***

Visual fruit quality assessment was done weekly, discarding fruits found with unacceptable market quality. The non-marketable fruits were sorted based on defects on fruit skin i.e., visible mould growth, decay, shriveling, smoothness, and loss of fruits' shininess rendering them unsuitable for the local market. Finally, the percentage of marketable fruits was calculated based on equation 3.

$$Marketable\ fruits(\%) = \frac{Number\ of\ marketable\ fruits}{Total\ number\ of\ sampled\ fruits} \times 100 \quad (3)$$

***Rate of electricity consumption per storage condition***

The average amount of electricity (KWh/day) used in each CB-CR unit (13±1°C and 16±1°C) was recorded daily using a single-phase electric meter (DDS28II, Eurotrix, PRC) throughout the storage period to establish the rate of power consumption for the storage technology.

**Data Analysis**

The data was subjected to the analysis of variance (ANOVA) using Genstat statistical software (Version 16, VSN International, UK). Prior ANOVA, the collected and processed data were subjected to normality test using Shapiro-Wilk Test, no further transformation was executed as the data was found to be normally distributed. Mean separation was based on Tukey HSD at p = 0.05. Since it was a 2x3 factorial experiment with storage condition (A) and fruit harvesting stage (B) at two (i2) and three (j3) levels, respectively, the ANOVA model for this experiment was:

$$Y_{ijk} = \mu + \tau_i + \delta_j + (\tau\delta)_{ij} + \in_{ijk} \quad (4)$$

where:

μ represents the overall mean effect

τi is the effect of the ith level of factor A (i = 1, ith)

$\delta_j$ is the effect of the jth level of factor B (j = 1, 2, jth)

$(\tau\delta)_{ij}$ represents the interaction effect between A and B

$\epsilon_{ijk}$ represents the random error terms (which are assumed to be normally distributed with a mean of zero and variance of σ2) and the subscript k denotes the m replicates (k = 1, 2, m)

## Results

### Fruit external colour change

In tomato, colour change from green to red colour indicated by the decrease in Hue angle (H*) and Lightness (L*) and increase in Chroma (C*) values serves as the major index of harvest maturity, ripening and/or senescence during storage. This study tracked the colour change of mature green, breaker, and light-red tomato fruits during the 42 days of storage in CB-CR at 13±1°C and 16±1°C conditions. The results (Fig. 2) indicated a significant ($p<0.001$) delay in decrease of H*, L* and increase of C* values among fruit maturity stages over storage time at both storage conditions post harvesting time of tomato fruits stored in CB-CR at 13±1°C and 16±1°C. Colour change was delayed on mature green compared to other stages in both CB-CR (at 13±1°C and 16±1°C) from yellow yellow-green (L*C*h*=57, 31.7, 110) to yellow yellow-red (L*h*C*= 39.7, 42.3, 43.0).

### Percentage weight loss

Regardless of the storage conditions, percentage physiological weight loss of the stored tomato fruits differed significantly ($p<0.001$) among maturity stages during the 42 days of storage in CoolBot Cold-rooms (Fig. 3). At both storage conditions, tomato

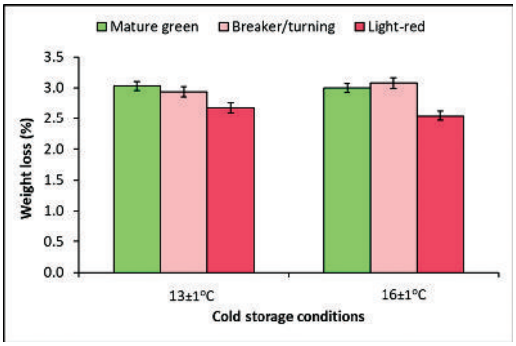


**Figure 3: Effect of maturity stage and storage conditions on physiological weight loss of tomato fruits following 42 days of storage in CoolBot Cold-rooms at 13±1°C and 16±1°C conditions**

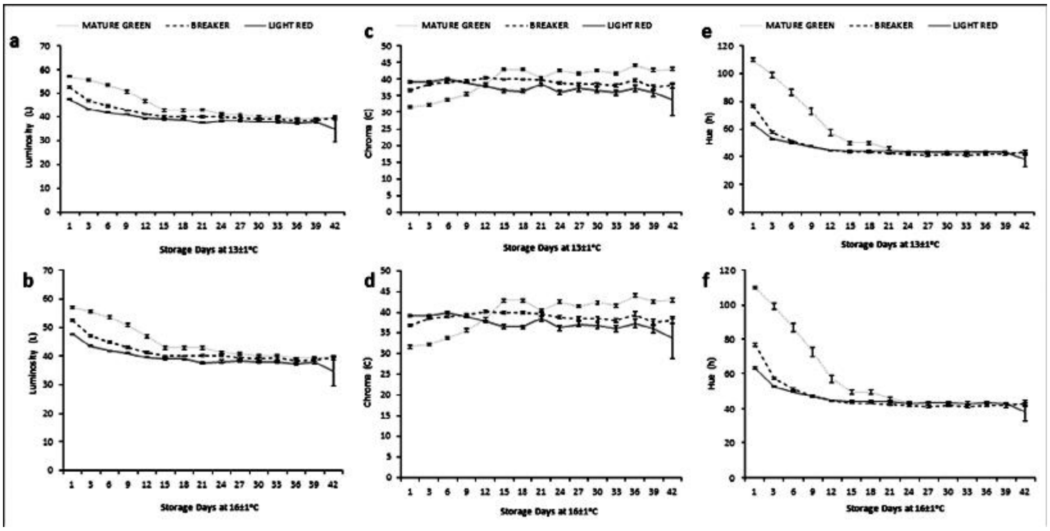


**Figure 2: Trend of change in colour lightness (L*) (a & b), colour intensity (C*) (c & d) and, actual colour (h*) (e & f) respectively on mature green, breaker, and light-red tomato during the 42 days storage in CB-CR at 13±1°C and 16±1°C, respectively.**

fruits at light-red maturity stage experienced the lowest physiological weight loss (2.6%) than those at mature green and breaker stages (3%). However, the percentage weight loss did not differ significantly among the two storage conditions (p=0.90), as well as the interaction (p=0.188) between the storage conditions and fruit maturity stages.

**Fruit firmness**

The force required to compress and puncture the stored fruits differed significantly (p<0.001) among maturity stages during the 42 days of storage in CoolBot Cold-rooms regardless of the storage conditions (Fig. 4a,b). The lowest compression and puncture force was recorded on breaker (1.94 kg/cm$^2$, 1.51 Kg/cm$^2$) and light-red (1.95 kg/cm$^2$, 1.33 kg/cm$^2$) than those stored on mature green (2.2 kg/cm$^2$, 1.7 kg/cm$^2$). However, the force required to compress and puncture the fruits did not differ significantly among the two storage conditions (p=0.128, p=0.934), as well as the interaction (p=0.539, p=0.553) between the storage conditions and maturity stages.

**Soluble solid content (SSC) and Titratable acidity (TA)**

Soluble Solid Content and TA varied significantly (p<0.001) with fruit maturity stages despite the storage condition whereby, mature green fruits had higher SSC (3.91%) and TA (4.68 MeqL-1) than breaker (3.57%, 3.34 MeqL-1) and light-red (3.58%, 3.12 MeqL-1) fruits (Fig. 5a,b). However, both storage condition and the interaction between the storage conditions and maturity stages showed no significant effect on SSC (p=0.463, p=0.373) and TA (p=0.364, p=0.224).

**Percentage marketable fruits**

Following 42 days storage of tomato fruits

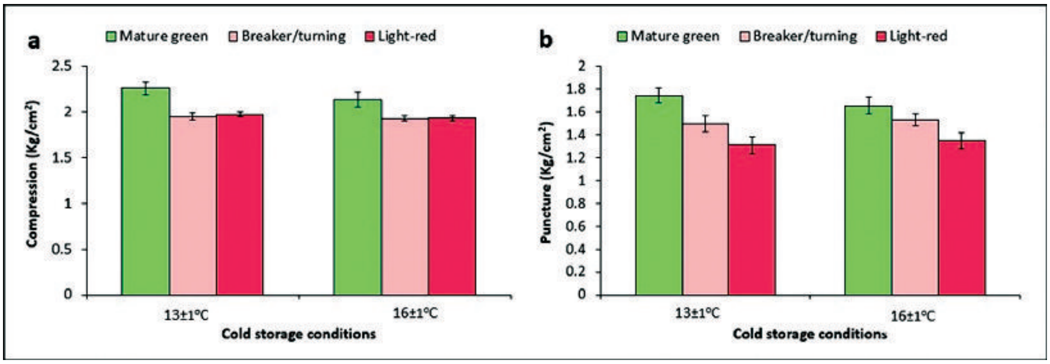


**Figure 4: Effect of maturity stage and storage condition on fruit firmness (kg/cm$^2$); (a) compression and (b) puncture force following 42 days of storage in CoolBot Cold-rooms at 13±1$^o$C and 16±1$^o$C conditions**

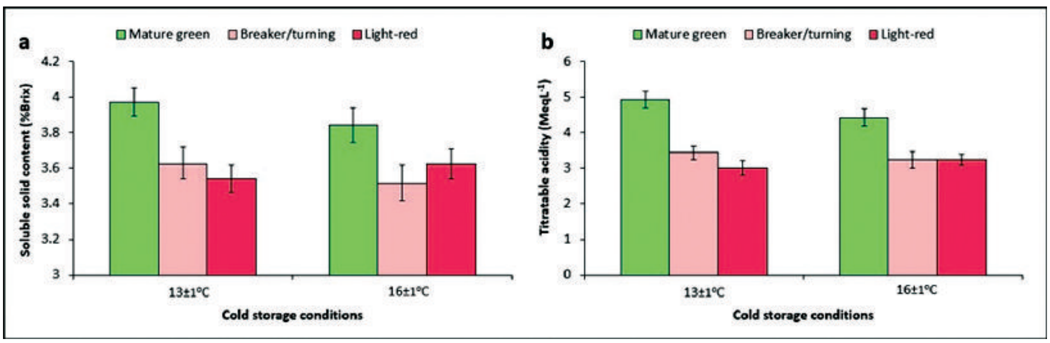


**Figure 5: Effect of maturity stage and storage conditions on (a) soluble solid content and (b) titratable acidity of tomato fruits following 42 days of storage in CoolBot Cold-rooms at 13±1$^o$C and 16±1$^o$C conditions**

in CB-CR 13±1°C and 16±1°C, overall results (Fig. 6) indicated significantly ($p<0.001$) higher percentage of marketable fruits on mature green fruits stored in CB-CR at 13±1°C (87%) and CB-CR at 16±1°C (83%) than on other maturity stages across storage conditions. The lowest percentage of marketable fruits was found on light-red fruits stored in CB-CR at 13±1°C (47.1%) and CB-CR at 16±1°C (50.1%). Comparative effectiveness of the storage conditions with respect to fruits harvesting stages indicated that, storage of mature green and breaker fruits in CB-CR at 13±1°C can give 4% and 2% more marketable fruits, respectively than in CB-CR at 16±1°C, while storage of light-red in CB-CR at 16±1°C can give 3% more than those stored in CB-CR at 13±1°C.

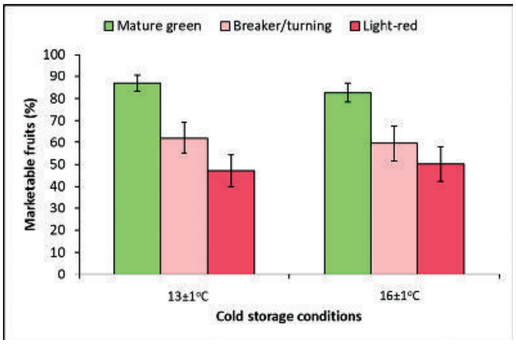


**Figure 6: Effect of maturity stage and storage conditions on fruit marketability following 42 days of storage in CoolBot Cold-rooms at 13±1°C and 16±1°C conditions**

**Rate of electricity consumption per storage condition**

The results (Fig. 7) revealed that, the average amount of electricity consumed during the six weeks (42 days) of storage differed significantly ($p<0.001$) among the two CoolBot Cold-room storage conditions. Generally, the comparative effectiveness of the storage conditions indicated that, with an average consumption of 5.986 KWh/day (251.4 KWh/42 days), storage in CB-CR at 13±1°C consumed more electricity than storage in CB-CR at 16±1°C which used 4.879 KWh/day (204.9 KWh/42 days). Storage in CB-CR at 13±1°C consumed 46.5 KWh more than CB-CR at 16±1°C for the 42 days of storage.

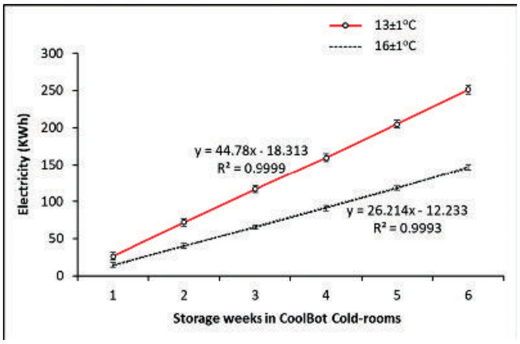


**Figure 7: Rate of electricity consumption associated with storage of tomato fruits in CoolBot Cold-rooms at 13±1°C and 16±1°C conditions for 42 days**

**Discussion**

Storage of mature green tomato fruits in CB-CR at13±1°C and 16±1°C conditions was much effective in delaying fruit colour change during the 42 days of storage. The observed delay in colour change as indicated by higher H* and lower C* values on mature green compared to breaker and light-red stored in CB-CR at 13±1°C and 16±1°C was consistent with previous studies (Getinet *et al.,* 2008; Pinheiro *et al.,* 2013). Like our findings, Roberts *et al.* (2002) also reported faster colour change on tomato fruits stored at 20°C than at 12°C. High rate of colour change indicates how fast tomato fruit ripens and or senescence (Baldwin *et al.,* 2011) and it is a function of maturity stage, variety, and storage environment including temperature (Getinet *et al.,* 2008; Tigist *et al.,* 2013; Arah *et al.,* 2015). High storage temperatures increase respiration rate and accelerates ethylene production that hastened ripening (Mutari and Debbie, 2011). However, early maturity stages; mature green and breaker tend to have lower ethylene production and respiration rates at early days of storage than pink and red-ripe fruits (Tilahun *et al.,* 2019).

Physiological weight loss is the major cause of produce shriveling and loss in freshness, on the other hand fruit firmness is also a physical indicator of fruit loss in freshness. Firm, turgid, uniform, and shiny color appearance as well as absence of signs of mechanical injury, shriveling, or decay indicate high-quality tomato fruits (Sargent and Moretti, 2016). The lower physiological weight loss and firmness of tomato fruits stored in CB-CR at 13±1°C and 16±1°C observed in this study during the 42 days of storage could be attributed to low storage temperature. Physiologically fresh produce tends to have higher water content than shriveled ones and hence are more turgid and prone to transpiration. Low storage temperature reduces vapour pressure difference between fruits and surroundings (Getinet *et al.,* 2008). Such differences in vapour pressure tend to minimize the rate of moisture removal from tomato fruits to surroundings and reduces/slower the deterioration (Seyoum and Woldetsadik, 2004). In the present study, firmness measured in terms of resistance to compression and puncture force was higher on mature green fruits when stored in CB-CR at 13±1°C and 16±1°C than on other maturity stages under same storage conditions during the 42 days of storage. The relatively lower storage temperature observed in CB-CR at 13±1°C and 16±1°C storage conditions may have a significant contribution in decelerating cell break down due to respiration. Fruit softening has been attributed to either loss of cell turgidity caused by water loss and or cell wall breakdown due to respiratory processes (Mutari and Debbie, 2011). Similarly, the lower physiological weight loss experienced in CB-CR at 13±1°C and 16±1°C storage conditions likely accounts for enhanced firmness of the stored tomato fruits.

In the present study, the interaction between fruit maturity stage and storage condition did not have significant effect on amount of SSC and TA. Both SSC and TA served as indicators of change in internal fruit quality during maturity and storage. The higher SSC and TA on mature green fruits stored in CB-CR at 13±1°C and 16±1°C than on light-red and breaker fruits, respectively indicated an interactive effect of storage condition (temperature) and maturity stage. These results were consistent with Baldwin *et al.* (2011) who reported higher TA on mature green tomatoes of variety Florida 47 stored at 13°C. Similarly, Tilahun *et al.* (2019) reported relatively high TA on breaker compared to pink and red tomato of cultivar TY Megaton on 12 days of storage. Previous study by Teka (2013) reported a decline in TA through advancement of maturity stage with the highest on mature green fruits. Similar to our findings, Tilahun *et al.* (2019) also reported no significant difference in SSC between breaker, pink and red maturity stages of tomato cultivar TY Megaton stored at 12°C. Optimal storage temperatures depend on the maturity stage of the tomatoes, whereby the ideal conditions for ripening are 19 to 21°C with 90 to 95% RH (Sargent and Moretti, 2016). Storage of tomatoes at temperatures >27°C reduces intensity of red color, while storage at <13°C slows ripening and result to development of chilling injury, especially in tomatoes stored at the mature-green stage. Red tomatoes can be stored at 7°C for several days, though tomatoes stored at 10°C turn out to have low in flavor and aroma than those held at 13°C (Sargent and Moretti, 2016).

Overall performance of the tested storage technologies indicated higher percentage of marketable fruits when fruits harvested at mature green stage and stored in CB-CR at 13±1°C or 16±1°C than other maturity stages under same storage conditions. The observed high percentage of marketable mature green tomato fruits in CB-CR at 13±1°C and 16±1°C could be associated with low physiological weight loss accounted by low storage temperatures. Similarly, Huidrom *et al.* (2016) reported significant retention of higher marketable Chilli, torai, brinjal, okra and tomato fruits following 21 days of storage in cold room at 12-15°C compared to those stored at ambient. In respect to maturity stage, Getinet *et al.* (2008) found higher percentage of marketable fruits among mature green tomato stored under cold storage than turning and light-red fruits at same or ambient storage conditions. Higher storage temperature increase rate of transpiration, respiration and ethylene production and hence hasten senescence (Mutari and Debbie, 2011). Harvesting at an improper maturity stage hastens postharvest losses in fresh produces including tomato (Sargent and Moretti, 2016).

Pertaining electricity consumption rate, storage of tomato in CB-CR at 16±1°C was more beneficial than in CB-CR at 13±1°C due to less power consumption. However, more benefit can be realized when CB-CR storage is combined with proper harvest maturity stage.

It is well established that, energy consumption rate of refrigeration unit tends to increase with condition, type, and quantity of the stored produce (Adre and Hellickson, 1989). The speculated benefit of the CB-CR technology may also vary up or down stream among seasons in a year with increase or decrease in rate of produce price change. Therefore, it should be noted that any change on these factors could alter the benefit gained out of the CB-CR technology. Storage of fresh tomato fruits may be financially feasible if the cost of storage (including electricity consumption) is less than the increased value of the stored produces when sold during the off-season (PI LLC, 2017). The approach of using a room AC and CoolBot device effectively minimizes on-farm electricity use compared to a conventional refrigeration system, therefore saving not only the installation and repair costs but also helps to save electricity.

**Conclusion and recommendations**

The study evaluated comparative performance on tomato quality retention and electricity consumption effectiveness of CoolBot Cold-rooms (CB-CR) at 13±1°C and 16±1°C conditions. Tomato fruits of variety "Assila" as a model crop at mature green, breaker and light-red maturity stage were stored for 42 days in each storage condition. Based on the results, it could be concluded that; despite the higher performance of CB-CR 13±1°C than CB-CR at 16±1°C, the two storage conditions were effective in reducing fruit physiological weight loss, delaying fruit colour change, maintaining fruit firmness, TA, SSC, and higher percentage of marketable fruits particularly when fruits were harvested at mature green stage. Storage of tomato in CB-CR at 16±1°C was more beneficial than in CB-CR at 13±1°C in terms of less power consumption. Nevertheless, more benefit can be realized when CB-CR storage is combined with proper harvest maturity stage. Further studies are suggested to evaluate performance and cost effectiveness of the technology for high value horticultural crops particularly fruits and vegetables with export potential such as snap beans, broccoli, and cauliflowers. Studies are also required to map the demand, supply, and price changes across seasons for high value horticultural crops to enhance utilization of the technology.

**Acknowledgment**

Authors are grateful to USAID/UC Davis Horticulture Innovation Lab, the sponsor of the project "Capacity Building on Produce Postharvest Management in Tanzania" through Kansas State University (prime project leader) of the SUA sub-award.

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# Safety of Traditional Leafy Vegetable Powders from Lindi in Tanzania

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**Abstract**

*Postharvest losses in the fruits and vegetables sector remain a major problem in the world, and especially in Sub Saharan Africa. Up to 50% of fruits and vegetables produced in developing countries is lost in the supply chain between harvest and consumption. Though WHO recommends consumption of at least 400 grams of fruits and vegetables daily, the actual consumption is much less. Two billon people are still suffering from micronutrient deficiencies and almost 800 million from caloric deficiencies on a global scale (Achadi et al., 2016). Lindi in Tanzania, is among the most affected in the country. To combat this problem, one of the interventions that can be used to address the problem is to preserve vegetables. In this study, three types of Traditional Leafy Vegetables (TLVs) - Amaranths (AML), Sweet potato (SPL) and Cassava leaves (CAL), grown in Ruangwa and Nachingwea Districts in Lindi Region were carefully collected from Home Gardens (HG) and Low Land (LL). They were solar dried and made into powders that had been optimized for Iron content. The vegetable powders were then mixed with water and spices to make four (4) soup formulations. The safety of these products had not been determined. This study was therefore conducted to evaluate the microbiological quality (Total plate count and E. coli) of the vegetable powders. Significant differences ($p \leq 0.05$) in microbial load among raw vegetables were observed. Sample CAL had the highest load ($3.67 \times 10^2$) whereas sample SPL had the lowest ($3.15 \times 10^2$). The microbial load between the two sites also differed significantly ($p < 0.05$). However, there were no significant differences ($p \geq 0.05$) in microbial quality of the vegetable powders, all of which were below the TBS standards. No E. coli was detected in any of the samples studied. The absence of E. coli in the samples indicates appropriate handling of the vegetables. With the year 2021 being the International year of fruits and vegetables, it is crucial to raise awareness of their role in human nutrition, food security and health. Consuming sufficient fruits and vegetables is important as a source of micronutrients and support the immune systems. They also lower risk of depression and anxiety, obesity and non-communicable diseases; promote gut health (UN news, 2020). Thus, solar dried TLVs and the developed products are recommended for use due to their safety and quality. These TLVs are a potential source of micronutrients if properly processed and utilized.*

***Key words:*** Micronutrients, Vegetables soup powder, Safety, E. coli, Solar drying

## Introduction

Vegetables are low in calories, high in fiber content and are also the best sources of antioxidants and other phytonutrients (Niththiya *et al.,* 2014). Adequate vegetables consumption can be protective to some chronic diseases such as diabetes, cancer, obesity, metabolic syndrome, cardiovascular diseases, as well as improve risk factors related with these diseases (Ulger *et al.,* 2018). Vegetables are abundant during the wet season but without post-harvest preservation, the excess after consumption goes to waste which limits their marketability (Chege and Kimiywe, 2016). The high moisture content of Traditional Leafy Vegetables (TLVs) renders them perishable while their seasonal availability limits their utilization all year round (Njoroge *et al.,* 2015). Due to the high perishability nature of the TLVs, most are dried without adding any preservatives so as to enhance availability throughout the year (Managa *et al,* 2020). However, solar drying is recommended for preservation of green leafy vegetables (Chege *et al.,* 2014). The removal of moisture arrests the growth and reproduction of microorganisms that would cause decay and minimizes many of the moisture mediated deterioration reactions (Ahmed *et al.,* 2013). Any microbial contamination in leafy vegetables is commonly associated with the environment through which the product has passed (Taura and Habibu, 2009). Consumption of these types of vegetables, if not prepared hygienically could be the source for ingestion of considerable numbers of human pathogenic bacteria resulting in diseases (Kimaro, 2017). Hence microbiological control is important in food industry as to prevent food borne diseases and provide safe and quality product. This study was carried out to assess the microbiological quality of raw and processed traditional leafy vegetables for health and safety of consumers.

## Materials and Methods

### Study area

The study was carried out at Mibure and Mitumbati, villages from Ruangwa and Nachingwea districts respectively in Lindi region. Lindi region is situated in Southern Tanzania between latitudes 70 55' and 100 50' South of the equator and longitudes 360 51' to 400 East. It is a coastal town located at the far end of Lindi Bay, on the Indian Ocean in Southeastern Tanzania. The dominant climate is hot and humid.

### Materials

Materials used included Traditional Leafy Vegetables (TLVs) namely Amaranth leaves (*Amaranthus hybridus* L.) (AHL), sweet potato leaves (*Ipomoea batatas*) (IBL) and cassava leaves (*Manihot esculenta*) (MEL) from two villages Mtumbati and Mibure in Lindi Region, Tanzania and vegetable soup powder formulations.

Equipment used included cool box and sampling bags, weighing balance Mettler Toledo (Model XP205 from United States), Incubator Memmert (Fisher scientific model, German), Media dispenser, Herathrm oven (Model OMH180-S made in German), Colony-counting mashine (Model D-37079 made in German Centrifuge (Model 300R-Hettich, made in German), Vortex bohemia (Model K-550-GE, made in U.S.A) and pH meter (Model Orion 4 star plus, Thermo scientific, from U.S.A),petri dishes made of glass and total delivery graduated pippete in 0.1 ml division.

All chemicals used were of analytical quality, and were from Sigma-Aldrich Chema Gmbh, Germany, unless otherwise stated.

### Study design

Cross sectional design was used in this study. Samples for microbiological parameters (Total plate count and E. coli) were drawn from three TLVs across the sites (home garden and low land

### Sampling plan and data collection

Purposive sampling procedure was used to collect samples from selected points. Sampling was carried out in the morning during a rainy season from February to March 2019. Amaranths (*Amaranthus hybridus* L.) Sweet potatoes (*Ipomea batatas*) and Cassava (*Manihot esculenta*) samples were collected in duplicate from two sites, home garden (HG) and low land (LL) from Lindi. Thus, a total of 12 samples were collected i.e. 3 types of TLVs *2 points (HG and LL) *1 Region, all in duplicates, making a total of 12 sample from both sites. In addition, 4 vegetable soup formulations were also analysed in duplicates (8 samples). The total sample size was 20. These samples were analyzed in triplicate to make a total of 60 for each parameter.

Samples were collected from the sites and transported in closed polyethylene bags, which were stored in a cool box containing ice maintained at 4°C to SUGECO (Sokoine University Graduate Entrepreneurs Cooperative, SUA, Morogoro) for sample preparation and solar drying. Both solar dried vegetables and powdered soup formulations were transported to the Tanzania Bureau of Standards (TBS) laboratory for microbial analysis.

## Sample preparation

About 2.5 kg of each of the fresh TLVs samples was thoroughly washed with potable water to remove adhering physical ring dust and impurities, and the leafy edible parts of the vegetables were separated from the main plant. They were then sliced, blanched with water (containing 10 % of NaCl) at temperature of 80°C for 2 minutes. Addition of salts of various metals (zinc, iron, copper) helps to stabilize chlorophyll content in chlorophyll-containing vegetables hence preserve colour loss. (Belinska *et al.,* 2018). The blanched vegetables were then drained and spread on trays for 10-15 minutes. Solar drying was done at SUGECO - as per procedure by Mongi (2013) with some modifications. Blanched samples were loaded into the solar dryer. The temperature in the solar dryer ranged between 45-55°C and drying was completed in 3 days. About 1.5 kgs of each dried TLVs were packed separately in labeled freezer bags and stored at room temperature in a dark dry place. After solar drying, the dried vegetables were ground by a machine (Gaoxin 1250 gx-25, China). Each TLVs was ground separately and passed through a fine 315-micron sieve to obtain fine powders. TLVs powders were then packed in labeled food freezer bags and stored at room temperature (25°C) in a dark dry place prior to product formulations and analysis.

## Product formulation

Three types of TLVs samples were used to formulate iron rich powders. Various proportions of vegetables were used based on iron optimization to meet the RDA of iron for children aged between 1-5 years (Matemu, 2018). Table 1 shows the amount of solar dried TLV samples and Table 3 shows spices used to make formulation after pretesting in the

**AML- amaranth leaves CAL-cassava leaves SPL-Sweet potatoes leaves**

Tanzania Bureau of Standards (TBS) laboratory. The powder formulations were made by mixing 90g of solar dried TLVs with 10g of spices (F1, F2, F3 and F4). These formulations were analysed for microbiological quality.

**Table 2: Spices added for soup formulations**

| Spices | (Amount per g) |
|---|---|
| Garlic | 0.5 |
| Ginger | 0.5 |
| Coriander | 0.5 |
| Cumin | 0.5 |
| Corn Flour | 4.0 |
| Salt | 2.0 |
| Sugar | 2.0 |
| Total | 100 |

## Microbiological analyses

### Media preparation and storage

All the media used in this study were prepared according to manufacturer's instructions.

### Preparation of analytical sample by serial dilution

About 25g of each vegetable powder was weighed into 225mls BPW to obtain initial suspension ($10^{-1}$) dilution, 1ml from ($10^{-1}$ dilution) was taken by use of sterile pipette into 9ml of 0.1% buffer peptone water to prepare ($10^{-2}$ dilution), the above procedure was repeated for further serial dilution up to $10^{-4}$ dilutions.

### Detection and Enumeration of *Escherichia coli*

This was done according to ISO 16649-2:2001(E). Results were expressed in CFU/g.

**Table 1: Soup formulations from 3 traditional leafy vegetables (90% of formulation)**

| Materials | (F1) | (F2) | ( F3) | (F4) |
|---|---|---|---|---|
| (Amount per g) | | | | |
| *Amaranthus hybridus* L (AML) | 60.0 | 70.0 | 80.0 | 40.0 |
| *Manihot esculenta* (CAL) | 7.50 | 5.00 | 2.50 | 10.0 |
| *Ipomea batatas* (SPL) | 22.5 | 15.0 | 7.50 | 40.0 |

**Detection and Enumeration of Total plate count**

This was done according to ISO 4833-1:2013(E). Results were expressed in CFU/g

**Expression of results**

The countable bacterial colonies from two consecutive plates of each sample were converted into colony forming units per g using a formula

$$N = \sum C / (V \times (n1 + 0.1\,n2) \times \mathrm{d}) \qquad (1)$$

Where;

N = number of bacterial colonies counted,

C = sum of colonies identified on two consecutive dilution steps, where at least one contained 10 colonies,

V = volume of inoculum on each dish/plate, in ml and

d = dilution rate corresponding to the first dilution selected (the initial suspension is a dilution)

**Statistical analysis**

Descriptive statistics were used to describe, summarize and present data for both TLVs and vegetable soup powder formulation. Mixed level factorial was used to determine microbial quality of dried TLV and TLVP by using the following model:

$$Y_{ijkl} = \mu + \tau + \alpha_k + \tau\alpha_{ik} + \varepsilon_{ijkl} \qquad (2)$$

Where,

i = 1,2

j = 1,2

k = 1,2,3

Where by:

$Y_{ijk}$ = Dependant variable, μ=General mean, and

ε = Random error

$\tau_i$ = is the ith site effect

$\alpha_k$ = is the kth type of vegetable effect

Data was analyzed using R statistical package software. Analysis of Variance (ANOVA) was carried out to determine the significant differences in microbial count between solar dried vegetables and vegetable powder formulations among the 36 samples of TLVs with respect to sites type of vegetables. Means were separated using Tukey's Honest at $p<0.05$.

**Results**

**Microbiological parameters**

Microbial Load of selected Traditional Leafy Vegetables cultivated in different farm sites and their vegetable soup formulations.

**Total Plate Count and *E. coli* count of selected Traditional Leafy Vegetables**

The mean Total Plate Count (TPC) of selected vegetables is shown in Table 3 and Fig 1 while the mean *E. coli* count is presented in Table 4. The Total plate count reported from the studied vegetables were in the range of 102 CFU/g while *E. coli* was absent in all samples analysed. Cassava leaves had the highest bacterial load followed by amaranth and sweet potatoes. The mean TPC for all vegetables varied significantly ($p<0.05$) with cassava leaves having the highest level and sweet potato leaves had lowest. There was no *E. coli* growth in any of the vegetables (Table 4)

**Bacterial load of selected Traditional Leafy Vegetables cultivated in different Farm Sites**

The Mean Total Plate Count (TPC) and *E.*

**Table 3: Mean Total Plate Count (CFU/g) for selected dried TLVs grown in Lindi region**

| Vegetables | Mean Total Plate Count (CFU/g) | (TZS1657:2014-EAS:2013) Microbiological limit (CFU/g) |
|---|---|---|
| AML | 3.54 x 102±9.9$^{b}$ | 103 |
| CAL | 3.67 x 102±10.5$^{a}$ | 103 |
| SPL | 3.15 x 102±12.3$^{c}$ | 103 |

*Values are expressed as mean ±SD (n=12); Mean values with different superscripts letters down the column are significantly different from each other at different at p<0.05 (Tukey's Honest). AML-Amaranth leaves; CAL-Cassava leaves; SPL- Sweet potatoes leaves. CFU-Colon forming unit, TZS-Tanzania standard –EAS-East Africa Standard*

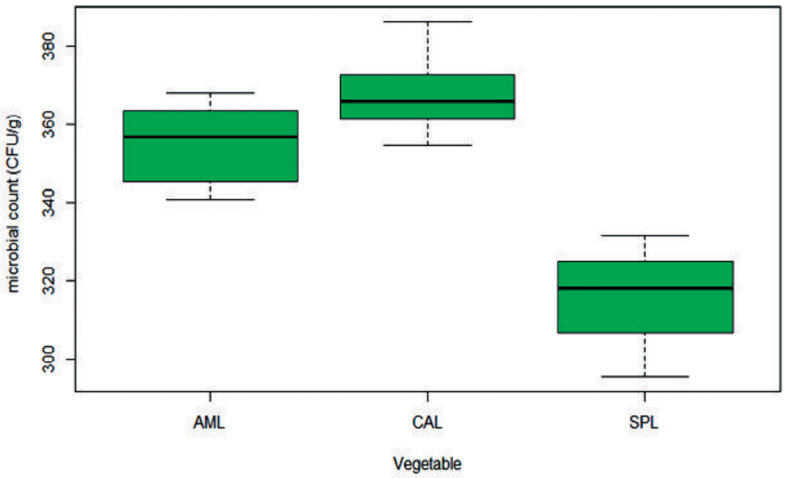


**Figure 1: The mean TPC for solar dried vegetables**

**Table 4: Mean *E. coli* count (CFU/g) for selected dried TLVs grown in Lindi Region**

| Vegetables | Mean E. coli count (CFU/g) | (TZS1657:2014-EAS:2013) Microbiological limit (CFU/g) |
|---|---|---|
| AML | ND | Absent |
| CAL | ND | Absent |
| SPL | ND | Absent |

*Values are expressed as mean ±SD (n=12); AML-Amaranth leaves; CAL-Cassava leaves; SPL- Sweet potatoes leaves, CFU-Colony Forming Unit, NIL-Absent, ND-Not detected, TZS-Tanzania standard –EAS- East Africa Standard*

*coli* for vegetables found in Home garden (HG) and Low Land (LL) are expressed in Table 5 and Fig. 2. Results show that the Mean TPC for all vegetables varied significantly ($p<0.05$) with LL vegetables having higher TPC whereas Sweet potatoes leaves had the lowest TPC. Also, from the Table 6, there was no *E. coli* among the vegetables found in the two sites.

**Microbial Mean for Vegetable Soup Powder Formulation**

The Mean Total Plate Count (TPC) and

**Table 5: Mean Total Plate Count (CFU/ g) for samples from the two sites**

| Site | Mean Total Plate Count (TPC) (CFU/g) | (TZS1657:2014-EAS:2013) Microbiological Limit (CFU/g) |
|---|---|---|
| HG | 3.40 x 102± 25.6$^{b}$ | 103 |
| LL | 3.51 x 102±23.4$^{a}$ | 103 |

*Values are expressed as mean ±SD (n=18); Mean values with different superscripts letters down the column are significantly different from each other at different at p<0.05 (Tukey's Honest). HG- Home garden, LL- Low land. TZS-Tanzania standard –EAS- East Africa Standard*

**Table 6: Mean Microbial Load for E. coli across the Sites**

| Site | Mean E. coli (CFU/g) | (TZS1657:2014-EAS:2013) Microbiological limit (CFU/g) |
|---|---|---|
| HG | ND | Absent |
| LL | ND | Absent |

*Values are expressed as mean (n=18); HG- Home garden, LL- Low land. CFU-Colony Forming Unit, NIL-Absent ND-Not detected TZS-Tanzania standard –EAS- East Africa Standard*

**Table 7: Total Plate Count (CFU/g) for Vegetable Soup Powder Formulation**

| Vegetables | Mean Total Plate Count (CFU/g) | (TZS1657:2014-EAS:2013) Microbiological limit (CFU/g) |
|---|---|---|
| F1 | 3.42 x 102±34.19[a] | 103 |
| F2 | 3.45 x 102±17.81[a] | 103 |
| F3 | 3.52 x 102±12.08[a] | 103 |
| F4 | 3.64 x 102 ±16.51[a] | 103 |

*Values are expressed as mean ±SD (n=6); Mean values with different superscripts letters down the column are significantly different at different at p<0.05 (Tukey's Honest), F1-(60:7.5:22.5: A, C, S) F2-(70:5:15: AML, CAL, SPL) F3-(80:2.5:7.5, AML, CAL, SPL) F4-(40:10:40: AML, CAL, SPL), CFU-Colony Forming Unit, TZS-Tanzania standard –EAS- East Africa Standard*

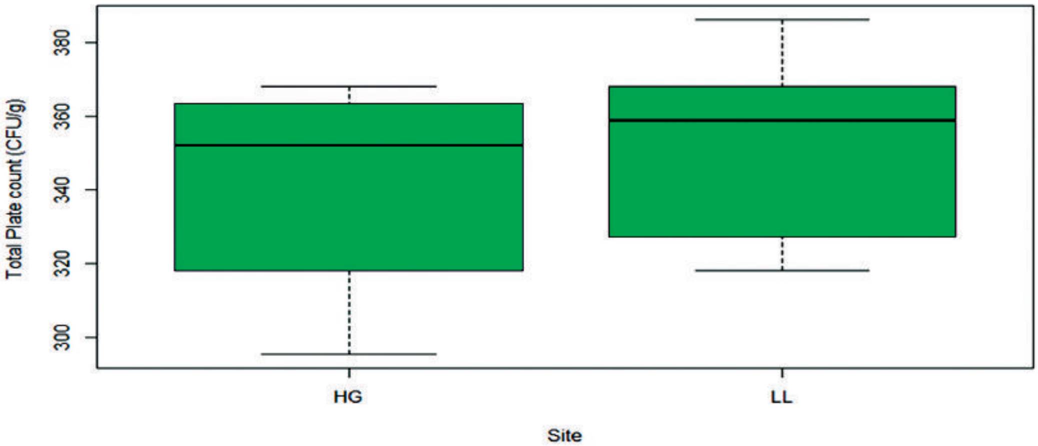


**Figure 2: The mean results of Total plate count across the Sites**

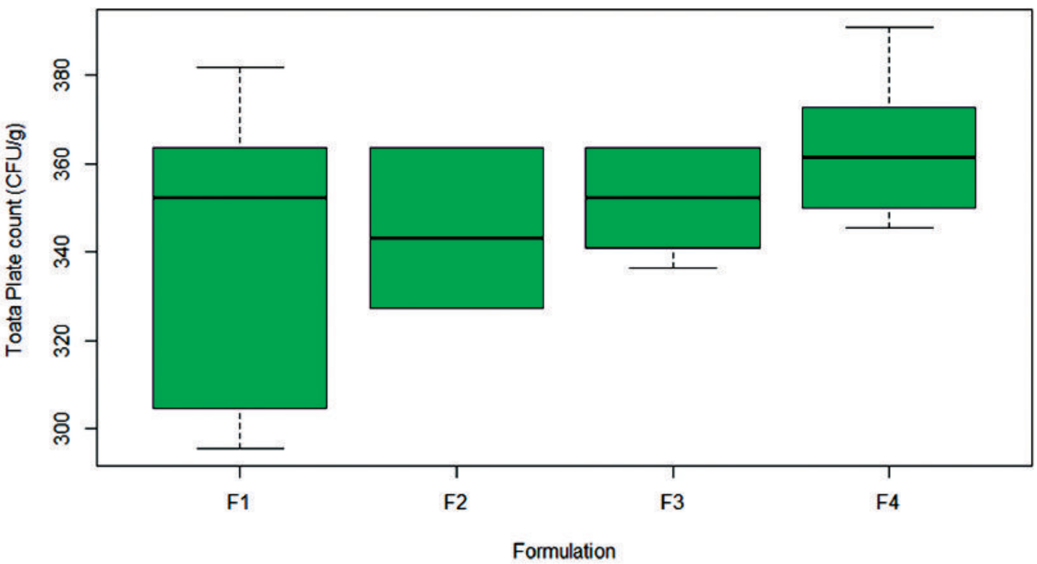


**Figure 3: The mean results of Total plate count among Formulation**

Mean *E. coli* for vegetables soup powder formulation are presented in Table 7 (and Figure 3) and Table 8 respectively. Though sample F4 had the highest microbial load and sample F1 the lowest, there were no significant differences ($p<0.05$) in mean TPC between any of the formulations. Also, from the Table 8, *E.coli* was not detected in any of the vegetable soup formulations.

**Table 8: Microbial Mean for *E. coli* (CFU/g) in Vegetable Soup Powder Formulation**

| Vegetables | Mean E. coli (CFU/g) | (TZS1657:2014-EAS:2013) Microbiological limit (CFU/g) |
|---|---|---|
| F1 | ND | Absent |
| F2 | ND | Absent |
| F3 | ND | Absent |
| F4 | ND | Absent |

*Values are expressed as mean ±SD (n=6); ND-Not detected Mean values with different superscripts letters down the column are significantly different from each other at different at p<0.05 (Tukey's Honest), F1-(60:7.5:22.5: AML, CAL, SPL) F2-(70:5:15: AML, CAL, S,) F3-(80:2.5:7.5, AML, CAL, SPL) F4-(40:10:40: AML, CAL, SPL), CFU-Colony Forming TZS-Tanzania standard –EAS- East Africa Standard*

## Discussion

Food safety is among the most important parameters involved in the quality of food. The presence of pathogenic and deteriorating microorganisms has been extensively related to foodborne diseases or the reduced shelf life of processed vegetables (Schuh *et al.,* 2019). *Escherichia coli* is an innocuous member of the human and warm-blooded animal gut microbiota; however, pathogenic strains may cause intestinal and extra intestinal infections. These primary hosts may acquire *E. coli* from water and food (Luna-Guevara *et al.,* 2019). The test for *E. coli* assesses the cleanliness of an environment or food, and can also be used to gather information regarding the potential for contamination (Bai *et al.,* 2007) hence used as an indicator for safety. While Total Plate Count (TPC) gives a quantitative estimate of the concentration of microorganisms such as bacteria, yeast or mould spores in a sample, the TPC can be used to evaluate sanitary quality, sensory acceptability, and conformance with good manufacturing practices (GMPs). Results of the TPC can provide a food processor with information on the quality or handling history of raw materials, food processing and storage conditions, and handling of the finished product. Thus it can be used to determine the shelf-life or forthcoming sensory change in a food product (Mendonca, *et al.,* 2020).

### Total Plate Count and *E. coli* count of selected TLVs

This study revealed higher TPC for dried Cassava leaves, followed by amaranth and finally sweet potatoes as indicated in Table 3. The trend may be associated with the moisture content (from the same study, but results not shown) for each vegetable where it was higher for cassava leaves (9.17±0.58) followed by amaranth (8.47±0.55) and finally sweet potatoes leaves (8.12±0.51). It is generally known that the higher the moisture content the higher the microbial load and vice versa. Removal of moisture prevents the growth and reproduction of micro-organisms which would otherwise cause food spoilage. This is the basis for food preservation and hence increased shelf life for foods with low moisture content. A decreased water activity inhibits the growth of most bacteria, yeasts, and molds, which are unable to grow below 0.87, 0.88, and 0.80, respectively (Beuchat *et al.,* 2013).

Some studies have indicated that aerobic mesophilic microorganisms found in food are important microbiological indicators for food quality, and most foods are regarded as harmful when they have large populations of these microorganisms, even if the organisms are not known to be pathogens (Weldezgina and Muleta 2016) and (Sudershan *et al.,* 2009). Factors which might be accountable for the counts may include drying vegetables on exposed surfaces and packing them in containers not adequately cleaned (Kudjawu *et al.,* 2011). However, present results furthermore indicated that microbial load was not as high (103 -105) and that the vegetables may possibly be preserved over a considerable period of time (Ukegbu and Okereke, 2013). However, it is important to note that if pathogenic microorganisms are present, these may cause food poisoning which may result into severe illnesses, depending on the dose and the type of microorganism.

The presence of *E. coli* in foods is usually due improper/poor handling during processing and preservation Several studies have indicated that high coliforms count in dried vegetables is an indication of poor handling in the whole value chain from farm to fork. Some important sources of contamination among leafy vegetables occured during pre-harvest which included soil, irrigation water, inadequately composted manure, human handling, reconstituted fungicides and insecticides. Postharvest sources included harvesting equipment, transport container, contaminated water used for washing, transport vehicles, processing equipment, unclean implements, poor hygiene of hands and cross contamination during preparation or storage (Njoroge *et al.,* 2015; Luna-Guevara *et al.,* 2019). The present study results are different from the findings reported by Victor, 2017 who indicated heavy fecal coliform contamination in vegetables ranging from 4.0 × 103 to 9.3 × 108 MPN/g) in Ghana and assign microbial contamination in vegetables to sources such as soil, manure, water and poor post-harvest handling and storage. Also Oranusi and Braide, 2012 explained that, total aerobic count (TAC) and fecal coliform (FC) are real indicator organisms (that is, for hygiene and sanitary conditions) and for this reason their presence in high numbers in dried fruits and vegetables implies poor hygiene and sanitary conditions during processing. However, from the present study as shown in Table 4, it was found that none of the dried TLVs vegetables had *E. coli.* This could be attributed to the blanching temperatures of 80°C for 2 minutes and enclosure of the samples in a solar-drier. Solar dryers are free from microbial contamination and are better preservers and give good quality products than sun dried products (Udomkun *et al.,* 2020)

**Bacterial load of selected Traditional Leafy Vegetables cultivated at the two different Farm Sites**

Regarding the mean microbial load of vegetables across planting sites, there was significant difference in CFU observed for Low Land (LL) compared to High Land (HL) as presented in Table 5. The observations from this study were supported by Kimaro, 2017 indicated that lower sections of the farm site registered significantly higher bacterial loads compared to the middle and upper section. At the farm, vegetable contamination can be due to contact with cattle, sheep, birds, insects and feces (Kayombo, 2018) or associated with the presence of feces from cattle and other animals, especially during heavy rainfall (Luna-Guevara, (2019). High risks of fecal contamination may have originated from people reported to be entering and/or urinating/defecating in the farms. Fertilizers, irrigation water, wild animal intrusion, insects, pesticides/fungicides, crop debris, and flooding area also potential sources of microbial contamination at production level (Kapeleka, 2020). However, practice found in the study area showed that people were not using contaminated water to irrigate vegetables and they also used toilets for urinating and defecating rather to using reserved water ponds thus no *E.coli* found. Present results further show that both TPC and *E. coli* counts were found to be lower than the maximum limit level.

**Mean microbial load of vegetable soup powder formulation**

The mean bacterial load was highest for F4 followed by F3, then F2, and lastly F1. The present results in Table 7 indicated that there was no significant differences ($p<0.05$) between the formulations. In addition, all TPC and *E. coli* were not above the recommended limit in accordance with TBS standard and the East African Standard (TZS1657:2014; EAS:2013). These results are in agreement with those of Farzana, (2017,) who found that the microbial quality of the vegetable soup powder formulation were 3 × 102 total plate count while no *E. coli* of which were within the acceptable limit according to Food Standards Australia New Zealand 2001. This was supported by Niththiya *et al.,* 2014 and Singh and Kaur, 2020, who reported that the product would be considered microbiologically safe if the total microbial count of dehydrated soups is less than 1x104 cfu/g. Other authors however, stated that samples with counts higher than 1.1×103 CFU/g are unfit for consumption (Schuh *et al,* 2019). The standard limit for aerobic mesophilic bacterial count for food should be less than 105 CFU/ml (Kimaro, 2017). Chege and Kiminywe (2016), found the level of microbes solar dried amaranth were within the within the levels recommended by the International Commission of Microbial Specification for Foods (ICMSF) which is 105 and absent (NIL) for TPC and *E. coli* respectively. According TBS standard (TZS1657:2014-EAS:2013) specification stated that microorganism maximum limit for Total plate count, cfu/g, was 1×103 for method of test ISO 4833 while *Escherichia coli*, (cfu/g), was Absent for method of test ISO 4832. Tables 7 and 8, show that microbes were below the maximum allowable levels for both TPC and *E. coli*. The absence of *E. coli* and meeting the limit for TPC in the tested formulation samples may signify good hygienic and handling practices. Generally, this is an indication of minimum adherence to Good Health Practices (GHP) and Good Manufacturing Practices (GMP).

## Conclusion

The findings of the present study indicate that the mean TPC and E. coli (CFU/g) among the raw vegetables indicated higher levels in cassava than amaranth leaves, whereas sweet potatoes leaves had the lowest count. Vegetables grown under low land sites had significantly higher ($p< 0.05$) mean TPC than those grown at home garden sites. No E. coli was found in any samples analysed in this study. For vegetable soup powder samples, the mean TPC count was of the order F4>F3>F2>F1 while no E. coli was found. Though the mean TPC count was high in all samples, they were all lower than the recommended levels and hence all samples were of acceptable standards. The absence of E. coli indicates proper handling of vegetables across the value chain. Thus the formulated vegetable soup powders may be recommended as being safe for consumption.

## Recommendations

From this study it is recommended that:

i. Vegetables found in home gardens (HG) are recommended for consumer usage because of lesser colony units indicating greater microbiological quality compared to Low Land (LL) vegetables.
ii. Education must be imparted to communities on the proper handling, including storage and transportation of the vegetables and practicing hygiene since they significantly reduce microbial load in food products.
Other studies may be conducted to determine shelf life of the formulated vegetable soups.
iii. Farmers, vegetable processors and consumers who suffer from bulk loses and microbial destruction of raw vegetables can use this idea of processing vegetables soup powder as it assured microbiological safety of the vegetables and also create new products as well as market segments.

## Acknowledgments

The study was partially funded by the Veg-Leg project which was supported by funds from the Germany Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE); Tanzania Meat Board that granted half of financial support for the study and SUA- for providing desk space for laboratory work.

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# *Trans* Fatty Acids in Tanzania: are Consumers and Processors Aware of the Associated Health Hazards? a Case of Morogoro

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**Abstract**

*Several studies have shown an association between Trans Fatty acids (TFAs) consumption and increased risk of cardiovascular diseases (CVD). FAO and WHO recommend that the TFAs in human dietary fat should be reduced to less than 1%. This study was conducted to assess the awareness regarding TFAs among consumers and food/oil processors in Morogoro region, using a cross-sectional study design. Study sample included 340 households, whereby 176 were from Morogoro urban and 164 from Morogoro rural districts, as well as 32 food/oil processors (22 = small scale; 10 = large scale). Structured questionnaires were used to collect data. Descriptive statistics were conducted to determine the awareness on TFAs and the health effects associated with the consumption of foods containing TFAs. About 98% of all consumers had neither knowledge nor awareness about TFAs and associated health effects. Nevertheless, awareness level was observed to improve with residence location and level of education. The level of awareness of TFAs in MjiMkuu ward (urban) was significantly different from Kiroka ward in rural area (OR:=18.111; P= 0.020). No significant differences were observed in the level of awareness between consumers in Kiroka (rural) and in Mazimbu ward (urban) (OR:= 5.397; p=0.126). Large scale food and oil processors were more aware about TFAs than small scale food and oil processors. General awareness on TFAs and the associated adverse health effects among consumers were very low compared to that of processors which were also influenced by residential location and level of education. The current study shows that consumers in the study area were at high risk of exposure to TFAs and developing conditions such as cardiovascular diseases (CVDs) which may result in stroke, leading to significant disability, emotional problems and death in the worst case.*

***Keywords:*** TFAs, Cardiovascular Diseases, Awareness, Consumers, Food/Oil Processors

## Introduction

*Trans* fatty acids (TFAs) are types of unsaturated fatty acids and can be classified as either naturally occurring or industrially produced (Kamel, *et al.,* 2018). Naturally occurring TFAs or ruminant Trans fatty acids (rTFAs) are found in small amounts (3-6%) in food products such as meat and milk products from animals (Mouratidou *et al.,* 2014). Industrially produced Trans fatty acids (iTFAs) are formed by the process of partial hydrogenation in the industrial production of partially hydrogenated oils (PHOs) (Tsuzuki *et al.,* 2010; Afaneh *et al.,* 2017; Pfeuffer and Jahreis, 2018). During the process, oil is hardened, which improves its commercial appeal by enhancing its sensory and texture profiles, also increasing its shelf life; factors that often attract most food manufacturers to prefer PHOs (Dhaka *et al.,* 2011; Mouratidou *et al.,* 2014; Blocks, 2019). PHOs are the main source of TFAs (up to 60%) and are used as bakery shortening, frying oil and in house¬hold cooking (Taher *et al.,* 2018). Although PHOs are edible their consumption is associated with increased risk of coronary heart diseases (CHD) (Sartika, 2011; Derbyshire, 2012; Musvosvi and Mhlanga, 2016). The adverse health effects of TFAs in humans are mediated by increased plasma concentrations of low-density lipoprotein cholesterol (LDL-C) and reductions in high-density lipoprotein cholesterol (HDL-C) (Wu *et al.,* 2017), which leads to promotion of inflammation, endothelial dysfunction, insulin resistance and displacement of essential fatty acids from membranes (Mitrou & Lawrence, 2014). CHDs contribute to the global burden of disease especially in low and middle income countries (Derbyshire, 2012; Banseria *et al.,* 2016; Taher *et al.,* 2018; Li *et al,* 2019). It is estimated that 2% increase in energy intake from TFAs is associated with a 23% increase in the risk of heart disease (Banseria *et al.,* 2016). The World Health Organization (WHO) recommends reducing TFAs intake to less than 1% of total daily dietary energy intake (Li *et al.,* 2019). PHOs are the major source of fats/oils in Tanzania by about 60% and its importation has reached about 500,000 Metric tonnes (3ADI+, 2019). The annual consumption of such volumes of dietary source of fat could pose health threat especially CHDs to consumers (Kagiono *et al.,* 2018). However, there is still limited information and awareness regarding the levels of TFAs and their underlying health hazards to the Tanzanian population (Codex Alimentarius Commission, 2017). Tanzania has recorded increased incidences of diet related non-communicable disease (DR-NCD) especially cardiovascular health problems and deaths from 27% in 2010 (Mayige *et al.,* 2011) to 33% in 2016 (Mayige, 2016; URT, 2016; WHO, 2018). The aim of this study was to assess the level of awareness about Trans fatty acids (TFAs) among consumers, edible oil producers and food processors. This study was envisaged to contribute to examining the knowledge of Trans fatty acids with regards to the emerging rise in DR-NCDs and guide policy formulation by the Government and interventions by nutrition stakeholders.

## Materials and Methods

### Study area

This study was conducted in Morogoro urban and rural districts (Morogoro region; 6°, 49'S, 37°, 40'E). Morogoro region was selected for the study because previous studies have reported that, it was among the three sites (including Dar es Salaam and Hai - Kilimanjaro) which demonstrated a considerably high risk of dying from non-communicable diseases (NCDs) during adulthood (15-59 years) in Tanzania (Mayige and Kagaruki., 2013).

### Sample size determination

The sample size was calculated using the Fisher's equation shown below:-

$$n = \frac{z^2 \times p(1-p)}{e^2} \qquad (1)$$

Where by n = sample size, p = population proportion 33% (National prevalence of NCDs), e = Margin of error, set 5% for this study and Z = standard variance at a given confidence level, for this study 95%, confidence level = 1.96 (Kothari and Garg, 2014).

### Study population

The study population included adult consumers residing in urban and rural households and edible oil producers and food processors.

### Sampling procedure

Simple random and purposive sampling approach was used in the study. Morogoro region was randomly selected out of 3 sites (including Dar es Salaam and Hai-Kilimanjaro) reported with high risk of dying from non-communicable diseases during adulthood in Tanzania (Mayige and Kagaruki, 2013). Also,simple random sampling was employed in selecting the two districts (Morogoro urban and rural) out of eight. Furthermore, purposive sampling was employed in selecting two wards (MjiMkuu and Mazimbu) out of 29 wards from Morogoro urban district, and one ward (Kiroka) out of 31wards from Morogoro rural district (Mazimbu and Kiroka wards were the most populated wards in their respective districts, while MjiMkuu ward was selected because it was situated at the town centre). Finally simple random sampling was employed to get streets/villages whereby; four streets (Karume A, Uhuru, Darajani and Boma

A) out of 14 streets were selected from the two wards in Morogoro urban and two (Kiroka and Kiziwa) out of four villages were selected from one ward in Morogoro rural district. The random selection (districts and streets/villages) was done by using a computer program for random number generation. Furthermore a total of 340 households were randomly allocated according to population proportion by using lists of all names of household's heads from village/street leaders, whereby one adult individual per household was eligible to participate in the study (Fig. 1).

currently working in edible oil and food processing factories (small and large scale) to make a total of 32 participants (Fig. 2). Most of the branded industrial products (e.g. edible partially hydrogenated cooking oils/fats) were manufactured in Dar es Salaam region, and hence large scale processors (edible PHOs and other products such as biscuits and breads), were assessed. Some key questions included their general knowledge regarding TFAs, rich sources, associated health problems, how they are formed, and regulatory issues with regards to TFAs.

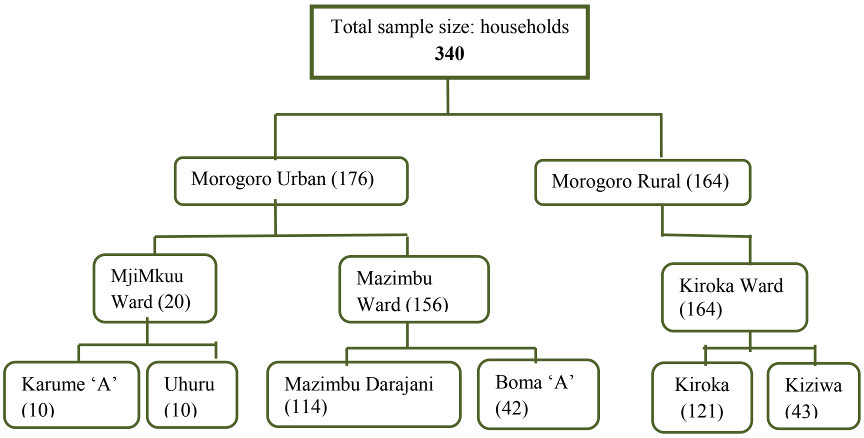


**Figure 1: Distribution of consumers**

**Data collection**

Data on Trans fatty acids awareness assessment were collected from 340 respondents representing the group of consumers, 14 participants involved in edible oil and 18 in food production. Structured questionnaires were administered to 176 consumers in Morogoro urban and 164 in Morogoro rural districts. Also there was an addition of some key people (Quality control/production personnel)

**Data analysis**

Descriptive data were calculated as percentage and frequencies for the variables such as knowledge and awareness. The software for data analysis was SPSS version 20.0 (IBM - SPSS Inc., Chicago, USA) whereby the Fishers exact test was used to determine significance for the relationship between variables. Moreover binary logistic regression was used to test for associations between awareness as dependent

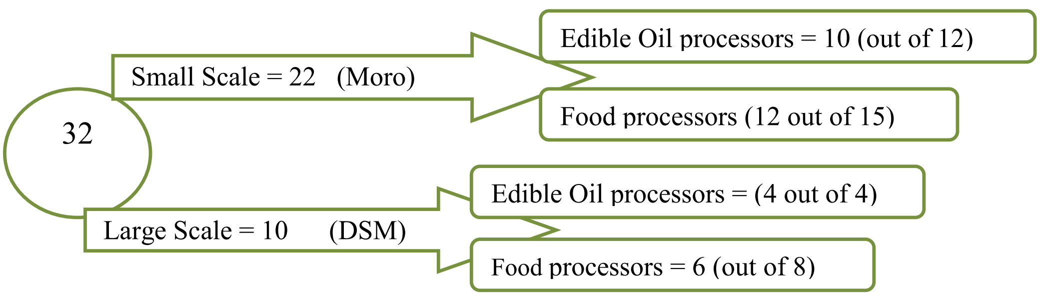


**Figure 2: Distribution of Edible oil and Food processors**

and residence location, education level as independent variables.

For the consumers' awareness component, each item was given a score of "0" ,"1" or "2" for the incorrect, not sure and correct responses respectively. Hence, the total score for the 5 questions in this section was 10 (0-10) for each participant. For the processors' awareness; each item was given a score of "2" for a correct answer, "1" for "Not sure" and "0" for incorrect or negative response. Hence, the total score for this section of 7 questions was 14 (0–14) for each participant. Participants' overall knowledge was categorized using modified Bloom's cut-off point (Seid and Hussen, 2018).

**Results**

**Demographic information**

A total of 340 respondents were enrolled in the study, 176 from Morogoro urban and 164 from Morogoro rural district. About 94% of all respondents were female; 35% of the respondents' age ranged between 31 and 45 years old. Close to 61% of all respondents had attained primary education level; 62% from rural and 59% from urban areas. Generally, farming was the main source of income for 58% of all respondents. In Morogoro rural, 88% of the respondents depended on Agriculture and in Morogoro urban 47% of the respondents depended on small business as their main source of income (Table 1).

**Table 1: Demographic information of respondents**

| Characteristic | Category | Morogoro Urban | | Morogoro Rural | | Total | |
|---|---|---|---|---|---|---|---|
| | | N=176 | | N=164 | | N=340 | |
| | | n | % | n | % | n | % |
| **Sex of respondents** | | | | | | | |
| | Male | 10 | 5.7 | 9 | 5.5 | 19 | 5.6 |
| | Female | 166 | 94.3 | 155 | 94.5 | 321 | 94.4 |
| | **Total** | **176** | **100** | **164** | **100** | **340** | **100** |
| **Age of respondents** | | | | | | | |
| | 21 -30 | 54 | 30.7 | 48 | 29.3 | 102 | 30.0 |
| | 31 - 45 | 56 | 31.8 | 64 | 39 | 120 | 35.3 |
| | 46 - 59 | 34 | 19.3 | 28 | 17.1 | 62 | 18.2 |
| | 60 and Above | 32 | 18.2 | 24 | 14.6 | 56 | 16.5 |
| | **Total** | **176** | **100** | **164** | **100** | **340** | **100** |
| **Education level** | | | | | | | |
| | Informal | 19 | 10.8 | 40 | 24.4 | 59 | 17.4 |
| | Primary | 104 | 59.1 | 102 | 62.2 | 206 | 60.6 |
| | Secondary | 43 | 24.4 | 20 | 12.2 | 63 | 18.5 |
| | Tertiary | 10 | 5.7 | 2 | 1.2 | 12 | 3.6 |
| | **Total** | **176** | **100** | **164** | **100** | **340** | **100** |
| **Main source of income** | | | | | | | |
| | Formal employment | 23 | 13.0 | 5 | 3.0 | 28 | 8.3 |
| | Casual Labour | 18 | 10.2 | 0 | 0 | 18 | 5.3 |
| | Farming | 54 | 30.1 | 145 | 88.4 | 198 | 58.2 |
| | Small business | 82 | 46.6 | 14 | 8.5 | 96 | 28.2 |
| | **Total** | **176** | **100** | **164** | **100** | **340** | **100** |

**Knowledge on *Trans* fatty acids (TFAs) among Consumers**

Results in Table 2 show that of all (340) surveyed consumers, 97.6% had no information or awareness of Trans fatty acids before and 98.8% had no knowledge on how Trans fatty acids are formed. knowledge on foods with Trans fatty acids and associated health effects among consumers was very low. Only 5% of consumers in MjiMkuu ward, 3% in Mazimbu ward and 0.0% in Kiroka ward had knowledge on foods rich in Trans fatty acids and associated health hazards (Table 2).

**Table 2: Consumer's knowledge on *Trans* fatty acids**

| Variables | Response | Total N=340 | | Wards: Mazimbu N=156 | | Wards: Mji mkuu N=20 | | Wards: Kiroka N=164 | |
|---|---|---|---|---|---|---|---|---|---|
| | | n | % | n | % | n | % | n | % |
| **Heard of *trans* fatty acids?** | | | | | | | | | |
| | Yes | 8 | 2.4 | 5 | 3.2 | 2 | 10 | 1 | 0.6 |
| | No | 332 | 97.6 | 151 | 96.8 | 18 | 90 | 163 | 99.4 |
| **Knowledge on how *trans* fatty acids are formed?** | | | | | | | | | |
| | Yes | 4 | 1.2 | 3 | 1.9 | 1 | 5 | 0 | 0 |
| | No | 336 | 98.8 | 153 | 98.1 | 19 | 95 | 164 | 100 |
| **Ways on how *trans* fatty acids are formed** | | | | | | | | | |
| | Industrial process during preparation of Vegetable oils | 4 | 1.2 | 3 | 1.9 | 1 | 5 | 0 | 0 |
| | Formed naturally | 1 | 0.3 | 0 | 0 | 0 | 0 | 1 | 0.6 |
| | No idea | 335 | 98.5 | 153 | 98.1 | 19 | 95 | 163 | 99.4 |
| **Knowledge on Foods rich in *trans* fatty acids and associated health effect?** | | | | | | | | | |
| | Yes | 5 | 1.5 | 4 | 2.6 | 1 | 5 | 0 | 0 |
| | No | 335 | 98.5 | 152 | 97.4 | 19 | 95 | 164 | 100 |
| **Who told you about foods rich in *trans* fatty acids and associated health effects?** | | | | | | | | | |
| | Through studies/ readings | 4 | 80 | 3 | 1.9 | 1 | 5 | 0 | 0 |
| | Health officer | 1 | 20 | 1 | 0.6 | 0 | 0 | 0 | 0 |

In addition, 98.5% of all consumers had no knowledge about the foods rich in Trans fatty acids and their associated health effects. Furthermore, for few consumers who had knowledge about Trans fatty acids and associated health risks, 80% indicated that their source of information was through individual studies/readings, 20% obtained information from Health Officers. About 99% of consumers in Kiroka ward had never heard of Trans fatty acids followed by consumers in Mazimbu ward (96.7%) and lastly MjiMkuu ward (90%). The

**General Consumer's awareness on *Trans* fatty acids**

There was no significant difference in awareness on TFAs between consumers in Kiroka and Mazimbu wards (OR: 5.397; p=0.126). There was a significant difference on the level of awareness on TFAs between consumers in Kiroka ward and MjiMkuu ward (OR:=18.111; P=0.020). The odd of being aware was higher for consumers in MjiMkuu and Mazimbu wards than in Kiroka ward (Fig. 3).

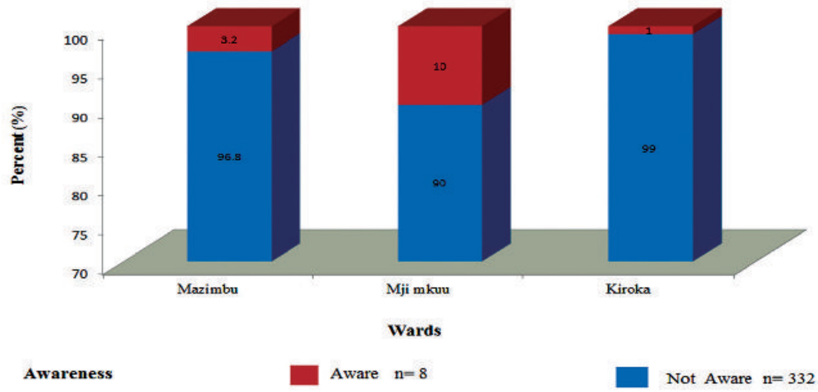


**Figure 3: General Consumer's awareness on Trans fatty acids**

**Knowledge and awareness on Trans fatty acids among edible oil and food processors**

About 41% of the edible oil and food processors were aware about Trans fatty acids (TFAs). All (100%) respondents from large scale edible oil and food processors, had prior knowledge about TFAs, followed by the group of small scale food processors who scored 17%, and lastly was the group of small scale oil processors (10%). Only 13% of all surveyed groups had knowledge on how TFAs are formed. About 50% of the group of large scale edible oil processors had higher knowledge on how TFAs are formed compared to other groups (Table 3).

Only 16% of all respondents surveyed, had knowledge on foods rich in TFAs and associated health hazards. More (25%) of the large scale edible oil processors had knowledge about foods rich in TFAs compared to small (17%) and large scale food processors (17%) and small scale edible oil processors (10%). The main source of information was through studies/ readings for 60% of the respondents, and 40% obtained information from health facilities. large scale food processors had the highest (83.3%) knowledge of the association between concentration of TFAs and the level of low density lipoprotein (LDL) - cholesterol in blood followed by the large scale edible oil processors (75%), small scale food processors (17%) and small scale edible oil processors (0.0%) (Table 3).

**General Awareness on TFAs among edible oil and food processors**

Generally for the group of edible oil, results show that; the awareness of all (100%) edible oil large scale processors on TFAs was above average, followed by 10% of the small scale edible oil processor's group (Fig. 4). The Fishers test results showed a significant difference (P= 0.005) among the small and large scale edible oil processors in terms of general awareness on TFAs.

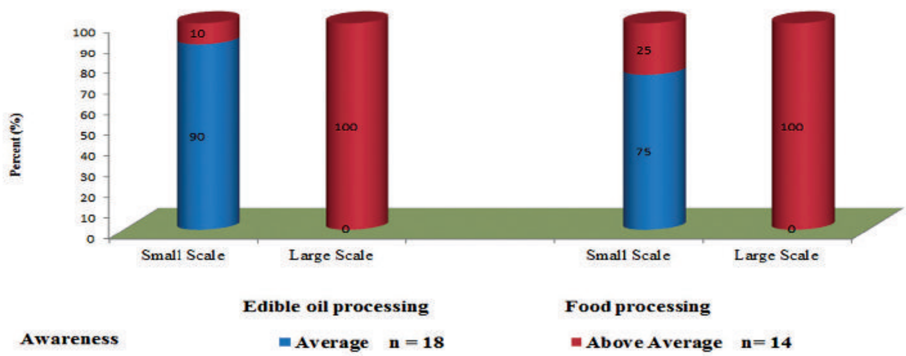


**Figure 4: General Awareness on TFAs among edible oil and food processors**

**Table 3: Consumer's knowledge on *Trans* fatty acids**

| | | Edible oil/Food Processors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variables** | **Response** | **Total N=32** | | **Small scale edible oil N=10** | | **Small scale food N=12** | | **Large scale edible oil N=4** | | **Large scale food N=6** | |
| | | n | % | n | % | n | % | n | % | n | % |
| **Have you heard of *trans* fatty acids?** | | | | | | | | | | | |
| | Yes | 13 | 40.6 | 1 | 10.0 | 2 | 16.7 | 4 | 100 | 6 | 100 |
| | No | 19 | 59.4 | 9 | 90.0 | 10 | 83.3 | 0 | 0.0 | 0 | 0.0 |
| **Knowledge on how *trans* fatty acids are formed?** | | | | | | | | | | | |
| | Yes | 4 | 12.5 | 1 | 10.0 | 1 | 8.3 | 2 | 50.0 | 0 | 0.0 |
| | No | 28 | 87.5 | 9 | 90.0 | 11 | 91.7 | 2 | 50.0 | 6 | 100 |
| **Ways on how *trans* fatty acids are formed** | | | | | | | | | | | |
| | Industrial process | 5 | 15.6 | 1 | 10.0 | 1 | 8.3 | 3 | 75.0 | 0 | 0.0 |
| | Not sure | 27 | 84.4 | 9 | 90.0 | 11 | 91.7 | 1 | 25.0 | 6 | 100 |
| **Knowledge on Foods rich in *trans* fatty acids and associated health effect?** | | | | | | | | | | | |
| | Yes | 5 | 15.6 | 1 | 10.0 | 2 | 16.7 | 1 | 25.0 | 1 | 16.7 |
| | No | 27 | 84.4 | 9 | 90.0 | 10 | 83.3 | 3 | 75.0 | 5 | 83.3 |
| **Who told you about foods rich in *trans* fatty acids and associated health effects** | | | | | | | | | | | |
| | Health officer | 2 | 40 | 1 | 10.0 | 1 | 8.3 | 0 | 0.0 | 0 | 0.0 |
| | Through studies | 3 | 60 | 0 | 0.0 | 1 | 8.3 | 1 | 25.0 | 1 | 16.7 |
| **Any relationship between concentration of TFAs and the level of LDL - cholesterol in blood?** | | | | | | | | | | | |
| | Yes | 10 | 31.3 | 0 | 0.0 | 2 | 16.7 | 3 | 75.0 | 5 | 83.3 |
| | Not sure | 22 | 68.8 | 10 | 100 | 10 | 83.3 | 1 | 25.0 | 1 | 16.7 |
| **Margarine usually contains low proportions of TFAs?** | | | | | | | | | | | |
| | Yes | 2 | 6.3 | 0 | 0.0 | 2 | 16.7 | 0 | 0.0 | 0 | 0.0 |
| | No | 5 | 15.6 | 0 | 0.0 | 1 | 8.3 | 2 | 50.0 | 2 | 33.3 |
| | Not sure | 25 | 78.1 | 10 | 100 | 9 | 75 | 2 | 50.0 | 4 | 66.7 |

For the food processors group, results show that; all large scale processors were more aware on TFAs compared to 25% of small scale food processors whose awareness on TFAs was generally average. Fishers test for association results showed that; there was a significant difference (P=0.009) in awareness among the small and large scale food processors in terms of general awareness on TFAs (Fig. 4).

**Awareness among edible oil and food processors on policies/regulations regarding Trans fatty acids (TFAs)**

Edible oil and food processors had varied responses (Not sure = 72%, No = 22% and Yes = 6%) regarding presence of regulation (s) in Tanzania or WHO that prompt food processors to limit the amount of TFAs in processed foods. Nevertheless, all (100%) of small scale edible oil processors of small scale food processors (92%) were "Not sure "about the existence of policy/regulation governing TFAs. Large scale edible oil (75%) and food processors (67%) were not aware of the existence of policy/regulations governing TFAs.

The surveyed processors were not sure (59%) and had no information (41%) of the existence of policy/regulation that requires food processors to indicate the amount of TFAs content in processed foods (Fig. 6). All large scale edible oil processors and 83% of large scale food processors were 'Not sure' of the existence of policy/regulations on revealing content of TFAs in foods and oils. Similarly, 58%of the small scale food and edible oil processors (50%) had "No idea" about the policy/regulation.

**General awareness of edible oil and food processors on policies/regulations regarding Trans fatty acids (TFAs)**

Generally 63% of all processors had an average awareness on policies and regulations regarding TFAs. About 83% of all large food processors and 58% of all small scale food processors had an average score on awareness. There was no significant difference (P=0.600) between large and small scale food processors in terms of awareness about policies/regulations on TFAs (Fig. 5). Similarly, 75% of large scale and 50% of small scale edible oil processors had an average score on awareness. No significant difference (P=0.580) was observed between small and large scale edible oil processors in terms of awareness regarding policies/regulations on TFAs (Fig. 5).

**Discussion**

The current study has revealed that most of the surveyed consumers had low level of knowledge and awareness on Trans fatty acids (TFAs) and their associated adverse health effects. There were differences between rural districts and urban districts. Most of the respondents from Morogoro rural district had attained Primary School Education whereas those in urban district had attained Secondary school certificate (and even Tertiary education levels).

In the present study, education level was probably one of the factors that contributed to increased level of consumer's awareness in urban compared to their counterparts in rural districts. Similarly, households in urban were more exposed to many sources of information regarding healthy eating such as Television, Radios, newspapers, posters and health centres compared to rural areas. Despite all these sources of information, still they consumed more on unhealthy foodstuffs such as processed and PHOs, less on vegetables and fruits. Meanwhile those rural households despite their low education, they consumed more on minimally processed foods like vegetables,

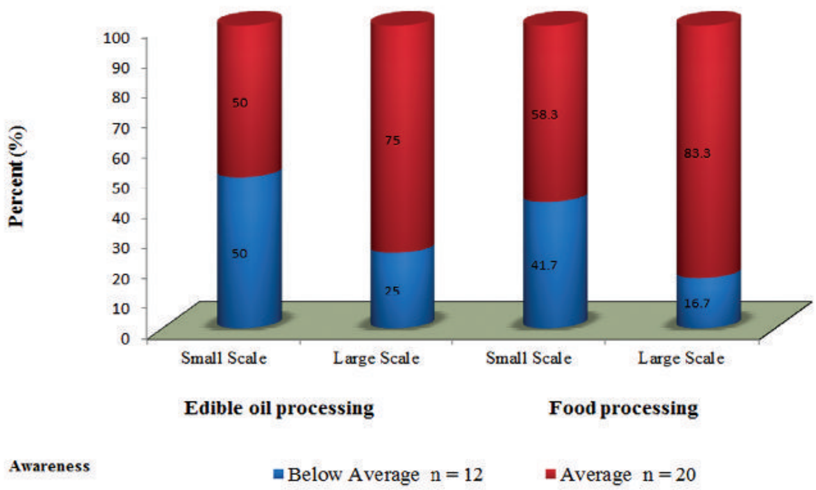


**Figure 5: General awareness on policies and regulations regarding TFAs among processors**

beans but more on PHOs because it was cheap and readily available. A similar study done by Banseria *et al.* (2016) in central India found that an awareness regarding the presence of TFAs in packaged food items and their harmful effects among participants increased from 62% before being trained and exposed to sources of information regarding healthy eating to 96% after intervention.

Furthermore the observed low level of knowledge and awareness in the current study could be attributed by low nutrition education regarding overconsumption of edible oils, TFAs and their associated health effects in general, also the absence of government policy to limit TFAs in processed foods could be the major factor for lack of awareness and limited control of the amounts and presence in foods. This in turn exacerbates the high level of exposure to TFAs for both urban as well as rural households. A similar study done by Musvosvi and Mhlanga (2016) observed that the level of awareness of consumers on TFAs in Kitwe –Zambia increased with the level of education. Also Pletzke *et al.* (2010) observed that nutrition education was associated with more TFAs knowledge and awareness scores among consumers.

According to the results of the current study, the group of edible oils show that; large scale edible oil processors were more aware on TFAs compared to small scale edible oil processors whose level of awareness on TFAs were just an average. The observed differences in their awareness might be contributed by the fact that; all small scale processors were dealing with Sunflower oil (seed oil) processing of which literature have reported that they are healthy, on the other hand large scale oil processors were dealing with partially hydrogenated vegetable oil (PHOs) either in processing or repackaging, that's why their awareness level were higher, moreover; most previous studies had reported that PHOs from industrial sources contain higher proportional of TFAs due to the process of partial hydrogenation during their preparation (Mozaffarian *et al.,* 2013; Pfeuffer, and Jahreis, 2018; Thornton, 2018).

Furthermore in the current study, results for food processors group showed that; large scale food processors were more aware on TFAs compared to small scale food processors who their awareness level was average; this might be contributed by the fact that most of the personnel involved in large scale food processing attained tertiary education, while majority of the small scale food processors attained primary and only few secondary level of education., This is supported by other studies (Lin *et al.,* 2010; Musvosvi and Mhlanga, 2016) where awareness on TFAs was observed to improve with education. Also being in the large scale processing industry could be another factor that favoured large scale processors on being aware on TFAs than those small scale processors. This instance puts most consumers in Morogoro at risk of diet related non communicable disease especially cardiovascular disease (CVDs) in particular, since most of them consume processed foodstuffs manufactured/prepared either by small or large scale processors.

The findings in current study reported that awareness among all groups of edible oil and food processors towards the country's policies and regulations regarding TFAs were generally average. Moreover, some minor variations were observed, whereby the score for large scale processors were slightly higher compared to small scale processors, besides both group having an average awareness.

The observed moderate awareness of both large and small scale processors regarding policies and regulations on TFAs could be contributed by the fact that in Tanzania, the policies and regulations on TFAs were not yet set in place. This situation predisposes consumers at more risk of non-communicable diseases especially CVDs. The obtained findings are also supported by Li *et al.* (2019) from the study on evidence from global surveillance of TFAs which showed that Tanzania was one among countries in Africa which had not yet set the regulations and policies on TFAs. The current study is also in parallel with another study done by Juma *et al.* (2016) which found that; in sub-Saharan Africa, there is limited research on the application and success of multi-sectoral approach in the formulation and implementation of policies aimed at prevention of non-communicable diseases. Furthermore, findings of the current study is in good agreement with the

World Health Organization (WHO, 2019) which argued that, understanding TFAs sources, the supply chain, stakeholders, regulatory agencies and legal processes will help inform which policy intervention will be most effective and practical to reduce consumption of industrially produced TFAs.

## Conclusion

Better nutrition knowledge, especially knowledge about diet-disease relationships, can help promote healthful dietary choices and enhance health literacy among consumers.

Awareness and understanding of different fats to food consumers, edible oil and food processors may also help decrease the risks of diet related non communicable diseases (NCDs) as attributed by Trans fatty acids.

It is recommended that; there is a need to increase awareness regarding the danger of Trans fatty acids among Morogoro households which will reduce or cut down their usage in their diet plans.

A further research to be conducted by considering other factors that might be contributing to the low level of awareness towards Trans fatty acids among households/ consumers and also considering other consumer locations in Tanzania.

It is better for the government through the Ministry of Health Community Development, Gender, Elders and Children in collaboration with other relevant authorities to provide guidance on policy options and steps to design, enact and implement legislative and regulatory actions suitable to the Tanzanian context in order to reduce industrially produced Trans fatty acids in the food supply. However, the results of the current study may be gender biased due to the fact that, most of the participants for the study were women.

## Acknowledgments

Authors are deeply grateful for the financial support provided by the Ministry of Agriculture -Tanzania and the Sokoine University of Agriculture for their technical support to accomplish this study.

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# Agricultural Value Chain Incubation Programmes and Youth Employment: A Case of the Sokoine University Graduates Entrepreneurs Cooperative, Morogoro, Tanzania

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**Abstract**

*Youth unemployment is on the rise globally Tanzania inclusive. Nonetheless, for Tanzania, the agricultural sector has a potential for employment creation at the various nodes of the agricultural value chain. Therefore, the study generally examines the contribution of the Sokoine University Graduates Entrepreneurs Cooperative (SUGECO) in enabling its graduate's self-employ while creating employment for others. Specifically, the study examines the contribution of the above-mentioned programme to youth's employment; identifies challenges facing the programme, and examines the policy gaps. The study is based on the cross-sectional research design whereby data were collected using a structured questionnaire from 88 respondents. In addition, data were collected from five key informants. Quantitative data were analyzed using SPPS and qualitative data through content analysis. Generally, study findings show that SUGECO has the potential to support young entrepreneurs' development and job creation in Tanzania. Findings also show that SUGECO offers a variety of trainings which equip its graduates with business management and employment skills. In addition, marital status and being trained in agribusiness were significantly (P≤0.05) associated with the graduates' employment creation. However, the findings show that SUGECO and its graduates face a number of challenges including lack of funding, lack of commitment among the graduates, and unsupportive government policies. Therefore, SUGECO needs to adhere to its pre-defined criteria when selecting candidates for incubation programme so as to only recruit the committed ones. In addition, the Government and non-governmental organizations should collaborate and put some efforts to promote the SUGECO agribusiness incubation programme as it has the potential for employment creation and poverty reduction among the youth.*

***Keywords:*** Incubation programme, SUGECO, Youth, employment creation

## Introduction

### Background Information

Globally, employment issues differ between developing and developed countries. However, the latter's benefit system for the unemployed allows their employment services to maintain records of the youth before they become long-term unemployed (Eichhorst and Ulf, 2017). Youth unemployment remains a major concern in many countries hence, poor socio-economic status and welfare of the people (IEG, 2013).

Tanzania's populationin 2020 was estimated to be 57, 637, 628 million people with the youth aged 18 to 35 years making 28 % (NBS *et al.*, 2018). In addition, the population is projected to be 77,537,166 people by the year 2030 with the youth being 28% of this projection, therefore, the need for more employment opportunities. One major challenge currently faced by Tanzania is youth unemployment (Agwanda & Aman, 2014). Furthermore, the increase of new universities and free education policy has resulted in a large number of young individuals without formal jobs. It is estimated that every year more than 700,000 youth enter the job market (Mabala, 2019). In addition, despite youth from universities and vocational training institutions having knowledge and skills, many remain jobless. Furthermore, youth from universities/vocational training institutions approximately stay 5.5 years jobless while searching for a job after their graduation/ completion of studies (Haji, 2015). This joblessness is contrary to expectations of most families who have high hopes of their children finding jobs after graduation hence, lack of positive contribution to their families' welfare due to lack of stable employment (Msigwa and Kishepa, 2013).

Incubation programmes have been identified as good sources of employment creation, wealth generation at local and national level and reduction of poverty in general (Aldrich and Zimmer, 2011). Through youth's involvement in incubation programmes, they can gain skills and knowledge on how to start and manage a business and create self-employment hence, reduction of youth unemployment worldwide. According to Aranha (2003), the primary mission of successful incubation programme is to create employment opportunities. Any successful programmes also enclose community problems by combining the entrepreneurial activities with the solutions to solve the problem such as quality of education, safety and security, and access to money. Business incubation and entrepreneurship are very closely linked. The benefit obtained by entrepreneurs in the incubation center including access to advisory services, capacity building such as business training, mentoring, specialized technical training, linkages and networking, access to technology, markets and finance (Rajeev *et al.,* 2017). Therefore, more young enterprises need to be supported through incubation centres to increase the chance of self-employment hence, greater economic success in an increasingly competitive global economy.

Globally, incubation programmes have been seen to have positive impact. For example, a study by the State of Missouri in United States of America examined nine incubation programmes with 175 incubated businesses and confirmed that there is a positive impact on employment creation and economic development. According to the study a total of 502 jobs were created which on average means that 60.5 jobs were formed per programme (Wagner, 2006). Furthermore, a study by Lalkaka *et al.* (2003) on the impact of business incubators revealed that in China, business incubators had good financial return with the investment per year.

The need for employment creation and nurturing of young entrepreneurs has lead to establishment of a number of incubation programmes in Tanzania among which is SUGECO (The Sokoine University Graduates Entrepreneurs Cooperative). Therefore, the study on which the paper evaluated how the SUGECO incubation programme has been successful in enabling those who go through it to self-employ themselves and/or create employment for others

**Business Incubator Operational Models**

According to literature (Global forum, 2013) there are several models for business incubation and they differ depending on the business environment, objectives and their owners and funders. However, according to Aranha (2003) there are four (4) incubation models which include; bricks and mortar; virtual portal; the hub and Eggubator. Generally, the 'Bricks and mortar (historical model)' model focuses on providing services such as office support, physical facilities and onsite services to the entrepreneurs. Under this model entrepreneurs are provided physical gathering place with no fund where they can work. On the other hand the 'Virtual portal or without walls', is a new model in start-up phase of business incubators with no solid track record. Therefore, under this model entrepreneurs are provided with a range of electronic service and given access to a limited amount of fund. Hub or venture incubator, this model combines the brick and mortar and the virtual portal models. The business incubators offer their clients' specialized good range of services and network to the outsider also, entrepreneurs are provide with a limited amount of fund. Lastly, the 'Eggubator' model incorporates the above models. The Eggubator offers an array of services including high quality information and fund while at the same time acting as the mother company, the source of network and support (Aranha, 2003).

## Methodology

### Description of the Study Area

The study involved the Sokoine University Entrepreneurs Cooperative (SUGECO), which is located at Sokoine University of Agriculture, Morogoro Municipality. SUGECO was established in July 2011 in Morogoro and it is a membership-based organization whose goal is to promote entrepreneurship in Tanzania so as to contribute to the creation of a vibrant private sector economy. SUGECO's basic role is to support innovation and knowledge-intensive entrepreneurship among Tanzanian youth. The Institution's core objective is to conceptualize, unfold and implement the student entrepreneurship value chain. Generally, SUGECO offers selected participants an exciting opportunity to be mentored through the Youth Entrepreneur Incubation Program located at SUGECOs Incubation Centre at Sokoine University of Agriculture, Morogoro. Besides, young entrepreneurs are provided with time and space to test and market their products (SUGECO, 2017). In reference to sub-section 1.2 above SUGECO falls under the 'Eggubator' model as the organization prepares, enables, and supports knowledge-intensive and innovative entrepreneurs as they build successful businesses along agricultural and agribusiness value chains. SUGECO was selected because it deals with fresh graduates and it offers training in entrepreneurship, business ecosystem and network development and business start-up support through business incubation services and access to finance organization particularly for agriculturally based enterprises/value chains (SUGECO, 2017).

### Research design

The study employed a cross-sectional research design, which allows data to be collected at one point in time (Creswell, 2014). In addition, it is also relatively inexpensive since it takes little time to conduct and there is no loss to follow-up (Hemed, 2015). Further to the above, the study used a mixed-methods approach whereby both qualitative and quantitative data were collected using key informants interviews and open-ended questions in the structured questionnaire respectively. The mixed methods approach was essential so as to allow triangulation.

### Sampling procedures and sample size

The study employed probability and non-probability sampling to select respondents. In addition, the sampling was multi-stage. First, SUGECO was purposively selected because it is among the programs dealing with fresh graduate entrepreneurs. The second stage involved a simple random sampling of 88 respondents from whom data were collected. According to the literature (Kish, 1965; cited by Louangrath, 2017), the minimum sample size for social science research can be 30 as this is reasonable when it comes to generalization of a study's findings.

### Data analysis

Content analysis was used to analyze qualitative data whereby field data (collected through interview and observation) were summarized based on the themes and objectives of the study. The primary data collected through the questionnaire were coded and analysed using IBM SPSS software (version 20). SPSS was used to determine descriptive statistics (frequencies and percentage distribution of the responses). In addition, inferential statistics were determined using a binary logistic regression model to show the probability of SUGECO incubation programme graduates creating employment. The binary logistic regression model was specified as follows:

The logistic regression model is based on the logistic probability function given as:

$$Pi = f(Z_i) = 1/1+e^{-z} \qquad (1)$$

Where Pi is the probability of success, the probability that a SUGECO graduate may create employment, and Zi represents exposure to factors that may influence the creation of employment, $Zi=\alpha+\beta Xi$ and its probability is expressed as,

$$Zi = \ln(Pi/1-Pi) \qquad (2)$$

Thus;

$$Zi = \ln(Pi/1-Pi) = \beta o+ \beta 1X1+ \beta 2X2+ \beta 3X3+\ldots+\beta nXn+\varepsilon i \qquad (3)$$

$$Z_i = \text{Employment creation} = \beta 0 + \beta 1\text{Age} + \beta 2\text{Sex} + \beta 3\text{MaritalStatus} + \beta 4\text{HouseholdSize} + \beta 5\text{Programofstudy} + \beta 6\text{Doingbusinessbefore} + \beta 7\text{Number of employees} + \beta 8\text{Sourceofcapital} + \beta 9\text{Initial investment} + \beta 10\text{Agribusness} + \beta 11\text{Duration of study} + \varepsilon i \quad (4)$$

Where $\varepsilon_i$ is the error term, $P_i$ is the probability of creating employment, and $1-P_i$ is the probability of not creating employment, $\beta 0$ is the constant of the equation. The description of the variables entered into the model as described in Table 1 below.

**Table 1: Description of variables used in the logistic regression model**

| Variable | Description | Measurement |
|---|---|---|
| Sex | Sex of the youth | 1= Male, 0 = Female |
| Marital status | Marital status of youth | 0 = Single/divorced/ otherwise, 1 = Married |
| Educational level | Youth educational level | 1 = Undergraduate/Post graduate 0 = Certificate/ diploma |
| Household size | Youth's household size | 1 = 1-5, 0 = above 5 |
| Parents occupation | Youth's parent's/guardian's occupation | 1 = Business/entrepreneur, 0 = Otherwise |
| Programme studied | Youth's programme of study college/university | 1 = Agriculture economics and Agribusiness, 0 = Otherwise |
| Training in Agribusiness | Youth's access to agribusiness training by SUGECO | 1 = Yes, 0 = No |
| Source of capital | Source of youth's capital | 1=Parent/guardian/relative 0 = Otherwise |
| Doing business before joining SUGECO | Youth's experience in business before joining SUGECO | 1= Yes, 0=No |

## Findings and Discussion

### Socio-economic factors responsible for one's participation in the SUGECO Incubation programme

Study findings (Table 2) show that over a half (51.1%) of the respondents were females, According to Broeck and Kilic (2019) employment in agribusiness is relatively dominated by females. In addition, distribution by age shows that older youth were the majority (59.1%) suggesting that individuals with this age are expected to be very active in business activities or other income generations activities to be able to meet their needs and those of other household members (younger youth were those aged 20 - 27 years and older youth were those aged 28 - 35 years). The findings also show that the majority (60.2%) of respondents were single. Furthermore, the findings show most of the respondent's household's size was 6 members and above. With regard to the respondents' education level most (80.7%) of had a bachelor's degree.

Study findings (Table 2) also show that SUGECO has been recruiting incubatees without discrimination by sex, therefore, a more or less equal representation of both sexes. According to Sasakawa Peace Foundation's *et al.* (2019) creating equal access in programmes and organizations to all genders fosters an inclusive environment that responds to their needs while unlocking their skills, experience, and potentials. Besides, it helps to increase the accessibility of programmes to all genders which can increase the effectiveness and value of the programme(s). Moreover, it also increases the gender diversity of the entrepreneurs and better support to them, thus, increasing their chances of achieving venture growth (impact and revenue) and sustainability.

Furthermore, the findings (Table 2) show that SUGECO mostly deals with the youth aged 18 to 35 years. The findings conform to what has been reported by Wachira *et al.* (2017) that most of business incubation programmes are dominated by the youth especially, when it comes to university-based business incubation. According to Bathula *et al.* (2011) provision of training opportunities and business outlet for faculty research was cited as the major reason for having business incubators for universities.

Another observed socio-economic factor was the incubatees 'education level whereby the majority of those joining SUGECO had a bachelor's degree suggesting that most had a high level of education. Therefore, their thinking capacity and ability to make good business decisions is also expected to be high. Generally, education is important for decision-making in relation to business start-ups as well as independence and self-confidence. Moreover, educated individuals have good knowledge of alternative job opportunities, and education expands the individual's perceptions (Belás *et al.,* 2017; Hamida *et al.,* 2017; Fayolle and Gailly, 2015). According to Davey *et al.* (2016) education, primarily delivered by universities, is a vital component in the creation and continuing development of entrepreneurial attitudes.

**Contribution of the SUGECO incubation programme to graduates self-employment and employment of others**

The binary logistic regression results (Table 3) show that out of the eight independent variables entered into the model only two variables that is marital status ($P \leq 0.05$) and training in agribusiness ($P \leq 0.05$) were significantly associated with the surveyed youth's employment creation (self-employment and employment of others). Marital status was significantly ($p \leq 0.05$) associated with one's ability to create self-employment and employment of others. In addition its coefficient was positive suggesting that individuals who were single were eight times more likely to self-employ and create employment for others compared to those married. Generally, the chances of single youth's to engage in any business and work any at time he/she wants is high since he/she is not limited with family responsibilities compared to those married. According to Baque *et al.* (2017) marriage can have a negative effect on one of the spouse's labour market outcomes. If the wife is expected to take on a larger share of household and child related responsibilities her disposable time devoted to market work would be diminished. The study's finding is contrary to what some have reported in the literature (Dvouletý, 2018;

**Table 2: Respondents' Socio-economic characteristics (n=88)**

| Variable | Category | Frequency | Percent |
|---|---|---|---|
| **Sex** | Male | 43 | 48.9 |
| | Female | 45 | 51.1 |
| **Age** | Young youth | 36 | 40.9 |
| | Older youth | 52 | 59.1 |
| **Marital status** | Single | 53 | 60.2 |
| | Married | 3 | 39.8 |
| **Household size** | 1-5 | 34 | 38.6 |
| | 6> | 54 | 61.4 |
| **Education level** | Certificate | 7 | 8.0 |
| | Diploma | 4 | 4.5 |
| | Bachelor | 71 | 80.7 |
| | Masters | 6 | 6.8 |

Ayele, 2014) that married people are more likely to be self-employed, as a result of availability of income from the person they are married to. On the other hand, this literature contends that if the new business is not successful, there is always the opportunity to use the spouse income, which gives an extra security.

The logistic regression result (Table 3) also shows that training in agribusiness was significantly (p≤0.05) and positively associated with self-employment or creation of employment for others. Training in agribusiness had an Exp (B) of 6.197implying that the youth with agribusiness education were six times more likely to self-employ themselves and employothers compared to their counterparts. This is because the agricultural sector provides many opportunities for self-employment. But, without knowledge it is not easy to run and manage agricultural related business so as to generate employment for oneself and for others. According to Koira, (2014) and Proctor and Lucchesi (2012), agribusiness presents great employment opportunities in Sub-Saharan Africa.

Furthermore, though some of the variables (source of capital, sex and parent occupation) were not significant, their Exp (B) were positive suggesting an increased likelihood to create self-employment and for others. According to the findings, some of the youth got their source of capital from their parents/guardians/relatives. Therefore, for such youth their chances to engage in business and create employment increased two-fold compared to their counterparts due to their ease inaccessing capital for their business. According to Baque *et al.* (2017), the main factors affecting the decision to become an entrepreneur among other things depends upon an individual entitlement to an inheritance or gift. Moreover, potential entrepreneurs say that raising capital is the principal obstacle they face.

The logistic regression results (Table 3) also show that sex was not significantly associated with employment creation. However, it had a positive Exp (B) of 1.158, suggesting that the chance of male youth to create self-employment and create employment for others was relatively higher than that of female youth. When considering self-employment, most literature

**Table 3: Factors associated with SUGECO graduates in employment creation (self employment or employment of others)**

| Variable | B | S.E. | Wald | df | Sig. | Exp(B) | 95% C.I. for EXP(B) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| Household size | -.733 | .721 | 1.032 | 1 | .310 | .481 | .117 | 1.976 |
| Programme of study | -.197 | .717 | .075 | 1 | .784 | .822 | .202 | 3.348 |
| Parent occupation | .086 | .275 | .098 | 1 | .754 | 1.090 | .636 | 1.869 |
| Education level | -.143 | 1.112 | .016 | 1 | .898 | .867 | .098 | 7.672 |
| Business experience before SUGECO | -1.133 | .736 | 2.372 | 1 | .124 | .322 | .076 | 1.362 |
| Source of capital | .874 | .906 | .929 | 1 | .335 | 2.396 | .405 | 14.156 |
| Marital status | 2.045 | .921 | 4.931 | 1 | .026* | 7.730 | 1.271 | 47.005 |
| Sex | .147 | .762 | .037 | 1 | .847 | 1.158 | .260 | 5.157 |
| Training in agribusiness | 1.824 | .927 | 3.870 | 1 | .049* | 6.197 | 1.007 | 38.141 |
| Constant | .451 | 1.319 | .117 | 1 | .733 | 1.569 | | |

***NB:*** **Significant level at P ≤ 0.05.Dependent variable = employment creation, Overall Wald statistic =34.030 (p = 0.000); Omnibus Tests of Model Coefficients chi-square =17.097 (p = 0.007); Hosmer and Lemeshow Test chi-square = 7.498 (p = 0.484); -2log likelihood = 56.603a; Cox & Snell R2 = 0.442; Nagelkerke R2 = 0.627, model was correctly predicted by 87.5%.*

gives attention to the study of menmay be due to the same being more likely to self-employ relative to women. The study's finding is in line with the findings by Nikolova and Bargar (2010) and Ayele (2014). Furthermore, Watson and McNaughton, (2007) reported that women still dedicate a significant part of their time to household management and parenting, and are therefore less available for entrepreneurial ventures.

The binary logistic results (Table 3) also show that the surveyed youth's parents/ guardians' occupation was positively but not significantly associated with the youth's employment creation. Thus, suggesting that having a parent/guardian who is a business person/entrepreneur increases the odds of the youth to self-employ and employ others. A simple explanation to the observation is parents/ guardians act as role model for their children hence, making it easy for the children to emulate what their parents/guardians do. According to the literature (Ayele, 2014; Simoes *et al.,* 2016), an individual's probability of becoming self-employed increases if his/her parents/guardians were self-employed. Moreover, having at least one parent with self-employment experience is positively associated with a higher chance to becoming self-employed, because the children tend to follow similar career pathways as their parents.

**Challenges faced by the youth graduates from the SUGECO Incubation Programme**

The findings (Table 4) show that SUGECO incubation programme graduates face several challenges in relation to their self-employment and creation of employment for others. The challenge reported by most (46.6%) was that of startup capital. The finding is supported by the qualitative data collected by the study as shown in the quote below:

*"SUGECO does not provide start-up capital to the incubatees because there is no enough money to do this and at the same time be in a position to run the programme"* (Key Informant, SUGECO Office, Morogoro, November 2019).

Generally, lack of startup capital makes it difficult or impossible for some of the graduates to create employment. According to literature (Pompa, 2013), credit constraints and a lack of capital, in general, have been identified as restraints for enterprise growth, particularly for developing countries enterprises. SMEs in developing countries face significant constraints when it comes to access to finance due to the high cost of capital, high collateral requirements, and lack of experience with financial intermediaries.

According to SUPER (2018) lack of access to specific forms of financing is significantly more constraining for small firms and that, access to finance is a key component to create an economic environment in which graduates can grow and flourish. Therefore, to address the above-mentioned challenge SUGECO can borrow a leaf from the Zanzibar technology and Business Incubator (ZTBI) created a revolving fund to provide seed capital to its youth incubatees to start their own business as a way to solve the problem of start-up capital. The initial capital of TZS 100 Million was jointly created by ZTBI and Milele Zanzibar Foundation. Therefore, ZTBI support has led to a reduction of startup business failures due to lack of (Rajeev *et al.,* 2017).

The other major challenge faced by the SUGECO incubation programme graduates is lack of commitment among them: some are not sure of whom they want to be as they still have in mind the idea of being employed instead of self-employment. The study findings conform to Rolfe *et al.* (2010) who reported that some of the entrepreneurs just start SMEs for survival as they wait for formal sector jobs. Further to the above one of male respondents said:

*"Some of the incubatees do not take serious the trainings offered by SUGECO because they believe that they are here just to buy time before they get employed by the government or other organizations. Generally, such mentality reduces the ability of working hard and thinking big so as to create your own employment. In addition, it also contributes into laziness"* (A Male SUGECO incubation programme graduate, December, 2019).

Furthermore, lack of confidence and patience was a major challenge as shown in Table 4. Generally, entrepreneurship requires not only entrepreneurial skills but, also being enthusiastic towards a given opportunity. There are a lot of business opportunities in the society which graduates fail to grab due to lack of confidence. Successful grabbing of business opportunities requires a clear understanding of the business, such as the nature of clients, business market analysis and national policy. In addition, most of the graduates like to undertake small and easy businesses that yield quick profits in a short period of time. Therefore, most are impatient which hinders their gradual growth. According to Asoni (2011), self-confidence is one of the important determinants of entrepreneurship, it increases the probability of owning and managing a firm and it also has a positive effect on business survival. Just like raising a child, managing growth of a firm/enterprise brings on many challenges as one navigates each stage of his/her businesses development. Creating systems, building a structure, hiring staff, raising money, managing cash flows, growing revenues, also take patience and hard work. Although it may not be as fun and rewarding as the startup for many entrepreneurs, it is the key to building a successful venture (Jeffiey, 2013).

Findings from this study (Table 4) further show that graduates face difficulties when it comes to putting what they have in mind as a business idea into implementation. Hence, fear to start a new venture. According to Rajeev *et al.* (2017) a business incubator offers an ideal environment for start-ups and entrepreneurs to transform their ideas into viable business ventures. Therefore, incubators such as SUGECO need to offer entrepreneurs and small businesses proper backup and guidance to be able to concretely market their business concepts, operate effectively and keep up with the pace of change whilst remaining competitive.

Insufficient working equipment and infrastructure was also reported to be challenge by the SUGECO incubatees programme (Table 4). One of the female graduates said:

*"We still have the problem of working equipment such as solar dryers, machines and fridges. In addition, infrastructure such as offices, meeting rooms, water and electricity are also challenges sometimes. The equipment at SUGECO is not enough compared to the number of people needing the same leading to incubatees' working in shifts. For example, users of solar the dryers work in shifts because space is not enough so some have to wait for those using them to finish. This is a big challenge as it may lead to the delay of delivery of products especially if ones customers want them urgently/ timely"* (A female SUGECO incubation programme graduate, November 2019).

According to Khalil and Olafsen (2009), business incubation programmes should be proactive in assisting the client and offer assistance in areas that the entrepreneurs may not be prepared to deal with on their own. Therefore, they should offer shared infrastructure (to

**Table 4: Challenges facing youth after they graduate from the SUGECO Incubation Programme (n= 88)**

| Challenges | Frequency | Percent |
|---|---|---|
| Start-up capital | 41 | 46.6 |
| Market problem | 7 | 8 |
| Lack of commitment | 23 | 26.1 |
| Poor supervision and coaching | 6 | 6.8 |
| Time | 7 | 7.9 |
| Land problem | 5 | 5.9 |
| Unpredictable climate change | 9 | 10.2 |
| Lack of confidence and patient | 18 | 20.5 |
| Insufficient working equipment and infrastructure | 23 | 26.1 |
| Hard to put idea into implementation | 13 | 14.8 |

***NB:*** *The total number of responses exceeds the sample size due to multiple responses* reducing start-up costs) such as office space, meeting rooms, telecommunication, and reliable electricity and in some environment security services. An incubator should create opportunities and a conducive environment for the incubatees by locating them under one physical establishment with facilities such as cafeterias and meeting rooms which allows them to communicate, share information, resources and experience and communicate to each other about difficulties and success of their ventures (Marimuthu *et al.,* 2015).

Another challenge mentioned by SUGECO graduates was poor supervision and coaching. This was mainly due to SUGECO not having branches all over Tanzania therefore, monitoring and coaching of its graduates becomes a challenge. In addition, is very expensive in terms of transport and time thus, contributing into poor supervision as shown in the quote below:

*"After incubatees graduate from SUGECO we allow them to go where they can be comfortable to start what they plan to do according to the training received. However, we have found out that there is a problem when it comes to coaching and mentoring because they are scattered, and for those who are very far for example in Kigoma it at times becomes difficult to reach them due to transport costs"* (Key Informant, SUGECO Office, Morogoro, November 2019).

Generally, coaching of the entrepreneur allows him/her to develop, from a process of learning, various entrepreneurial behaviours. It also allows the entrepreneur to develop their own capacities and skills to manage the company, to improve its efficiency to carry out certain tasks, or still increase their self-confidence (Saadaam and Affess, 2015). Furthermore, according to InfoDev (2010) incubator's effectiveness can be improved by allowing it to evolve with the needs of the incubatees. Therefore, an Incubator should constantly monitor the performance of its incubatees, to do so; managers should gather information from their incubatees (financial, sales, employment, etc). Moreover, doing the above will enable the supervisors/coaches/mentors to affectively advice the entrepreneurs on how to increase their sales while cutting down operation costs thus, better profits.

## Conclusions and recommendations

### Conclusions

The main objective of this manuscript was to examine the contribution of SUGECO incubation programme graduates towards employment creation and challenges which they face after their graduation. Based on the findings and discussion, it is hereby concluded that the SUGECO incubation programme enables those going through it i.e.its graduates to self-employ themselves while also creating employment for others. It is also concluded that agribusiness education/training is very important as it increases the probability of the youth receiving such training to self-employ and create employment for others through agriculture. Lastly, it is concluded that despite the training and support received by incubatees from SUGECO many face the challenge of start-up capital after graduation.

### Recommendations

Based on the study findings and conclusions the following are recommended;

i. The Tanzanian government and development partners should collaborate to promote business incubation programmes especially those which deal with agribusiness value chain so as to generate more employment, especially to the youth.
ii. SUGECO and other similar incubators should establish clear graduation or entry and exit policy and strictly follow those policies/criteria's so as to only recruit suitable incubatees who will be actively involved in the programme. Doing so will increase the possibility of graduates being successful in their endeavor to establish their own firms/enterprises.
iii. SUGECO also needs to find a way on how it could become a more holistic incubation programme that meets most of the incubatees' expectations such as possibility for start-up capital. The above could be achieved through collaboration with the government (in particular the National Economic Empowerment Council (NEEC) Under the Prime Minister's Office). Doing

this could solve some of the issues around access to affordable credit/loans. Other options could be entering into partnership with other strong organization or investors interested in the youth's socio-economic development.

iv. Incubatees should take into consideration the core activities and the reputation of the incubation centre/programmes before signing the joining instruction form. This is critical for the incubatees (entrepreneur) as it determines their success thereafter.

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# Comparison of Three Shipping Packages in Reducing Postharvest Losses of Mandarin (*Citrus reticulate* Blanco) Fruits along the Value Chain

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**Abstract**

*A study was conducted to compare the effect of three shipping packages; traditional bamboo baskets (BAMB), bulk on truck (BULK) and stackable plastic crates (SPC) and the effect of fruit position in the package (bottom, middle, and top) on postharvest loss of mandarin (Citrus reticulate Blanco.) fruits along the value chain. A 3x3 factorial experimental design in a completely randomized design (CRD) was used to set up the trial. Harvested mandarin fruits were sorted and the uniform undamaged fruits packed in SPCs, BAMB, and BULK packages. Fruits were transported for 161km from Kikundi village in the Morogoro district through Chalinze to Sokoine University of Agriculture (SUA). On arrival at SUA, fruits were held under simulated wholesale (3 days) and retail conditions until when at least 50% of the fruits were rated unmarketable. During the study, fruits were evaluated for external and internal fruit quality including; proportion of decays, weight loss, pulp temperature, soluble solids content (SSC), titratable acidity (TA), SSC/TA, and Ascorbic acid. Results show a significant interaction between (i) shipping-packages and fruit position with respect to fruit pulp temperature and cumulative decay and (ii) storage time in terms of juice volume, SSC, TA, SSC/TA, and ascorbic acid. For fruit in SPC, decays was higher on fruits at top than at the middle and bottom of the package. SPC reduced fruit decay by 7.9% or 5.1% than those packed in BAMB or BULK, respectively. Mandarin fruits in SPC and BAMB particularly at the middle and bottom of SPC and BULK experienced lower pulp temperature than those at the top of packages. Fruit internal quality; soluble solids content (SSC), titratable acidity (TA), and ascorbic acid (ASC) changed only with storage duration. The study recommends use of SPC for reducing fruit decays, and for slowing fruit pulp temperature rise during shipping. Further study is recommended to establish the cost benefit of SPC over BAMB and BULK packaging as a means to enhance its adoption.*

***Keywords:*** Shipping packages, Citrus fruits, Mandarin fruit packaging, Fruit position in the package, Postharvest storage technologies

## Introduction

Mandarin (*Citrus reticulate* Blanco) fruits ranks the third in production volumes after sweet oranges (*Citrus cinensis* Mil.) and lemons (*Citrus limon*) and limes (*Citrus aurantiifolia*) fruits produced in East Africa and in the country (FAOSTAT, 2019). In Tanzania the major citrus fruits (including mandarin) growing areas are Tanga, Coastal and Morogoro regions, with 35,640 ha, 11,123 ha and 4,582 ha of the total national production area, respectively (NBS, 2013). Most of the citrus fruits from the regions are consumed locally in major cities and towns (Izamuhaye, 2008; Lynch, 1999) located 50 to 700 km away within the country and some exported to neighboring countries including Kenya (Izamuhaye, 2008). Fruit transportation is mainly conducted through bulk on truck, in a mixed load of sweet oranges and mandarins in the same truck (Lynch *et al.,* 1999; Msogoya and Kimaro, 2012; Tsa 2012).

Considerable postharvest loss in fruit quality and salable quantity has been reported along the mango (43.8%) and sweet oranges (48.3%) value chains (Tsa. 2012; Msogoya and Kimaro. 2012). Of the 48.3% losses in oranges, 17.9% occur at retail, 15.4% in wholesale trading, 12.0 % at the middlemen trading and 3.0% at farmer level. The main causes of postharvest losses in sweet oranges along the value chain in the order of magnitude were reported to be; microbial decay, mechanical damages, shriveling, and fruit flies (Tsa. 2012).

Due to its thin and brittle peel characteristics, mandarin fruits are much delicate than other citrus fruits (Brown, 2006), hence the postharvest losses experienced along the value chain are likely to be higher than those reported in sweet oranges. In India however, postharvest loss of mandarin fruits along the value chain from harvest to distribution was reported to be 46% (Bhattarai *et al,* 2003). Citrus fruits including mandarins have oil glands on the peel flavedo that when damaged during handling tend to release phytotoxic peel oil compounds causing brown/dark burning appearance on the fruit rind (Zhang *et al.,* 2011; Montero *et al.,* 2012). Damaged areas on the fruit peel also serves as entry points for decay microorganisms causing fruit deterioration during subsequent handling stages.

Unfortunately, despite the delicate nature of mandarin fruits among other citrus fruits, in Tanzania little is known about the effect of shipping packages on the quantity and quality loss of the fruit along the value chain. The main objective of this study is therefore to compare the effectiveness of traditional shipping packages; bamboo baskets (BAMB) and bulk on truck (BULK) with an improved package “stackable plastic crates” (SPC) on maintaining fruit quality and reducing postharvest loss of mandarin fruits along value chain (farm to retail marketing/ handling). This simulated study specifically evaluated change in external and internal fruit quality including; proportion of decays, weight loss, juice volume, pulp temperature, soluble solids content (SSC), titratable acidity (TA), SSC/TA, and Ascorbic acid for the different packages and fruit position (top, middle, and bottom) in the package during handling from harvest to storage/ marketing.

## Materials and Methods

### Mandarin Fruit Source

In the 2014/ 2015 seasons, mandarin fruits of local unknown cultivar were harvested from an orchard at Kikundi village, Kibungo ward in Morogoro district. Fruits were harvested from randomly selected trees using the Drop-Catch method. One picker climbed into the tree, picked fruits and dropped them down for another person to catch. Harvested fruits from random trees were combined, sorted, and the uniform, undamaged fruits packaged in SPCs, BAMB or BULK for shipping simulation trial in the same way wholesale traders, and farmers do pack their fruits during shipping. Three packaging for shipping methods; SPCs of 250 to 300 fruits capacity, BAMB of 500 to 800 fruits carrying capacity, and heaping of unpacked fruits on the floor of a 3.5 tones open top truck (BULK) were used during a simulation trial. In the trial, SPCs were used as a new introduced packaging practice.

### Experimental Design

The simulated shipping experiment was set as a 3x3 factorial experiment in a completely randomized block design (CRBD) with shipping package at three levels; SPC, BAMB, and BULK and fruit position in the packages at three levels; top, middle, and bottom. Each of the treatment combinations was replicated three times. The number of packages per packaging method was considered as replications. Under each packaging method, three layers of fruit positions were marked as; top, middle, and bottom. Package location on the truck served as blocks, whereas a set of each packaging method was placed at the front, middle, and rear part of the truck to avoid variations due to load position on the truck (Fig 1). For simulation of wholesale and retail handling conditions (before sale) on arrival at SUA, fruits in the SPC, BAMB, and BULK shipping packages were retained for


**Figure 1: Arrangement field packaging methods; (A) Bamboo baskets "BAMB", (B) Bulk on truck "BULK" and (C) Stackable plastic crates "SPC" on the truck during the simulated shipping trial of mandarin fruit.**

three days at outdoor with full sun exposure during the day and covering during the night. After the three days of wholesale simulation, fruits were unloaded from each package and placed on benches for display until at least 50% of the fruits per treatment combination rated unmarketable.

## Fruit packaging

### BAMB

The bamboo baskets of 500 to 800 fruits carrying capacity each were first lined with fresh grasses on the inner side and the three layers of fruits (bottom, middle, and top) each separated with a layer of grasses loaded into each package. Each layer had over 100 marked fruits of which ten fruits at each layer were numbered for tracing during data collection. Additional layer of fresh grasses was placed at the top and tied up with sisal ropes. The BAM packages were then loaded on the truck one onto the other with package tops covered with grasses facing to each other.

### BULK

BULK packaging involved placing a layer of fruits on fresh grass cushioning materials of about 10 cm thick spread on the truck floor, followed by another layer of cushioning materials before adding the second and third layers of fruits. Bulk packed fruits were separated in three categories; front, middle and rear part of the truck with each group containing 900 fruits. Each group was divided further into three equal sub groups, considered as replications. In each replication, at least 100 fruits were maintained on the top, middle and lower layer of fruits, respectively separated by grass cushioning materials.

### SPC

Plastic crates of 40 cm (width) by 58.5 cm (length), by 23.0 cm (depth) and carrying capacity of 250 to 300 fruits were used. A 2.5 cm layer of foam was placed at the bottom of the crate before packing the first layer of fruits and above the second and third layers of fruits. In each crate fruits were filled to allow stacking of one crate onto the other without compressing the fruits. No linings were added on the sides of the package during loading of the fruits to permit natural ventilation. Loaded SPC were packed onto the truck in three layers high. To avoid fruit leaping from SPC, an empty fourth crate was tied on top and secured using sisal ropes (Fig. 1). At least 100 fruits were maintained on the top, middle and lower layer of fruits in each SPC.

**Simulation of Shipping and Storage Conditions**

Most citrus fruits produced in Tanzania are consumed locally in big towns (Izamuhaye, 2008) including city centers within the region or nearby areas located at least 150 km from the production areas. Access to the production areas involves use of rough/ungraded and tarmac roads. Based on that, after packaging and loading, fruits were transported from Kikundi village at Matombo division in Morogoro district to Sokoine University of Agriculture (SUA) through Chalinze in the Pwani region. The produce was shipped for 1 hour on 18 km of ungraded, none-tarmac road and the remaining 143 km for 2 hours and 37 minutes on the tarmac road to cover a total distance of 161 km in 3 hours and 37 minutes. The tarmac road had 2-4 humps at about every 20 km distance. Similar to what most traders do during transportation of citrus fruits, the shipping simulation was conducted on a clear day starting at 18:30 hours to 22:07 hours, and the truck body/bed was partially covered to allow some air circulation. The ambient temperature range during transportation was be 29.5°C.

On arrival (Day 0) at SUA Horticulture Postharvest Laboratory, fruits were unloaded while maintaining treatment grouping and replications. Fruits under BULK were unloaded following the same heaping arrangement on a spread polypropene sheet and held outside at simulate wholesale traders handling conditions. Fruits in BAMB and SPC were retained in the packages and also placed on the sheet. All treatments were left open during the day and covered with polypropene sheet during the night simulating commercial wholesale conditions for three days (average period that wholesale traders hold their fruits during selling). On day 3 of wholesale simulation all packages were opened and fruit losses quantified. Undamaged fruits from all packages were then transferred inside to the horticulture postharvest laboratory to simulate retail traders handling. Similar treatment grouping were maintained but all on laboratory bench displays. Under the simulated retail handling conditions fruits were retained until when at least 50% rated unmarketable due to either decay and or shriveling. The mean temperature and relative humidity (RH) at retail simulated conditions (laboratory room) were at 24.7 °C, 79.9% RH.

**Analysis of Losses**

During the study, both internal and external/ physical fruit quality postharvest losses were evaluated across treatment combinations.

**Physical/External Fruit Quality**

**Percent Fruit Decay**

Assessment of fruit visual quality was done on Day 3 of wholesale simulation and every three days during retail storage simulation to identify and record fruits found with signs of decay. Then percentage cumulative fruit decay was calculated following equation 1.

$$Decayed\ fruits(\%) = \frac{Number\ of\ decayed\ fruits}{Total\ number\ of\ sampled\ fruits} \times 100 \quad (1)$$

**Physiological Weight Loss**

Fruit physiological weight was determined according to Huidrom *et al.* (2016) using a digital kitchen scale (Ozeri, ZK 14-S) and percentage physiological weight loss (PWL) established based on equation 2. Ten fruits from each packaging method and position replication were numbered and used for tracking of weight change during successive handling from day 0 of storage.

$$PWL(\%) = \frac{Initial\ weight(g) - Final\ weight(g)}{Initial\ weight(g)} \times 100 \quad (2)$$

**Internal Fruit Qualities**

Six (6) fruits randomly picked from each packaging method position (top, mid, bottom) per replication were sampled. Evaluations were conducted on Day 0 of wholesale simulation, Day 3 of storage (initial day of retail simulation), and every three days of storage during handling at retail simulated condition until 50% of the fruits in at least one of the treatment is rated unmarketable. Five internal fruit qualities; pulp temperature, juice volume (v/w%), soluble solids content (oBrix), titratable acidity (% citric acid), and ascorbic acid content (mg/100g) were evaluated.

**Fruit Pulp Temperature**

Fruit pulp temperature was measured using a long probe digital thermometer (TA804-PROBE, Lexington, KY USA) inserted to the middle of the fruit core through the pistil end. The probe was twisted to an angle towards the segments and maintained for one minute. Temperature readings (°C) were record separately for each of the sampled fruits.

**Juice Volume**

Fruits weight was measured using a digital kitchen scale (Ozeri, ZK 14-S), then each fruits was cut and the juice squeezed using a hand held juice squeezer. The juice from each fruit was filtered using a tea strainer into a plastic measuring cylinder and juice volume recorded. Percent juice volume was then calculated based on equation 3.

$$Percentage\ Juice\ Volume(v/w\%) = \frac{Juice\ volume(ml)}{Whole\ fruit\ weight(g)} \times 100 \quad (3)$$

**Soluble Solid Content (SSC) and Titratable acidity (TA)**

Fruit juice of six fruits per treatment was composited to make three samples (of two fruits each) and used for evaluation of SSC and TA. Fruit SSC was determined according to Huidrom *et al.* (2016) where 1m l of mandarin fruit juice samples were pipetted onto a handheld digital refractometer (Antago PAL-1, Japan) and readings in degree Brix recorded. Fruit TA was determined according to Rajwana *et al.* (2010) by pipetting 5 ml of the juice into 50 ml of distilled water and titrated against 0.1N NaOH to 8.2 pH using an automatic potentiometric titrator (HI 901, Hanna Instrument, USA). Percentage of the dominant acid (citric acid) was then calculated based on equation 4.

$$Titratable\ acidity(\%) = \frac{0.1N\ NaoH\ used \times 0.064}{Volume\ of\ sample\ used} \times 100 \quad (4)$$

Where; N = normality

**Fruit Total Ascorbic Acid Content**

Ascorbic acid (Vitamin C) content was determined according to Seki (1990) based on the oxidation reduction reaction principle. Two milliliters of the composite juice used for SSC were diluted to 50 ml with 10 % TCA solution and filtered using a Whatman filter papers No. 1. Ten milliliters of the filtrate was slowly titrated against a standard solution of 2,6 - Dichlorophenolindophenol and sodium salt until a pink colour marking the titration end-point attained. A blank solution of 10 % TCA solution was titrated against the standard solution (2,6-Dichlorophenolindophenol). The volumes of indophenol solution used to oxidize the ascorbic acid in the fruit juice sample extract and blank solution were recorded. The vitamin C content was then calculated using equation 5.

$$Fruit\ Vitamin\ C\ content(mg/100gm) = \frac{(A - B*C*V*100}{D*S} \quad (5)$$

Whereby:

A = volume (ml) of the Indophenol solution used for the sample

B = volume (ml) of the Indophenol solution used for the blank

C = mass (mg) of ascorbic acid equivalent to 1.0 mL indophenols solution

S = mass (g) of sample taken for analysis

V = total volume (ml) of extract

D = volume (ml) of sample filtrate taken for analysis

**Statistical Analysis**

Fruit pulp temperature, physiological weight loss, cumulative fruit decays, SSC, TTA, SSC/TTA, and content of fruit ascorbic acid were evaluated. Analysis of variance of data (ANOVA) was conducted using PROC GLM (SAS institute Inc., Version 9.3, Cary, NC, USA) based on a randomized complete block design. Post comparison Tukey's test at $p<0.05$ was conducted to separate the means for all evaluated parameters.

**Results**

Following the shipping simulation and storage experiment, fruits in most of the treatments evaluated took a maximum 12 days for ≥ 50% to be rated unmarketable. The results presented here, reflects the evaluation conducted during the period.

**Shipping Packages and Fruit Position in the Package**

Fruit decay following shipping simulation varied significantly ($p<0.01$) with both package type and fruit position in a package (Appendix 1, Table 1). Fruit packed in SPC particularly at the middle of package had the lowest decays (18.1%) compared to those packed at the same position in BAMB (37.7%) and BULK (32.5%) (Table 1). SPC reduced the percent of fruit decay by 7.9% and 5.1% more than the BAMB and BULK packaging methods, respectively. Similarly, SPC demonstrated lower decay (22.5%) on fruits located at the bottom of the package than fruits at same position in BULK (29.8%). SPC reduced decay of fruits located at the bottom of the package by 5.7% and 7.3% more over BAMB and BULK packaging, respectively. However, within the SPC package, fruits located at the middle (18.1%) and bottom (22.5%) experienced less decay than those at the top of the package (33%).

**Storage Time**

Fruit physiological weight loss ($p<0.0001$) and decay ($p<0.001$) varied significantly with storage time (Appendix 1, Table 2). Weight loss due to water loss was higher on Day 6 (3.9%) and Day 9 (3.9%) of storage than on Day 3 (0.9%) and Day 12 (2.4%). On the contrary, fruit decay was higher on Day 3 (13.5%) and Day 6 (13.7%) than on Day 9 (8%) and Day 12 (4.5%) of storage.

The fruit pulp temperature following the shipping simulation experiment varied significantly ($p<0.001$) with both package type and fruit position in a package (Table 3). Generally, fruits in BAMB retained the lowest fruit pulp temperature (23.7 °C) compared to SPC (25.1 °C) and BULK (29.7 °C) packages for the fruits located at the top of the packages. On the other hand SPC (23.5 °C) and BAMB (23.5 °C) packages were able to retain lower

**Table 1: Interaction effect of packaging method and fruit position in the package on cumulative fruit decay during storage at ambient condition after shipping simulation (12 days storage)**

| | Cumulative Fruit Decay (%) | | |
|---|---|---|---|
| Fruit Position in the Package | Stackable Plastic Crate (SPC) | Bamboo Basket (BAMB) | Bulk on Truck (BULK) |
| Top | 32.98 aA | 31.31 aA | 26.47 aA |
| Middle | 18.13 bB | 37.69 aA | 32.54 aA |
| Bottom | 22.45 bB | 28.18 aBA | 29.76 aA |

*Percentage cumulative fruit decay means within a column followed by the same low letter or by the same capital letter within a row do not differ significantly according to Tukey's test ($p<0.05$).*

**Table 2: Effect of fruit storage time on cumulative fruit decay and weight loss during storage at ambient condition following shipping with SPC, BAMB, and BULK field packages**

| Fruit Storage Time | Cumulative Fruit Decay (%) | Change in cumulative fruit decay (%) | Cumulative Weight Loss (%) | Change in weight loss (%) |
|---|---|---|---|---|
| Day 3 | 13.47 | 13.47 a | 0.923 | 0.92 b |
| Day 6 | 27.15 | 13.68 a | 4.77 | 3.85 a |
| Day 9 | 35.10 | 7.95 b | 8.70 | 3.93 a |
| Day 12 | 39.61 | 4.51 b | 11.12 | 2.42 b |

*Percentage cumulative fruit decay and cumulative weight loss means within a column followed by the same letter do not differ significantly according to Tukey HS test ($p<0.05$)*

fruit pulp temperature than BULK (25.4 °C) packaging for the fruits located at the middle of the package. Interestingly, pulp temperature on fruits under BULK package decreased with depth from top to the bottom of the package, being highest at top (29.7 °C) and least at the bottom (23.7 °C). Whereas for SPC, pulp temperature was equally lower on fruits at the middle (23.5 °C) and bottom (23.9 °C ) than at top (25.1 °C) of the package.

Percent of fruit juice volume (v/w%) during storage following shipping varied significantly (P<0.05) with both packaging method and storage duration (Appendix 1, Fig.2). Both SPC and BAM had similar trend of change in juice volume, being high on day 3 and Day 12 of storage, while BULK maintained an increasing trend that peaked on day 9 (39.5%) of storage. On Day 3 of storage (end of wholesale simulation), BAMB package demonstrated higher juice volume than BULK whereas on Day 9 BULK (39.6%) had higher juice volume than SPC (34.7%). However, on day 12 (Day 9 at retail storage) fruits from BAMB packaging had higher juice volume than both BULK and SPC.

Both fruit SSC, TA, SSC/TA ratio, and ASC varied significantly (p<0.0001) with storage

**Table 3: Interaction effect of packaging method and fruit position in the package on fruit pulp temperature at wholesale storage conditions (day 3) after shipping simulation**

| | Pulp temperature (°C) | | |
|---|---|---|---|
| **Fruit Position in the Package z** | **Stackable plastic crate (SPC)** | **Bamboo basket (BAMB)** | **Bulk on truck (BULK)** |
| Top | 25.1 aB | 23.7 aC | 29.7 aA |
| Middle | 23.5 bB | 23.5 aB | 25.4 bA |
| Bottom | 23.9 bA | 23.2 aA | 23.7 cA |

*Fruit pulp temperature means within a column followed by the same low letter or by the same capital letter within a row do not differ significantly according to Tukey's test (p<0.05)*

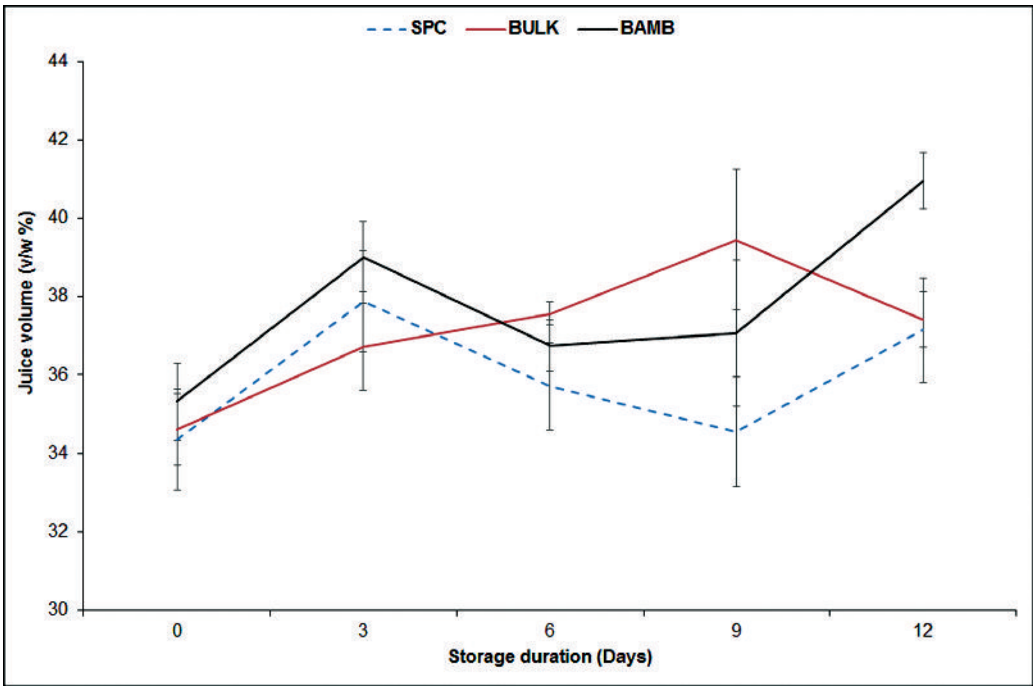


**Figure 2: Effect of packaging methods; SPC, BAMB, and BULK on percentage juice volume following 12 days storage at ambient conditions**

duration (Appendix 2, Fig. 3). However, SSC was significantly higher on Day 12 (10.3 oBrix) than on the proceeding days of storage (Fig. 3a). Similarly the SSC/TA ratio started to increase significantly from Day 6 through Day 12 (Days 3 through 9 of retail storage) (Fig. 3c). On the contrary TA was high on Day 0 than on Day 6 (day 3 of retail handling) and the least on Day 9 through Day 12 (day 9 of retail handling) (Fig. 3b). Ascorbic acid (ASC) was significantly higher during the three days of wholesale simulation than on Day 9 and Day 12 after harvest (Day 6 and 9 of retail storage).

## Discussion

Fruit decay has been the major concern for wholesale and retail traders. The low decays in SPC compared to BAMB and BULK packaging observed in this study could be related to low contamination from cushioning materials. Both BAMB and BULK packaging used grasses as cushion materials which increases chances for produce contamination. On the other hand, fruit located at the top of the package can experience covert mechanical damage caused by fruit–fruit contact, and fruit to package impact or abrasion making fruits susceptible to attack by decay pathogens. Mechanical damages and high pulp temperature could be the reasons for the higher fruit decay observed on fruits located at the top of SPC than middle and bottom of the package. Damages provide entry points, while high temperature favour growth and multiplication of decay pathogen on produce (Barkai-Golan, 2001; Martinez-Romero *et al.,* 2004; Ladaniya, 2008; Kader and Yahia, 2011). Plastic crates are easily cleanable and have smooth inner surface, which reduce the chance for mechanical damage on fruit surface (Abejón *et al.,* 2020). Both BAM and BULK used grass cushioning materials which are likely to serve as source of decay pathogens. Bamboo baskets (BAMB) also have rough inner surfaces potential for causing surface abrasion and puncture on fruits (Ladaniya, 2008).

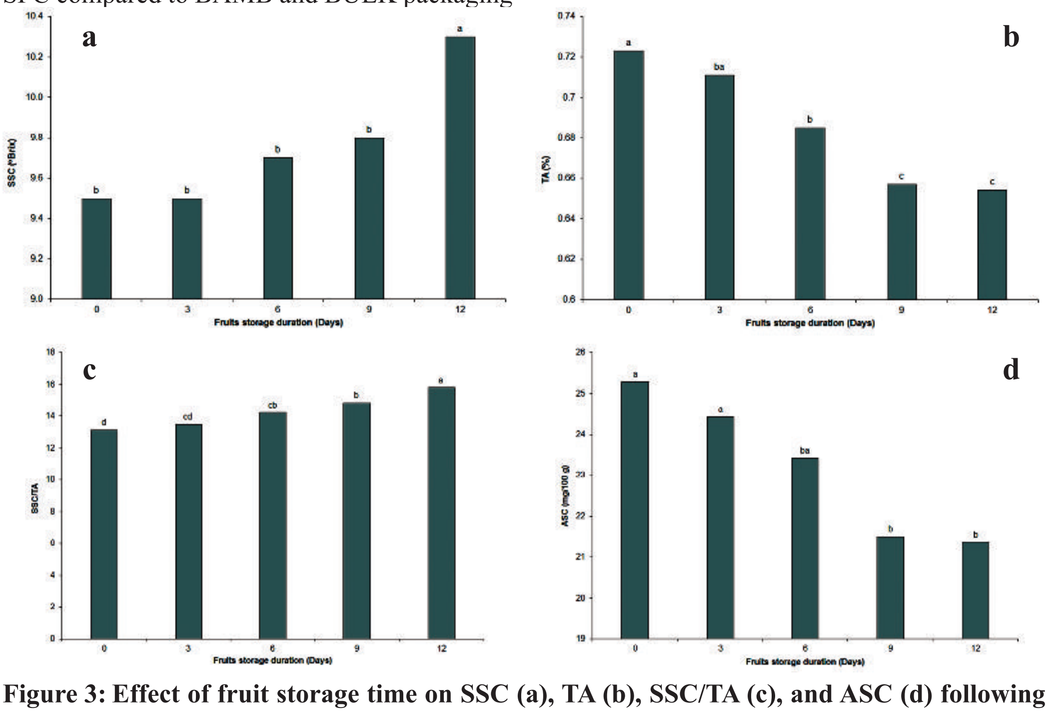


**Figure 3: Effect of fruit storage time on SSC (a), TA (b), SSC/TA (c), and ASC (d) following shipping simulation with SPC, BAMB, and BULK packaging**

On the other hand, the higher cumulative decay observed on fruits located at the middle of BULK and BAMB packages than at the middle of the SPC package may have been attributed to the prevailing high temperature (28.5 °C) and RH (89%) and poor ventilation in the packages compared to 27 °C and 85% in SPC. The dried banana leaves and raw grasses were used as cushioning but was likely to reduce air circulation in the packages. Soil borne decay pathogen like *Geotrichum candidum* (Sour rot) is known to live and grow on fermented grasses (Ladaniya, 2008). The middle and bottom part of BULK package was likely to provide favourable conditions for growth of decay pathogen than SPC. SPC package have vents on the side, which give better produce ventilation, also contain fewer fruits and more shallow depth that reduced compression damage and eliminated contact with any grass or soil materials.

In this study, wholesale handling conditions were found to exposed fruits to higher temperatures leading to variations in fruit pulp temperature among packages and between fruit position within the package. Produce handling conditions at wholesale exposes fruits at top packages, particularly under BULK packaging to direct sun exposure. That was the also the reason for the observed higher pulp temperature on fruits at the top than middle and bottom of the SPC package. Similar findings have been reported by Thompson *et al.* (2011) indicating high temperature on cherry fruits at top of the boxes than middle and bottom positions. This study also associate the dry banana leaves cushioning materials used as lining in the BAMB package with the relatively low pulp temperature and high RH recorded throughout the BAMB package positions.

Fruit cumulative decay increased with storage duration, however the observed higher decay on Day 3 (end of wholesale) suggest existence of covert fruit fly infestation, mechanical damage and or latent infection which may have been occurred in the field (harvesting) and during shipping. Whereas the higher increase in decay from Day 3 to Day 6 (day 3 of retail handling) than on day 9 and day 12 was likely attributed to latent infections and recontamination from sorted decayed fruits. The higher temperature and relatively low RH experienced at wholesale (23 to 29.7 °C, RH of 74 to 84.5%) and retail (24.6 °C, RH of 79.9%) simulated conditions was likely associated with the promotion of growth and development of decay pathogens such as *Penicillium digitatum* and *Geotrichum candidum* Link. (*Geotrichum citri-aurantii*) which grow well and rapid at an ambient temperatures of 25 to 30 °C and 28 to 30 °C, respectively (Smilanick *et al.,* 2006; Ladaniya, 2008). Such higher temperatures were also likely to encourage growth of *Diplodia natalensis* (Diplodia stem end rot) (Ismail *et al.,* 2004). Presence of any wound on fruit surface due to mechanical damage would also enhance attack by fungal pathogens (Ismail *et al.,* 2004; Ladaniya, 2008). The higher temperatures observed at wholesale handling in the packages during this study were likely associated with stimulating latent infections during simulated wholesale and handling conditions.

Physiological weight loss due to water loss increased with storage time, however the observed higher change in weight loss on day 6 and day 9 (day 3 and day 6 of retail storage) than on day 3 of wholesale storage was partly attributed to high storage temperature (24.6 °C) and low relative humidity (79.9%) recorded at retail simulated conditions. These results suggest that, maintaining fruit in their shipping container during wholesale handling reduced water loss more than when exposed on display during retail marketing conditions. Ladaniya (2008) has reported similar findings.

The higher juice volume (v/w%) observed on BULK than SPC packaging on day 9 and on BAMB than on both BULK and SPC in day 12 was partly related to water loss from the fruit peel that may have been varied slightly among fruits in the different packages. Water loss from the peel at constant juice volume, increased the percent of juice volume of individual fruits. The slightly less weight loss observed in this study on fruits previously packaged in SPC than BULK on day 9 and BAMB on day 12 could be the reason for the observed trends in juice content among packages over storage time.

Regardless of the packaging methods under practice, fruit SSC, TA, ratio of SSC/TA, and total ascorbic acid content varied considerably with storage time. The increase in SSC on day 12 (day 9 retail storage) was likely associated with the higher water loss (11.2%) under retail handling conditions. Burdon *et al.* (2007) also reported a slight non-significant increase in SSC following exposure of ‘Satsuma’ mandarin to 30 °C and 65% RH for 3 days. Similarly, a significant increase in SCC during storage has been reported in 'Hamlin' orange, 'Robinson' tangerines and 'Palestine' lime following four weeks of storage at 15 °C, 95% RH (Echeverria and Ismail, 1987).

The decrease in TA starting on day 6 (day 3 retail storage) observed in this study associated with metabolism of organic acids particularly citric acid (Hairai and Ueno, 1977; Marcilla *et al.,* 2006) accelerated by high temperature and low RH exposure during retail handling simulation (24.6 °C, 79.9% RH). Similarly, Burdon *et al.* (2007) reported a significant decrease in TA following exposure of Satsuma mandarin to high temperature and low RH (30 °C, 65% RH) for 3 to 5 days. On the other hand, a similar decrease in TTA in mandarin fruits during storage time has been reported in other studies (Echeverria and Ismail, 1987; Shellie *et al.,* 1993; Pérez *et al.,* 2005). The increase in soluble solids content and decrease in titratable acidity increased the SSC/TTA ratio. Similar findings have been reported in earlier studies (Echeverria and Ismail, 1987; Pérez *et al.,* 2005; Burdon *et al.,* 2007; Tietel *et al.,* 2010).

On the other hand, the observed decrease in ascorbic acid in this study starting on Day 9 (day 6 retail storage) was likely associated with retail storage conditions, particularly high temperature (24.6 °C). Ascorbic acid has been reported to be thermally instable, being very susceptible to degradation at high storage temperatures (Pérez *et al.,* 2005; Burdurlu *et al.* 2006). No changes in SSC, TTA, SSC/TTA or ascorbic acid content were attributed to the packaging methods used in this study. However, storage temperature and citrus senescence during storage have been reported to alter both flavor (SSC and TTA) and nutritional quality particularly ascorbic acid content (Miller, 1946; Biolatto *et al.,* 2005). Storage of citrus fruits at 5 to 8 °C, has been reported to minimize the loss in nutritional quality mainly ascorbic acid content (Grierson and Miller, 2006).

## Conclusions

The study assessed the performance of three field-packaging methods; BAM, SPC and BULK and the position of fruit in the packages (top, middle, and bottom) on physical fruit quality (decay, weight loss) and internal/ nutritional quality (juice volume, SSC, TA, SSC/ TA, and Ascorbic acid). During the study, SPC reduced fruit decay, and fruit pulp temperature particularly for the fruits at the middle and bottom of the package. In addition, it was observed that, retention of mandarin fruits in the shipping package (SPC and BAMB) help to reduce weight loss, maintain high juice volume, and minimize fruit heating. Among packages, BAMB was effective in minimizing fruit pulp temperature for fruits located at all positions in the package, however the insulation materials used; dry banana leaves and raw grasses are likely to reduce ventilation, retain high RH, and also serves as source of latent infection for later fruit decays. Packaging methods had no effect on internal fruit qualities. Internal fruit quality varied only with storage duration, with most of the fruit becoming unmarketable on the 9$^{th}$ day of retail handling. Fruit SSC, and SSC/TA increased and TA and Ascorbic acid decreased with storage duration. The increase in SSC and decrease of TA, and Ascorbic acid observed in this study associated with the increase in water loss during storage period. This study also associate the decline in ascorbic acid and titratble acidity and the increase in SSC and SSC/TTA ratio with the high storage temperature experienced at wholesale and retail levels.

Therefore, the study recommends use of SPC over BAMB and BULK methods as the best option to reduce fruit decays, fruit pulp temperature rise and hence reduce produce loss. The study also recommends retention of fruits in shipping container with few on display to reduce water loss during retail handling. However, it is still important to ensure proper shading of the fruits during wholesale and retail conditions as it may enhance respiration and growth of decay microorganisms. Use of banana leaves as insulation materials in BAMB is advocated to reduce fruit heating during handling, however study are required to ascertain its freeness from latent infections. In addition proper management of the crop in the field is required to ensure effective control of pest and disease along the fruit handling chain particularly to reduce latent infections that could grow during storage.

Further studies are recommended to establish the cost benefit of using plastic crates (SPC) over BAMB and BULK packaging as a means for advocating its adoption. Further studies are also required to evaluate the quality and use of existing insulating materials including banana leaves in reducing fruit pulp temperatures.

**Acknowledgement**

The author acknowledge that, this work was made possible by the generous support of the American people through the United States Agency for International Development (USAID) that funded the Innovative Agricultural Research Initiative project (iAGRI) (Award No. CA-621-A-00-11-00009-00). Nevertheless, opinions expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Agency for International Development or the United States Government.

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## Appendices

**Appendix 1: Analysis of variance for the effect of field packaging methods, fruit passion in the package and storage time on fruit quality following 12 days storage at ambient condition**

| Treatments | Cumulative Fruit Decay (%) | Cumulative Weight Loss (%) | Fruit Pulp Temperature (°C) | Juice Volume (v/w %) |
|---|---|---|---|---|
| Storage Duration (SD) | *** | **** | - | ns |
| Packaging Method (PM) | ** | ns | **** | ** |
| Fruit Position in Package (FP) | ns | - | **** | ns |
| SD X PM | ns | ns | - | * |
| SD X FP | ns | - | - | ns |
| PM X FP | ** | - | *** | ns |
| SD X PM X FP | ns | - | - | ns |

*ns, *, **, ***, or **** refers to non-significant, significant at p< 0.05, p< 0.01; p< 0.001, or p<0.0001, respectively.*

**Appendix 2: Analysis of variance of field packaging methods, fruit passion in the package and storage time on selected fruit quality following nine days storage at ambient condition**

| Treatment | SSC (°Brix) | TA (% citric acid) | SSC/TA (ratio) | Ascorbic Acid (mg $100g^{-1}$) |
|---|---|---|---|---|
| Storage Time (ST) | **** | **** | **** | **** |
| Packaging Method (SM) | ns | ns | ns | ns |
| Fruit Position in Package (FP) | ns | ns | ns | ns |
| **Interactions** | | | | |
| ST X SM | ns | ns | ns | ns |
| ST X FP | ns | ns | ns | ns |
| SM X FP | ns | ns | ns | ns |
| ST X SM X FP | ns | ns | ns | ns |

*ns, or ****, non-significant, or significant at p<0.0001, respectively*

# Examination of Seasonal Variability of Indicator Polychlorinated Biphenyls in Nile Perch Products from Lake Victoria, Tanzania

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**Abstract**

*In the current study, Nile perch products were analysed for seasonal variations in the levels of indicator polychlorinated biphenyls (PCBs). Samples of fish products were collected from Lake Victoria during the dry and rainy seasons and extracted using a common method referred to as QuEChERS (quick, easy, cheap, effective, rugged and safe) methodology. The residues of PCBs in fish samples were detected and quantified by using a Gas Chromatography equipped with Electron Capture Detectors and a Gas Chromatography equipped with Mass Spectrometer (GC-ECD/GC-MS). The concentrations of indicator PCBs in fish samples were generally greater during the rainy seasons than the dry seasons suggesting that seasonality has significant impacts on PCBs contamination in fish. However, the total PCBs in fish in the current study for both seasons were lower than the Maximum Recommended Limits of 75µg/kg that is set by the European Commission for fish and other fishery products. This indicates that the Nile perch products from Lake Victoria are safe for human consumption based on the studied toxicants.*

***Keywords:*** Indicator PCBs, Seasonality, fresh muscles, processed fish products, POPs.

## Introduction

Polychlorinated biphenyls are a group of manmade chemicals and one of the original persistent organic pollutants that are covered by the Stockholm Convention. Studies have indicated that PCBs are very stable mixtures that are resistant to extreme temperature variations and pressures (Polder *et al.,* 2014; Witczak, 2012). In the past, PCBs were widely used in electrical equipment such as capacitors and transformers as flame retardants. When they enter the environment, such toxicants resist degradation by biological or chemical means and they are considered to be lipophilic in nature (Cork *et al.,* 2007; Bjermo *et al.,* 2013), a property that enables them accumulate in fatty tissues of different living organisms. They are also generally toxic and have been observed to travel longer distances (LRAT) before their final deposition in ecological media (Liu *et al.,* 2007). They further have the ability to accumulate in the aquatic biota and increase in concentration with time when they enter organisms above their trophic niches (Wenaty *et al.,* 2019a). PCBs are also referred to as endocrine disrupting agents (EDs) (Bell, 2014) because of having the ability of disrupting and altering the regular working of the endocrine system (Frouin *et al.,* 2013; Wenaty *et al.,* 2019a, b). These compounds have also been reported to be potentially carcinogenic to human beings due to the fact that they are associated with occurrence of different kinds of cancers such as breast, liver and testicular cancers. They are similarly reported to have negative reproductive effects such as low birth weights, small head circumferences, miscarriages, poor sperm quality as well as low sperm counts (Wenaty *et al.,* 2019a, c).

Seasons of the year have been implicated to have a significant impact on the levels of persistent organic pollutants including the indicator PCBs in the aquatic environment (Polder *et al.,* 2014). During the rainy season they are transported from one place to the other thus contaminating environmental matrices in areas where they have never been used or produced.

Moreover, in the recent years fisheries in Lake Victoria has been associated with abusive history of using different chemicals for fishing that could be important sources of PCBs in fish (Henry and Kishimba, 2006). Several studies to establish the levels of PCBs in various species of fish and other environmental compartments and the associated human health risks have been undertaken around the globe (Polder *et al.,* 2014; Ssebugere *et al.,* 2014; Oluoch – Otiego *et al.,* 2016; Wenaty *et al.,* 2019b). However, studies to establish seasonal variations of these toxic persistent organic pollutants in fish and fish products are very limited.

The current study was thus planned to evaluate the influence of seasons of the year on the concentrations of indictor PCBs in fresh muscles and processed Nile perch products that are widely consumed in the area in question. The main focus was on indicator PCBs since different studies have previously reported that they have more significant health impacts than other classes of PCBs (Polder *et al.,* 2014).

## Materials and Methods

### Description of the study area

This study involved four regions constituting the Tanzanian side of Lake Victoria namely Mwanza, Kagera, Mara and Geita. The regions were purposively selected for this study based on the fact that they are intensively involved in Nile perch fishing and processing for domestic, regional and international markets.

### Collection and extraction of fish samples

This current study involved five products of Nile perch including; fresh fish, salted-sundried, trims, processed by smoking and fried products which were collected from randomly selected landing sites and fish processors and sellers at different fish markets in the study area during the dry and rainy seasons between 2016 and 2019. Three hundred samples consisting of 60 samples of individual fish products were prepared for analysis. The extraction and clean-up of fish samples for analytes detection and quantification was done by a QuEChERS procedure with some modifications at the National Fish Quality Control Laboratory (NFQCL) in Mwanza. Based on this method, thirty grams of each sample was measured in triplicates and blended to obtain a sample homogenate. Thereafter, thirty grams of the homogenized samples were transferred into 200 mL centrifuge tubes. Furthermore, 2.5 g of sodium bicarbonate ($NaHCO_3$), 60 mL of ethyl acetate and 15 g of anhydrous $Na_2SO_4$ were added and homogenized together for 20 min. Then the supernatants were transferred into 15 mL centrifuge tubes containing 0.125 g of Primary Secondary Amine (PSA) and 0.75 g of anhydrous $MgSO_4$ (Anastassiades *et al.,* 2003; Wenaty *et al.,* 2019a, b, c). The mixture was then centrifuged at 2500 rpm for 10 min and left for further 5 min to enable separation process. The supernatants were thereafter transferred into vials for Gas Chromatographic analysis.

### Recoveries and Analytical Quality Control

The recovery tests were performed for six indicator PCBs of interest to determine the efficacy of the extraction and clean-up processes. Blank samples were spiked with known concentrations of the indicator PCBs followed by extraction and analysis. Blanks and standards were run every after five samples for the purpose of maintaining the quality of analytical results. The percentage recoveries were determined using equation 1

$$\%Recovery = \frac{Spiked - Unspiked\ concentration}{Expected\ concentration} \times 100 \quad (1)$$

### Chemical Analysis

The chemical analysis was carried out in Mwanza at the National Fish Quality Control Laboratory. The samples of fish were analysed for 7 indicator polychlorinated biphenyls namely: PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153 and PCB-180. The selection of the congeners was based on their persistence in the environment and ultimate accumulation on the food chains.

### Analysis of samples by a Gas Chromatographic method

The indicator PCBs in the fish samples were quantified chromatographically as described by Wenaty *et al.* (2019a, b, c). The analysis was carried out using a gas chromatography (GC-2010, Shimadzu) equipped with 63Ni Electron Capture Detector (ECD) and a non-polar (HP-

5MS) capillary column of 30 m length, 0.25 mm internal diameter and 0.25 µm film thickness. Nitrogen was used as both a carrier and make-up gas and the flow rate was set at 23.7 mL min–1. The temperature programme was as follows: initial temperature of 120°C held for 2 min, then increased at a rate of 10°C min–1 to 270°C held for 1 min, and at a rate of 2°C min–1 to the final temperature of 290 °C held for 3 min. The injector and detector temperatures were 220°C and 290°C, respectively.

The Gas Chromatograph was operated in a splitless mode with an injection volume of 1 µL. The standard mixture was injected in the beginning and after every five samples. The samples were injected in duplicate. The findings were confirmed using gas chromatography- mass spectrometry (Shimadzu GC-MS QP 2010 Ultra equipped with a mass selective detector-MSD, fused silica capillary column Rtx-5MS of 30 m length, 0.25 mm internal diameter and 0.25 µm film thickness and an autosampler) as described by Mahugija *et al.* (2018) and Wenaty *et al.* (2019a). The GC-MS was performed in a split less injection mode and the mass spectrometer was operated in an electron impact (EI) ionization and full scan mode. The calibration/ working standard solutions were prepared by dissolving portions of the stock solutions in the same solvents as used for the samples. Calibration curves were prepared by running series of mixtures of standard solutions and plotting the peak areas against concentrations.
Identification of the compounds involved checking the matching of the retention times and the mass spectra of the PCBs in samples to those of external reference standards that were prepared and run at the same conditions as for the samples. Quantification was carried out by linear integration of the standards and sample data based on peak areas.

**Data Analysis**

The measured PCBs data were subjected to descriptive statistics to deduce the minimum, maximum, mean concentrations and standard deviations of the congeners. The data was further subjected to SPSS, Version 16.0 for analysis. The concentrations of the congeners were presented as mean ± SD. The one – way ANOVA was used to compare concentrations between products. In data processing, the concentrations of PCBs in samples established to be below the limit of detection (<LOD) were treated as zero. The separation of means was done using Duncan's Multiple Range Test. The significant difference was declared at $p<0.05$ for all analyses.

## Results and Discussion

**Percentage recoveries of indicator PCBs for the extraction and clean-up procedures**

The percentage recoveries of indicator PCBs are provided in Table 1. The mean percentage recoveries based on triplicate determinations of the analytes ranged from 71.3 to 92.5%. The percentage recoveries were carried out to determine the sensitivity, accuracy and suitability of analytical method. Different studies show that percentage recoveries from 70 to 120% are satisfactory and indicate good performance of the analytical method (Afful *et al.,* 2013a, b; Wenaty *et al.,* 2019a, b; Chamgenzi and Mugula, 2020). Thus the results herein suggest a good performance of a GC-MS/MS and that the extraction and clean-up

**Table 1: Percentage recoveries of indicator PCBs to determine the sensitivity, accuracy and suitability of analytical method**

| PCBs | Amount spiked (µg/kg) | Amount calculated (µg/kg) | Recoveries (%) |
|---|---|---|---|
| PCB- 28 | 0.75 | 0.694±0.13 | 92.53±0.19 |
| PCB- 52 | 0.50 | 0.410±0.24 | 82.00±0.45 |
| PCB- 118 | 2.00 | 1.672±0.35 | 83.60±0.13 |
| PCB- 138 | 2.60 | 2.034±0.47 | 78.23±0.27 |
| PCB- 153 | 2.80 | 2.103±0.43 | 75.11±0.19 |
| PCB- 180 | 3.90 | 2.780±0.93 | 71.28±0.23 |

processes were performed perfectly and that no corrections of the recoveries were needed.

**Mean concentrations of the PCBs in fish products during the dry and rainy seasons**

The results of the concentrations of indicator PCBs in µg/kg and their total concentrations that were measured in fresh muscles and processed products of Nile perch from the studied area are provided in Table 2. The results show that six indicator PCBs namely; PCB-28, PCB-52, PCB-118, PCB-138, PCB-153 and PCB-180 were discovered in different Nile perch products at quantifiable magnitudes in both the dry and rainy seasons during the study period whereas PCB- 101 was found to be below its limit of detection (<LOD) in any of the five Nile perch products that were considered in this study.

The results indicate further that the indicator PCBs were not detected (<LOD) in fresh Nile perch muscles during the dry seasons but three congeners namely; PCB-138, PCB-153 and PCB-180 were detected during the rainy seasons. The mean concentration of the three congeners that were detected in fresh Nile perch muscles were quantified to be 0.89, 1.93 and 2.34 µg/kg for PCB- 180, PCB- 138 and PCB- 153 respectively. For the salted- sundried Nile perch the levels ranged between 3.14 and 6.08 µg/kg during the dry season, while during the rainy season the average concentration of indicator PCBs ranged from 4.54 to 8.21 µg/kg. The results revealed further that, for trimmed fish products, the mean concentration of the detected indicator PCBs ranged from 1.88 to 7.83 µg/kg during the dry spell while during the rainy season the mean concentration was in the range between 2.79 and 10.48 µg/kg. On the other hand, the mean concentrations of indicator PCBs in smoked products ranged from 3.62 to 6.46 µg/kg and from 4.52 to 9.56 µg/kg during the dry and rainy seasons respectively.

Moreover, for deep fried Nile perch, the average amount of the congeners ranged between 1.25 and 3.40 µg/kg during the dry season and between 1.69 and 5.30 µg/kg during the rainy season. There were significantly high concentrations of the congeners in Nile perch during the rainy season compared to the dry season. This suggests that the rainy season has

**Table 2: The mean concentrations in µg/kg of the congener PCBs and the sum of the PCBs in Nile perch products from the study area during dry and rainy seasons**

| Samples | Fresh fish | | Salted- sundried | | Trims | | Smoked | | Deep fried | | MRL (EC, 2011) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | |
| PCBs | | | | | | | | | | | |
| PCB-28 | <LOD | <LOD | 6.08±1.95 | 8.21±0.97 | 4.92±1.38 | 5.64±0.93 | 5.20±1.58 | 6.90±1.43 | 1.75±0.35 | 2.27±0.51 | |
| PCB-52 | <LOD | <LOD | 3.14±3.00 | 4.54±1.46 | 3.72±0.87 | 4.52±1.20 | 3.62±0.77 | 4.52±0.90 | 1.25±0.21 | 1.69±0.40 | |
| PCB-101 | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | |
| PCB-118 | <LOD | <LOD | 4.24±3.04 | 5.80±2.73 | 1.88±0.76 | 2.79±0.87 | 5.50±0.98 | 6.70±1.32 | 3.40±0.57 | 4.37±0.73 | |
| PCB-138 | <LOD | 1.93±0.32 | 5.43±3.58 | 7.25±1.80 | 7.13±3.48 | 9.61±2.17 | 5.81±1.86 | 7.31±1.52 | 3.00±1.84 | 5.30±2.21 | |
| PCB-153 | <LOD | 2.34±0.70 | 5.74±5.18 | 8.34±2.90 | 7.83±4.65 | 10.48±2.77 | 6.46±4.05 | 9.56±3.12 | 3.30±0.14 | 3.69±0.83 | |
| PCB-180 | <LOD | 0.89±0.13 | 3.93±3.37 | 5.63±1.74 | 6.07±5.15 | 8.89±3.49 | 4.08±2.55 | 6.39±2.30 | 3.35±0.07 | 5.25±1.72 | |
| **∑PCBs** | **0.00** | **5.16** | **28.46** | **39.77** | **31.55** | **41.93** | **30.67** | **41.37** | **16.05** | **27.53** | **75** |

a significant impact on contaminant loading in the aquatic environment in the sense that some persistent organic compounds are carried out by rain from far distances thereby increasing in concentration in the aquatic biota.

The study revealed further a domination of three congener PCBs in all the Nile perch products that were considered in this study in both the dry and rainy seasons. In this study, the fish products were dominated by three PCBs; PCB-138, PCB-153 and PCB-180. This domination tendency has also been highlighted in other previous studies (Wenaty *et al.,* 2019a, c). The reason for this domination tendency could be due to the fact that the metabolism of PCB-138, PCB-153 and PCB-180 by certain organisms is hard compared to the rest of the congeners that have low degree of chlorination as reported by Ssebugere *et al.* (2014). This enables their easy detection in different environmental compartments (Wenaty *et al.,* 2019b).

The total indicator PCBs loading in Nile perch products during both the dry and rainy seasons are shown in Figure 1. For fresh Nile perch muscles the sum of the PCBs were below the detection limits (<LOD) during the dry season and 5.16 µg/kg during the rainy season. The loading of the congeners during the dry season for the salted- sundried Nile perch products were reported to be 28.46 µg/kg but 39.77 µg/kg during the rainy season. For the trimmed fish products, the sum of the indicator PCBs was 31.55 µg/kg during the dry season and 41.93 µg/kg during the rainy season. The study revealed further that the sum of the PCBs during the dry season for the smoked products of Nile perch were 30.67 µg/kg while during the rainy season the sum of the indicator PCBs was 41.37 µg/kg and for deep fried products, the sum of the PCBs were 16.05 µg/kg during the dry season and 27.53 µg/kg during the rainy season.

The percentage contribution of the three dominant congeners to the total loads of the congeners were 0 and 100% for fresh Nile perch muscles, 53.1 and 53.3% for salted-sundried fish products, 66.7 and 69.1% for trimmed fish products, 53.3 and 56.2% for products that were smoked and 60.1 and 51.7% for products that were deep fried during the dry and rainy seasons respectively. High percentage contribution of the three congeners of indicator PCBs were also reported by Wenaty *et al.* (2019a) and Ssebugere *et al.* (2014) in previous studies.

In this study, the deep fried Nile perch had low levels of PCBs compared to other fish products processed under different processing operations. This is probably because of high cooking temperatures of the oil that enables it to act as an extracting solvent. This phenomenon has also been reported in the previous findings (Witczak, 2009a, b; Wenaty *et al.,* 2019b). On the other hand, the trims of Nile perch had significantly higher PCBs loading compared to the rest of the products because of high amounts of fatty that makes them lipophilic in nature compared to other products (Wenaty *et al.,* 2019a).

The study revealed further predominantly high levels of PCBs in smoked fish products. This is due to a reduction in co-distillation process of the congeners with water vapour as suggested in the previous studies (Witczak and Ciereszko, 2006) and the removal of water from the products because the compounds are soluble in fat and lipids, therefore the removal of water concentrates other insoluble components as reported in some other previous studies (Wenaty *et al.,* 2019a, b, c).

Furthermore, the fresh Nile perch muscles had no residual PCBs during the dry seasons but very small amounts (ΣPCBs of 5.16) of the dominant congeners were detected during the rainy seasons. This suggests that the aquatic environment in Lake Victoria is not alarmingly contaminated by PCBs and that seasons have a significant influence on the levels of PCBs in the aquatic biota. However, the mean concentration of ΣPCBs in both dry and rainy seasons as indicated in this study were about two folds lower than the maximum recommended limit of 75 µg/kg set by the European Commission for fish and other fishery products (EC, 2011). This is an indication of the safety of the Nile perch products from Lake Victoria. The study revealed further that, processed Nile perch products had higher levels of indicator PCBs than fresh fish muscles. This suggests further that apart from seasons having significant impacts on the levels

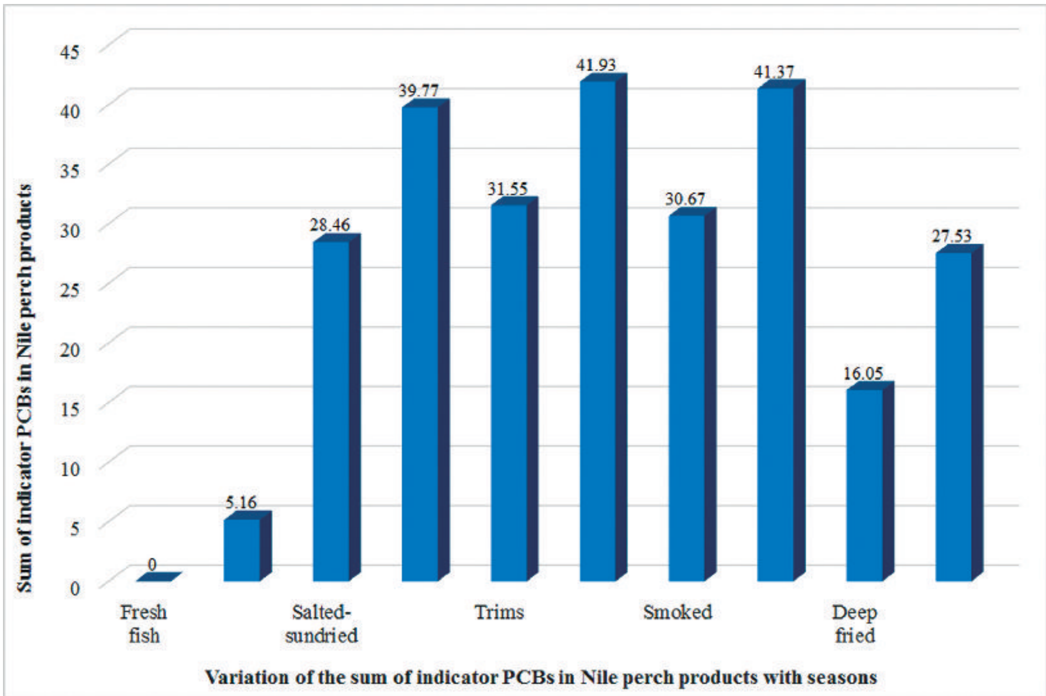


**Figure 1: Variations of the total indicators PCBs in Nile perch products during with seasons**

of PCBs, contaminations takes place in the Nile perch value chain.

Table 3 indicates the Analysis of Variance of the studied components that shows a significant difference in the levels of the studied indicator PCBs. This study revealed existence of significant differences in the levels of indicator PCBs between seasons with the rainy season reporting higher levels compared to the dry season. This suggests that the rain may serve as a media of transport of these toxic persistent organic pollutants from one place to the other.

## Conclusion and recommendations

The current study assessed the seasonal variability of indicatory congeners of PCBs in different products of Nile perch from the study area that are intended for domestic, regional and international markets. The levels of the detected indicator PCBs varied with seasons with the rainy seasons having significantly higher levels than the dry seasons. This suggests that seasonality has a significant impact on the levels of PCBs in Nile perch products from Lake Victoria.

**Table 3: Analysis of Variance of PCBs in processed fish products**

| | Sources of variation | | |
|---|---|---|---|
| **PCBs** | **DF** | **F** | **P** |
| PCB-28 | 4 | 3.59 | 0.042** |
| PCB-52 | 4 | 3.32 | 0.039** |
| PCB-118 | 4 | 9.63 | 0.001** |
| PCB-138 | 4 | 2.92 | 0.018** |
| PCB-153 | 4 | 0.68 | 0.023** |
| PCB-180 | 4 | 0.59 | 0.637 |

*** Indicates that the means are significantly different at a level of 0.05*
*DF: Stands for the degree of freedom, F: Stands for F-value and P: Stands for P–value*

However, in both seasons the loadings of the congeners were below MRL suggesting safety of fish products from Lake Victoria. Yet, follow up studies to assess the influence of different fish processing technologies such as smoking on the levels of different congeners of PCBs need to be undertaken.

## Acknowledgements

The authors acknowledge the financial support from the Danish International Development Agency (DANIDA) through the Innovations and Markets for Lake Victoria Fisheries (IMLAF) Project (DFC File No. 14–P01–TAN) that was coordinated by Prof. Robinson Mdegela.

## Conflict of interest

The authors declare that there is no conflict of interest.

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# Determination of Benzo(A)Pyrene and Heavy Metals Contamination in Smoked *Lates Niloticus* and *Oreochromis Niloticus* from Lake Victoria

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**Abstract**

*Fish remains to be an important source of proteins in developing countries including Tanzania. Fish processing methods like smoking aim at improving the shelf-life of smoked fish as well as taste and aroma. During smoking, smoke by-products from different materials used as source of heat are deposited on the fish. The deposited by-products include the carcinogenic polyclic aromatic hydrocarbons (PAHs) and heavy metals. Benzo(A)pyrene has been used as a marker for the occurrence of carcinogenic PAHs. The purpose of this study was to assess the different materials that are used in fish smoking practices, determine the levels of benzo(A)pyrene, mercury, cadmium and lead in smoked Lates niloticus (Nile Perch) and Oreochromis niloticus (Nile Tilapia) from different fish smoking areas in Mara and Mwanza regions. A total of 32 fish smokers were interviewed to assess the material used and how they use them to smoke their fish. This was followed by collection of 32 smoked fish samples for laboratory analysis of heavy metals (mercury, Cadmium and Lead) and concentration of benzo(A)pyrene. The findings of this study indicated that people engaged in smoking fish in the study areas are mostly using firewood and charcoal as their source of heat. There were no cases of the use of plastic materials. The laboratory results indicated that mercury and cadmium were not detected in all fish species while lead was detected at a mean concentration level of 0.28 µg/kg which is below the recommended level of 0.3 µg/kg as set by the EU. This indicated that smoked fish from Mara and Mwanza did not contain heavy metals to a harmful level. The Mean benzo(a)pyrene concentration detected was 4.79 µg/kg. This amount is higher compared to a level of 2 µg/kg set by the EU in 2014. There is therefore, a need for people who smoke fish to use other improved methods which will lower the levels of benzo(a)pyrene and the Government to have a continuous monitoring plan for these contaminants.*

***Keywords:*** *Smoked fish, Lates niloticus, Oreochromis niloticus, heavy metals, and Lake Victoria.*

## Introduction

Fish is an important source of nutrients as it contains high amount of protein and several essential micronutrients (Bene *et al.,* 2015). It is the main source of animal protein for over 20% of the world's population (FAO, 2020). The total world fish production (inland and marine waters) has increased from 101 million tonnes in 1995 to over 179 million tonnes in 2018 with a total first sale value estimated at USD 401 billion (FAO, 2020). Africa contributing about 11 million tonnes whereas Tanzania contributed 0.31 million tonnes (FAO, 2020). The total production in Tanzania includes fish from ocean, lakes, rivers and aquaculture. Aquaculture in Tanzania is dominated by freshwater fish farming in which small-scale farmers are practicing extensive and semi-intensive fish farming in small fish ponds of an average size of 150 to 500 m$^2$ (Shoko *et al.,* 2011). The main species farmed is the Nile Tilapia (*Oreochromis niloticus*) which is the dominant specie (99%) due to its superior growth compared to other species of the farmed fresh water fish (Rothuis *et al.,* 2014). Other farmed species include rainbow trout (*Oncorhynchus mykiss*), catfish (*Clarias gariepinus*) and milkfish (*Chanos chanos*) (Shoko *et al.,* 2011).

Moreover, fish are very perishable and they deteriorate rapidly under normal temperatures. The deterioration is influenced by several factors such as the habitat of the fish and nutritional composition. Bacteria grow on the outer and inner parts of the fish such as skin, gills and gastro-intestinal tract. Fish contain high protein (12-24%) and large amounts of non-protein-nitrogen (NPN) such as nucleotides, Trimethylamine Oxide (TMAO) and free amino acids. These serves as substrate for bacterial growth and upon decomposition, causes off odours and flavours. Also, fish have a lipid content of 0.1-22% which include the long-chain, polyunsaturated fatty acids which are highly susceptible to hydrolysis and oxidation (Esteves *et al.,* 2016). In addition, the high-water activity (aw) of fish makes them more susceptible to spoilage. In order to maintain the quality of fish and assure the safety, preservation and processing measures are important (Adeyeye and Oyewole, 2016). Fish preservation aims at maintaining the quality and extending the shelf-life. Major fish preservation methods include drying, salting, freezing, chilling, fermentation and smoking (Assogba *et al.,* 2019).

Smoking is the most common method of drying fish. The smoked fish are the most available form of fish in developing countries due to limited access to electricity to preserve fish (Tongo *et al.,* 2017). Smoking methods involve exposing fish directly to smoke from wood for several hours or days (2–3 days) which results into dehydration and deposition of combustion by-products on smoked fish (Forsberg *et al.,* 2012). The smoke gives the fish special taste, aroma and improves preservation due to its dehydrating and bactericidal properties. However, the deposited by products include some potentially harmful combustion by-products such as Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals (Tongo *et al.,* 2017). Polycyclic Aromatic Hydrocarbons (PAHs) refer to compounds which are chemically comprised of two or more benzene rings which are bonded in a linear, cluster or angular arrangements (Abdel-shafy & Mansour, 2015). They are ubiquitous and toxic to the environment and food processing contaminants produced by incomplete combustion or pyrolysis of organic materials (Purcaro *et al.,* 2013). The PAHs are known to be mutagens and carcinogenic in mammals. Several studies confirmed that diet such as smoked fish is the major way of human exposure to PAHs (Forsberg *et al.,* 2012; Roseiro *et al.,* 2011). The PAHs can enter the food through smoking and cooking processes. Food becomes contaminated by PAHs due to incomplete combustion of the materials used during smoking (Visciano *et al.,* 2009). In Tanzania, smoked fish is one of the commonly consumed foods and it serves as a good source of proteins, but there is limited information on PAHs and heavy metals on smoked fish especially from Lake Victoria region. In Tanzania there are no established standards for PAHs in smoked fish and no routine monitoring procedures are in place for safeguarding public health. The consumers of smoked fish have limited knowledge about the presence of PAHs in the smoked fish. Thus, the objective of this study was to find out the materials used to generate heat for smoking and determine the levels of benzo(a)pyrene and heavy metals in smoked Nile Perch (*Lates niloticus*) and Nile Tilapia (*Oreochronis niloticus*) from different fishing communities around Lake Victoria.

## Materials and methods

### Study Area

The study was conducted in Mwanza and Mara regions (Figure 1 A and B respectively). Mwanza is located on Southern part of Lake Victoria about 1200 - 1400 metres above the sea level; and lies between latitudes 1°30' and 3°00' South of the Equator and between longitudes 31°45' and 34°10' East of Greenwich. The region is bordered by Lake Victoria in the North, Kagera and Geita regions in the West, Mara region on the East, while Shinyanga and Simiyu regions are located on the South and South-eastern side of the region (Mwanza Region Investment Guide, 2017). According to 2012 population census (NBS, 2013), Mwanza region has a population of 2,772,509 people and about 3.3% of economically active population are engaged in fishing. Mara region is located in the northern part of Tanzania Mainland and it lies between latitudes 10° and 20° South and longitudes 31°10' and 35°15' East. The region is bordered by Kenya to the north, Simiyu region to the south, Arusha region to the east and Kagera region to the west (MRCO, 2005). The region has a population of 1,743,830 (NBS, 2013) and a small part of this population is engaged in fishing activities, including people who are living in the shores of the Lake Victoria (Mara Region report, 2007; NBS, 2013).

**Sampling Techniques**

The people engaged directly in fish smoking in Ilemela and Musoma were selected purposely. The fish smoking areas covered in Ilemela were Kirumba, Mwaloni, Kitangiri, Kiyungi, Igombe, Ibanda juu and Magomeni; and the areas covered in Musoma were Rukuba island and Bwai in Kiriba ward. Estimation of the sample size was done by using the equation proposed by Kothari (2009).

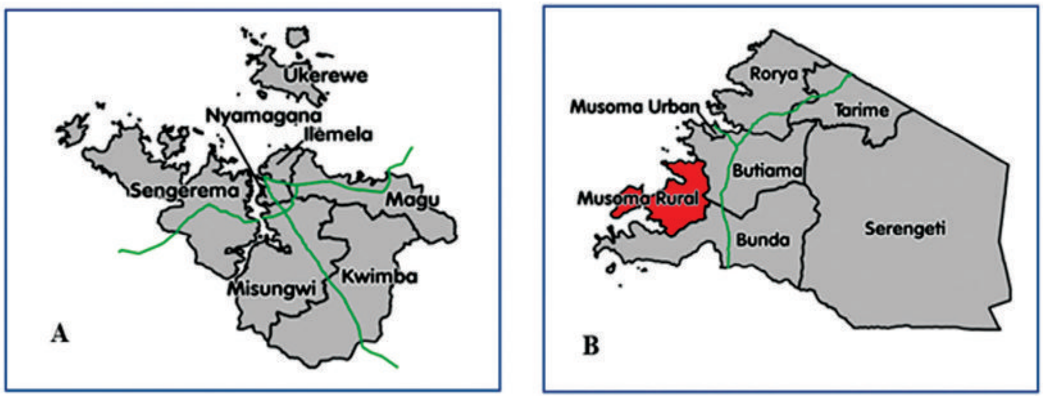


**Figure 1. A. Mwanza region and B. Mara region (www.wikipedia.org).**

**Study Design**

A cross-sectional research design was conducted where sociological and laboratory data were collected at one time. The design is flexible which minimizes bias and maximizes reliability and analysis (Kothari, 2004). Purposive sampling was used to select fish smoking dealers in Ilemela and Musoma Municipalities. People who are engaged in fish smoking activities were randomly selected and administered with structured questionnaire. Samples were collected for laboratory analysis and purchased at the same time from the randomly selected fish smokers.

**Study Population and Inclusion and Exclusion Criteria**

The study population comprised of selected people who were engaged in fish smoking activities, males and females in Ilemela and Musoma Municipalities. The selected people were those engaged in fish smoking activities and who were available at the time of data collection, willing to participate and ready to give the required information were included in the study.

$$N = \frac{Z^2 P(1-P)}{D^2} \qquad (1)$$

Whereas:
N= estimated sample size
Z=Confidence Interval
D=Precision level (acceptable error)
P=Estimated Prevalence

Samples of smoked fish were collected directly from the smoking premises and from the people who were interviewed after completing their questionnaire. The smoked fish samples were comprised of two species, *Lates niloticus* and *Oreochromis niloticus*. A total of 32 samples of smoked fish were collected from Mara and Mwanza (8 samples for each species from each region). The samples were then stored in properly-sealed plastic bags, labelled and then transported to Tanzania Food and Drugs Authority (TFDA) Lake Zone Laboratory in cooler box. Samples were then stored in a deep freezer at a temperature of -20 °C prior to analysis.

**Questionnaire Pre-Testing and Administration**

The questionnaire was pre-tested before commencing data collection at Nyatukara and Mtakuja wards in Sengerema District, Mwanza involving 5 fish smokers with the aim of checking the clarity and applicability of the questions. Questions which were unclear and difficult to answer were revised and others omitted. The revised questions were translated into Swahili for easy understanding by the majority of the people.

**Laboratory Analysis (lead, cadmium and mercury)**

Laboratory analysis of fish samples were carried out to determine the levels of three heavy metals namely lead, mercury and cadmium and the levels of benzo(a)pyrene contamination. On arrival of the samples to the laboratory, they were analysed for lead, cadmium and mercury contamination. The analysis was done using TFDA in-house method, 2018 (MP-AES manufacturer provided method) which involved preparation of stock solution, preparation of working standard and sample preparation prior to analysis.

**Data Analysis**

Questionnaire and laboratory data were recorded using Microsoft Excel and later imported into SPSS version 20 for analysis. Descriptive statistics-frequencies, percentages, means and counts from the responses were used to determine distribution and magnitude of variables. Duncan's test and confidence intervals were used to compare variables where the differences were deemed significant when $P<0.05$. Correlation analysis was done to test the association between different variables.

**Results and Discussion**

**Fish smoking practices and materials used in fish smoking**

***Demographic characteristics of the respondents***

The demographic characteristics of the people who are engaged in fish smoking are presented in Figure 1. Female respondents form the majority (81%) of people engaged in fish smoking activities across all regions while the number of males is represented by 19%. The results show that the majority (47%) of the respondents are between the age of 25-34 years who constitute the largest proportion. Respondents with more than 35 years represent 34% while respondents with age below 24

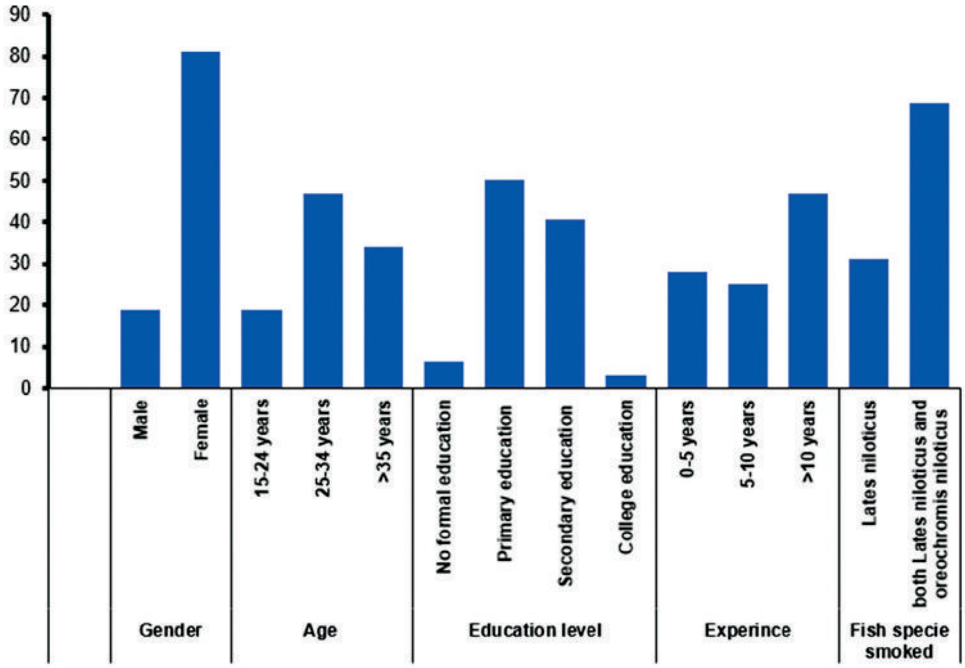


**Figure 2: Socio-demographic characteristics of the respondents (N = 32)**

years were 19%. The results show that 50% of the respondents had primary education, 41% secondary education, 6% no formal education and 3% college education. Almost half of the respondents (47%) had been in the fish smoking business for more than 10 years while 28% had been in business for less than 5 years. Twenty five percent (25%) of respondents had been engaged in the fish smoking business for a period of between 5 to 10 years.

This study showed that women are more engaged in smoking of fish than men across all regions (Fig. 1). Women have been reported to work in the fish industry in many parts of the world with different roles, depending on communities and type of fishing activity (Nwabueze, 2010). In most of these fishing communities, fishing has been viewed as men's role because it is tedious, sometimes being done at night. This reason causes women to focus more on the post-harvesting practices such as smoking, deep frying, drying and salting than on the night fishing activities (Nwabueze, 2010; Anihouvi *et al.,* 2012; FAO, 2015).

The findings of this study indicate that fish smoking is an important activity to women of Mara and Mwanza regions, and this is agreed with studies conducted by Onyango *et al.* (2017) who reported 85.2% of women engaged in fish processing compared to men who were 14.8%. Likewise, Medard *et al.* (2001) reported that over 76.5% of women participating in the fishery sector in Lake Victoria are involved in off-shore activities including fish smoking. Similarly, study conducted by Njenga & Mendum (2018) in Ghana showed that women comprised 100% of the fish smokers. The roles and contributions of women in the fisheries sector have been undervalued for a long time and they have been excluded in decision making (FAO, 2015).

**Materials used and fish smoking practices**

The materials used in fish smoking and safety knowledge of smoked fish are presented in Table 1. All fish for smoking are obtained from middlemen (100%) who buy the fish from fishermen and sell to people who smoke fish. It has been reported that middlemen are abundant in fish trade especially in developing countries (Surtida, 2000; Thuy *et al.,* 2019). In this case, it is important for the middlemen to have safety knowledge of handling of fresh fish so that they remain safe until further processed.

Before smoking, 59% of respondents store fresh fish on a wire mesh on the smoking kilns, 22% keep it on the ground, 13% are kept in cold storage and 6% are kept in plastic basins. Poor handling of the fresh fish prior to smoking may result in chances of contaminations in smoked fish (Igwegbe *et al.,* 2015). For example, storage of fresh fish on the ground (sand) exposes them to all forms of contaminations including heavy metals. The quality of the fresh fish is an important factor which determines the quality of the smoked fish product (Debbarma *et al.,* 2018). The current study found out that most of the fresh fish are stored in a wire mesh contained on the smoking kilns before smoking that reduce chances of contamination. This finding agrees that reported by Kabahenda *et al.* (2009) that shows before smoking fish products are usually placed in a rack in a kiln and allowed to drip to remove excess water for several hours. The results for fish size, smoking during and safety of materials used for smoking are shown in Table 1.

The current study shows that consumers are influenced by texture and appearance of the fish. For example, dry and moderately black or brownish smoked fish are the more preferred qualities. According to Abraha *et al.* (2018) texture and general appearance of smoked fish contributes to product acceptability by the consumers. In view of this, fish smokers may use other materials other than firewood which will result to dry, black or brownish fish such as plastic remains. The study found out that plastic materials and wastes were not used in fish smoking as the source of heat and smoke contrary to the study conducted by Kabahenda *et al.* (2009) that other materials such as cow dung was used as a source of fuel to smoke fish in Businga Island of Lake Victoria. Despite the fact that plastic materials were not used to smoke fish, majority of fish smokers admitted that sometimes these materials are used. The majority of the smokers can differentiate the firewood-smoked-fish from those smoked with plastic materials by physical appearances of the smoked fish.

| Category | | Region (frequency) | | Total | Percent |
|---|---|---|---|---|---|
| | | Mara | Mwanza | | |
| Fish species smoked | *Lates niloticus* | 5 | 5 | 10 | 31.3 |
| | both species | 11 | 11 | 22 | 68.8 |
| Fish storage | Cold storage | 2 | 2 | 4 | 12.5 |
| | On the ground | 4 | 3 | 7 | 21.9 |
| | In a container | 0 | 2 | 2 | 6.3 |
| | On wire mesh | 10 | 9 | 19 | 59.4 |
| Fish smoking time | day time | 12 | 10 | 22 | 68.8 |
| | at night | 0 | 1 | 1 | 3.1 |
| | Both | 4 | 5 | 9 | 28.1 |
| Obtaining firewood | Not easy | 0 | 4 | 4 | 12.5 |
| | Easy | 16 | 12 | 28 | 87.5 |
| Smoking fish using materials | No | 12 | 15 | 27 | 84.4 |
| | Yes | 4 | 1 | 5 | 15.6 |
| Why use other materials other than firewood | When having small amount of fish | 2 | 0 | 2 | 46.9 |
| | Lack of firewood | 1 | 2 | 3 | 25 |
| | Use of firewood is tedious | 1 | 0 | 1 | 3.1 |
| Why not use other materials | Firewood is easy to get | 4 | 11 | 15 | 46.9 |
| | Firewood results into fish of good quality | 6 | 2 | 8 | 25 |
| | Firewood is easy to use | 1 | 0 | 1 | 3.1 |
| Other materials used | Charcoal | 4 | 1 | 5 | 100 |
| Source of other materials | Market | 4 | 1 | 5 | 100 |
| Time taken to smoke fish | Less than 3 hours | 11 | 10 | 21 | 65.6 |
| | 4 hours | 1 | 4 | 5 | 15.6 |
| | 5 hours or more | 4 | 2 | 6 | 18.8 |
| Preferred fish size for smoking | Small size | 6 | 8 | 14 | 43.8 |
| | Medium size | 3 | 1 | 4 | 12.5 |
| | Large size | 6 | 1 | 7 | 21.9 |
| | Both sizes | 1 | 6 | 7 | 21.9 |
| What makes smoked fish to be perceived of good quality? | Taste | 2 | 1 | 3 | 9.4 |
| | Keeping quality | 14 | 15 | 29 | 90.6 |
| What are customers looking for in smoked fish | moderately black fish | 11 | 11 | 22 | 68.7 |
| | less black smoked fish | 1 | 1 | 2 | 6.3 |
| | brownish fish | 4 | 4 | 8 | 25 |
| Awareness of any chemicals from the smoking materials | Not aware | 16 | 16 | 32 | 100 |
| Awareness of the safety of materials used to smoke fish | Not aware | 16 | 16 | 32 | 100 |
| Difference in appearance between fish smoked by firewood and by plastic materials | Yes | 15 | 16 | 31 | 96.9 |

| Category | | Region (frequency) | | Total | Percent |
|---|---|---|---|---|---|
| | | Mara | Mwanza | | |
| | No | 1 | 0 | 1 | 3.1 |
| How they differ | Fish smoked by other materials are reddish and not dry | 2 | 1 | 3 | 9.7 |
| | Fish smoked by wood are darker | 1 | 2 | 3 | 9.7 |
| | Fish smoked by wood are drier | 12 | 13 | 25 | 80.6 |

### Heavy metal levels in smoked *L. niloticus* and *O. niloticus*

The results for heavy metal contamination in smoked *Lates niloticus* and *Oreochromis niloticus* are presented in Table 2. Lead (Pb) concentrations ranged from 0 mg/kg to 1.21 mg/kg which was detected in smoked *Lates niloticus* from Mwanza. Cadmium (Cd) and Mercury (Hg) were not detected in all samples.

The minimum, maximum and mean concentrations levels of Pb, Cd and Hg from the two fish species are indicated in Table 3. The levels of Pb observed in all samples were not significantly different (P>0.05).

**Table 2: Levels of Pb, Cd and Hg in smoked *L. niloticus* and *O. niloticus***

| Sample Code | Fish Specie | Lead (mg/kg) | SD | Cadmium (mg/kg) | SD | Mercury (mg/kg) | SD |
|---|---|---|---|---|---|---|---|
| MS O1 | *O. niloticus* | 0.79 | 0.18 | n.d | 0.15 | n.d | 0.01 |
| MS O2 | *O. niloticus* | n.d | 0.16 | n.d | 0.09 | n.d | 0.02 |
| MS O3 | *O. niloticus* | 0.31 | 0.19 | n.d | 0.08 | n.d | 0.02 |
| MS O4 | *O. niloticus* | 0.32 | 0.18 | n.d | 0.03 | n.d | 0.02 |
| MS O5 | *O. niloticus* | n.d | 0.05 | n.d | 0.07 | n.d | 0.02 |
| MS O6 | *O. niloticus* | 0.02 | 0.06 | n.d | 0.18 | n.d | 0.04 |
| MS O7 | *O. niloticus* | n.d | 0.06 | n.d | 0.11 | n.d | 0.01 |
| MS O8 | *O. niloticus* | n.d | 0.25 | n.d | 0.05 | n.d | 0.02 |
| MS L1 | *L. niloticus* | n.d | 0.64 | n.d | 0.07 | n.d | 0.02 |
| MS L2 | *L. niloticus* | n.d | 0.57 | n.d | 0.08 | n.d | 0.02 |
| MS L3 | *L. niloticus* | 0.89 | 0.39 | n.d | 0.02 | n.d | 0.02 |
| MS L4 | *L. niloticus* | 0.32 | 1.78 | n.d | 0.05 | n.d | 0.04 |
| MS L5 | *L. niloticus* | 0.69 | 0.01 | n.d | 0.04 | n.d | 0.05 |
| MS L6 | *L. niloticus* | 0.96 | 0.26 | n.d | 0.18 | n.d | 0.04 |
| MS L7 | *L. niloticus* | 0.22 | 0.03 | n.d | 0.04 | n.d | 0.03 |
| MS L8 | *L. niloticus* | n.d | 0.69 | n.d | 0.09 | n.d | 0.04 |
| M O1 | *O. niloticus* | n.d | 0.55 | n.d | 0.06 | n.d | 0.03 |
| M O2 | *O. niloticus* | n.d | 0.33 | n.d | 0.05 | n.d | 0.04 |
| M O3 | *O. niloticus* | 0.22 | 0.13 | n.d | 0.03 | n.d | 0.01 |
| M O4 | *O. niloticus* | n.d | 0.14 | n.d | 0.01 | n.d | 0.01 |
| M O5 | *O. niloticus* | n.d | 0.01 | n.d | 0.03 | n.d | 0.01 |
| M O6 | *O. niloticus* | 0.06 | 0.01 | n.d | 0.04 | n.d | 0.04 |
| M O7 | *O. niloticus* | n.d | 0.46 | n.d | 0.11 | n.d | 0.03 |

**Table 2: Levels of Pb, Cd and Hg in smoked *L. niloticus* and *O. niloticus***

| Sample Code | Fish Specie | Lead (mg/kg) | SD | Cadmium (mg/kg) | SD | Mercury (mg/kg) | SD |
|---|---|---|---|---|---|---|---|
| M O8 | *O. niloticus* | 0.79 | 0.28 | n.d | 0.02 | n.d | 0.02 |
| M L1 | *L. niloticus* | 1.21 | 0.02 | n.d | 0.05 | n.d | 0.05 |
| M L2 | *L. niloticus* | 0.62 | 0.14 | n.d | 0.1 | n.d | 0.05 |
| M L3 | *L. niloticus* | n.d | 0.89 | n.d | 0.08 | n.d | 0.03 |
| M L4 | *L. niloticus* | n.d | 0.06 | n.d | 0.05 | n.d | 0.13 |
| M L5 | *L. niloticus* | 0.94 | 0.03 | n.d | 0.04 | n.d | 0.01 |
| M L6 | *L. niloticus* | 0.26 | 0.26 | n.d | 0.07 | n.d | 0.03 |
| M L7 | *L. niloticus* | n.d | 0.18 | n.d | 0.06 | n.d | 0.02 |
| M L8 | *L. niloticus* | 0.72 | 0.17 | n.d | 0.08 | n.d | 0.04 |

*MS=samples from Mara, M=samples from Mwanza, n.d=not detected, L=Lates, O=Oreochromis, SD=Standard Deviation. Values are means of three replicates*

**Table 3: Levels of Pb, Cd and Hg in smoked *L. niloticus* and *O. niloticus* (N = 32)**

| Heavy metal | Minimum level (ppm) | Maximum level (ppm) | Mean (mg/kg) | Std. Deviation | t-value | P-value |
|---|---|---|---|---|---|---|
| Mercury | 0 | 0 | 0 | 0 | | |
| Lead | 0 | 1.21 | 0.28 | 0.38 | -0.269 | 0.790 |
| Cadmium | 0 | 0 | 0 | 0 | | |

The laboratory results were categorized based on the recommended level of Pb as a cutoff point to determine the percentage of those which are above or below the recommended level. The result in Table 4 shows that 65.6% of the samples were below the recommended limit of 0.3 mg/kg and 34.4% of the samples analyzed were above the recommended level.

**Table 4: Category of Pb level based on recommended level (0.3 mg/kg)**

| | Frequency | Percent |
|---|---|---|
| Below the recommended level | 21 | 65.6 |
| Above the recommended level | 11 | 34.4 |

The results show that there is a significant difference in Pb concentrations across species at $P \leq 0.05$. The mean Pb levels recorded for *Lates niloticus* and *Oreochromis niloticus* were 4.40 ± 0.43 and 0.15 ± 0.28 ppm, respectively. The mean Pb concentration recorded across regions on average were not statistically significantly different (Table 5).

The current study shows that smoked *Lates niloticus* and *Oreochromis niloticus* contained Pb in varying amounts. Lead was detected in some fish samples in a higher concentration but were not detected in other smoked fish samples. The highest concentration of Pb was found in smoked Lates niloticus with a concentration of 1.21 mg/kg from Mwanza.

**Table 5: Mean differences in Pb concentration across species and regions ($P \leq 0.05$)**

| Variable | | Mean (mg/kg) ±SD | F-ratio | (P-Value) |
|---|---|---|---|---|
| **Specie** | ***L. niloticus*** | 4.40 ± 0.43 | 3.918 | (0.05) |
| | ***O. niloticus*** | 0.15 ± 0.28 | | |
| **Region** | **Mara** | 0.26 ± 0.36 | 0.080 | (0.78) |
| | **Mwanza** | 0.30 ± 0.41 | | |

Lead, a non-essential metal has been shown to be toxic and there is no known level of exposure that is considered safe (Tchounwou *et al.,* 2012; WHO, 2017). Higher levels of lead in the human body have been linked to the damage of the nervous system, brain and kidney; gastrointestinal diseases and adverse effects in vitamin D metabolism (Ogwuegbu and Muhanga 2005; Tchounwou *et al.,* 2012). The mean Pb concentration detected was 0.28 mg/kg which is slightly lower than 0.3 mg/kg which is the maximum permissible level recommended by WHO (2017). The levels of Pb observed in the smoked fish samples could have come from the firewood is used as a source of heat and smoke, the smoking process or a result of bio-accumulation. It has reported that use of charcoal and materials containing paints in the smoking process produces smoke that contain Pb (Adekunle and Akinyemi, 2004). The Pb contained in the smoke may attach to the fish meat and contaminate it. Also, smoking of fish can result in increase of the concentration of toxic heavy metals (Wangboje and Miller, 2018). The heavy metals can also originate from the concentration of the metals contained in the fresh fish when moisture is removed by the smoking process (Igwegbe *et al.,* 2015; Adekunle and Akinyemi, 2004; Megasari *et al.,* 2019). Pollution of water reservoirs by municipal effluents and industrial activities are other sources of lead contamination in fish. Significant amount of lead may accumulate in fish depending on the degree of water pollution in their habitat, exposure to the pollution and eating habit of the fish (Winiarska-Mieczan *et al.,* 2018). This could attribute to the presence of lead in smoked *Lates niloticus* and *Oreochromis niloticus.*

There was a significant difference in lead levels between smoked *Lates niloticus* and smoked *Oreochromis niloticus* (Table 6). Higher valued was detected on *Lates niloticus* (4.40 ± 0.43 mg/kg) compared with *Oreochromis niloticus* (0.15 ± 0.28 mg/kg). The difference may be due to the size of the two species and the eating habit of the fish. *Lates niloticus* is a predator and may accumulate the metal contained in the fish preyed upon. Also, the large size of *Lates niloticus* compared to *Oreochromis niloticus* results to the use of more smoking materials thus allowing deposition of this metal in a great proportion. The findings of Pb concentration levels in smoked *Lates niloticus* and *Oreochromis niloticus* agreed with Igwegbe *et al.* (2015) who reported the increase of Pb levels in smoked fish after the smoking process, recording the highest concentration of Pb to be 0.00363 mg/kg. Also, Essuman (2005) found higher levels (2.8 mg/kg) of Pb in smoked fish. Likewise, the elevated levels of Pb in smoked fish in Nigeria were reported to increase after local smoking process to levels varying from 0.14 ± 0.02 mg/kg to 0.95 ± 0.01 mg/kg (Adekunle & Akinyemi, 2004).

Mercury is one of the heavy metals that can be toxic in food if present in high amounts. Higher levels of mercury in the human body affects the brain and cause impairment of other organs leading to the malfunctioning of nerves, kidneys and muscles (Jaishankar *et al.,* 2014). The recommended concentration level for Hg in smoked fish products is 0.5 mg/kg (WHO, 2017) above which is harmful to health of the consumers. This study observed the concentrations of Hg in smoked *Lates niloticus* and *Oreochromis niloticus* samples to be very low and below the detection limits. The low levels observed might be influenced by low or no accumulation of mercury by the fresh fish which were smoked, absence of mercury in the smoking materials used or degradation of methylmercury by the smoking process. Firewood and charcoal are the major source of heat and smoke in Mara and Mwanza. The absence of mercury in the smoked fish samples indicates that the firewood and charcoal used to smoke fish does not contain mercury. Moreover, it has been shown that mercury may contaminate fish through polluted water from contaminated run-offs, human activities like mining, agriculture and industrial activities (Igwegbe *et al.,* 2015). A study conducted by Mrosso &Werimo (2015) reported a huge and fast-growing human population in both rural and Urban areas surrounding Lake Victoria. These populations especially the urban produces industrial and domestic wastes which are discharged into the lake and become pollutants to the lake, affecting the water quality and organisms living in the Lake. Mercury may accumulate in fish tissue especially if their source water contains their residues (Sserunjogi, 2009). It has been reported that smoking of fish may degrade methylmercury, a toxic form of mercury (Donkor *et al.,* 2006). This could attribute to the absence of Hg in smoked *Lates niloticus* and *Oreochromis niloticus*. This study agreed with finding of Essuman (2005) in which mercury could not be detected in all smoked fish samples analysed. However, low levels of mercury were observed in a study conducted by Adeyeye *et al.* (2016) in fish smoked using different smoking methods of drum-smoking and convective smoking and the levels observed were below the permissible level set by the World Health Organization of 0.2 ppm (Adeyeye *et al.,* 2016).

The concentrations of Cadmium in smoked *Lates niloticus* and *Oreochromis niloticus* samples observed were very low and below the detection limits. The levels were lower than the set limit for Cd in smoked fish of 0.5 mg/kg. This may be due to low accumulation in fish muscles, size of fish and the smoking materials used. Cadmium is a metal which has no benefits to the human body and it is toxic even at very low concentrations (Kumar & Singh, 2010). The metal may accumulate in fish tissues if fish are exposed to polluted water (Winiarska-Mieczan *et al.,* 2018). The accumulation is greatest in the liver and kidney which are important organs for metabolism and detoxification of cadmium in fish. It has been shown that the muscles of fish accumulate negligible concentrations of cadmium (Chowdhury *et al.,* 2004). Prior to smoking, the fish is gutted during which the internal organs such as intestines, liver and kidneys are removed, then cut into pieces depending on the size of the fish (Vidacek & Janci, 2016). These internal organs are the ones which accumulates Cd in great amount compared to the muscles, which may explain the absence of Cd in the fish samples.

Moreover, the accumulation of cadmium in fish tissues has been shown to increase with age and size of fish, with small fish accumulating small concentrations and vice versa (Ciardullo *et al.,* 2008; Farkas *et al.,* 2003). This study found out that the fish smokers in Mara and Mwanza prefer small-sized fish which might influence the absence of Cd among the fish samples. Cadmium may also be present in smoked fish if the smoking materials used contain this toxic metal, such as plastics, paints and batteries (WHO, 2017). This study found that plastic materials and wastes were not used to smoke fish in the two regions attributing to the absence of Cd in the two fish species. These findings agree with Fakunle and Effiong (2012) who did not detect cadmium in all smoked fish species in the study. However, increase of the level of Hg and Cd after the smoking process has been reported by Igwegbe *et al.* (2015) contrary to the findings of this study.

**Benzo (A) pyrene (BaP) levels in smoked fish *Lates niloticus* and *Oreochromis niloticus***

The results for benzo (a) pyrene levels are presented in Table 6. From the results, BaP ranged from 0.87 μg/kg to 13.7 μg/kg. The mean BaP level was 4.79 μg/kg which is above the acceptable level of 2 μg/kg in smoked fish (EU, 2011).

**Table 6: Level of BaP in smoked *Lates niloticus* and *Oreochromis niloticus***

| Parameter | Recommended limit (μg $kg^{-1}$) | Minimum (μg $kg^{-1}$) | Maximum (μg $kg^{-1}$) | Mean (μg $kg^{-1}$) | Std. Deviation | P-Value |
|---|---|---|---|---|---|---|
| BaP | 2 | 0.87 | 13.7 | 4.79 | 3.48 | 0.00 |

One sample t-test was performed on levels of BaP and results indicated that the values are greater than the recommended limits at $P<0.05$ (P-Value=0.00). The result shows that there is a significant difference in concentrations of BaP between the species ($P<0.05$) as indicated in Table 7.

Benzo (a) pyrene has been used as a marker for the occurrence, concentration and effects of carcinogenic polycyclic aromatic hydrocarbons (EU, 2005). The presence of higher levels than the recommended levels in foods such as smoked fish poses a health risk to the consumers.

**Table 7: Mean differences in BaP concentration across species and regions (P<0.05)**

| Variable | Mean ± SD | F ratio | (P-Value) | |
|---|---|---|---|---|
| Specie | *L. niloticus* | 6.72 ± 3.71 | 16.59 | (0.00) |
| | *O. niloticus* | 2.61 ± 3.49 | | |
| Region | Mara | 4.63 ± 3.96 | 16.59 | (0.79) |
| | Mwanza | 4.96 ± 3.07 | | |

The maximum permissible levels of 0.002 mg/kg (2.0 µg/kg) wet weight for benzo (a) pyrene is recommended by the European Union (EU, 2011). Studies have shown that fish and marine invertebrates may naturally contain small amounts of different PAHs which are absorbed from the environment (Sirkoski & Stolyhwo, 2005). Some PAHs including benzo (a) pyrene are quickly metabolized in fresh fish but do not accumulate in the muscle meat of fish. Levels of benzo (a) pyrene in smoked fish products may greatly come from the materials which are used to smoke the fish. The current study observed levels of benzo (a) pyrene ranging from 0.87 µg/kg to 13.70 µg/kg with the mean concentration of 4.79 µg/kg. This amount is slightly higher than the recommended level of 2.0 µg/kg.

Significant variation (P<0.05) was observed among fish species in the concentrations of the benzo (a) pyrene. The *Lates niloticus* recorded high levels of benzo (a) pyrene of up to 13 µg/kg compared to *Oreochromis niloticus* which was 4.99 µg/kg. This could be attributed to the size of the fish and the time taken in smoking. During smoking fish are exposed to partially burning firewood which is used to generate the smoke. Since firewood is mostly used in fish smoking, the large size of the *Lates niloticus* take a lot of time and firewood to smoke. Some people during fish smoking carry out re-smoking in order to make sure that the fish are completely dry to increase their keeping quality or according to the needs of their customers (Akpambang *et al.,* 2009). This results in deposition of high amounts of benzo (a) pyrene in the fish skin and into the muscle meat of fish. Other reasons for the higher concentration in *Lates niloticus* compared to other species has been explained as differences in bioaccumulation, metabolism kinetics, age and feeding habits of the fish (Pointet & Milliet, 2000).

According to the EU (2011), the maximum permissible concentration levels of Benzo (a) pyrene in smoked fish products is 2 µg/kg wet weight in muscle meat of fish and smoked fish products. The levels of benzo (a) pyrene observed in this study were similar to other studies. A study on levels of PAHs in smoked and sun-dried *Synodontis victoriae*, *Haplochromis* spp and *Lates niloticus* fish samples from Lake Victoria areas in Mwanza, Tanzania indicated higher concentrations of benzo (a) pyrene in all the smoked fish samples ranging from 0.39 to 1.55 mg/kg. The concentrations of benzo (a) pyrene in *Lates niloticus* ranged from 0.51 to 1.27 mg/kg with a mean of 0.78 mg/kg (Andrew *et al.,* 2018). Likewise, Akpambang and others (2009) reported traditionally smoked and/or grilled fish from Nigerian market highly contaminated with benzo (a) pyrene with levels up to 38 µg/kg, which exceeds by far the limit of 2 µg/kg recommended by the European Commission in 2005. The benzo(a)pyrene concentration levels observed in this study is comparable with other studies (Table 8). This may be due to the type of smoking practices used in Mara and Mwanza in which most of the people use traditional smoking kilns, which use little wood, while others use charcoal. It has been indicated that the use of charcoal does not result in higher levels of benzo (a) pyrene when compared to the use of firewood (Akpambang *et al.,* 2009).

Smoking fish using small quantity of firewood and for a short time may result into low levels of the benzo(a)pyrene. Use of charcoal as it has been observed in the study gives lower levels of benzo(a)pyrene because charcoal is an already pyrolized material which produces clean smoke (Akpambang *et al.,* 2009).

**Table 8: BaP results from previous work in different countries**

| Country | Specie of smoked Fish | BaP Concentrations | Study by |
|---|---|---|---|
| Tanzania | *L.niloticus, O.niloticus* | 0.87 to 13.4 µg/kg | This Study |
| Tanzania | *S. victoria, Haplochromis spp* and *L. niloticus* | 0.39 to 1.55 mg/kg ww | J.A.M. Mahugija, E. Njale (2018) |
| Kenya | *L. niloticus* | 7.46 to 18.79µg/kg | Muyela, B (2012) unpublished |
| Southern Nigeria | *Clarias gariepinus, Tilapia zilli, Ethmalosa fimbriata,* and *Scomber scombrus* | max 0.28 mg/kg ww | Tongo *et al.* (2017) |
| Poland | *Sprats* | max 36.5 mg/kg | Zachara *et al.* (2017) |
| Nigeria | *Tilapia spp., Arius heudeloti* | 2.4 ± 0.1 to 64.6 ± 0.2 mg/kg | Okenyi *et al.* (2016) |

*L=Lates, O=Oreochromis*

**Conclusion**

The results of this study have relived that the smoking practices being carried out in Mara and Mwanza regions which are predominated by young women, uses two kinds of materials as a source of heat and smoke. These materials are firewood which is used in a great extent and charcoal to a lesser extent. The use of other materials like plastics and wastes was not observed. All the fish smokers in Mara and Mwanza were not aware of the harmful effects which may come from the smoke produced by the smoking materials. It was observed that the levels of lead, mercury and cadmium studied were all below the WHO permissible limits. Lead was detected in some fish samples in relatively low amount to high amounts but was not detected in others. On the average concentration, it indicates that lead in smoked fish samples is within the safe level.

It recommended that to carry out evaluation of smoked fish in Mara and Mwanza regions periodically in order to ascertain the use of plastic materials in fish smoking as consumers of smoked fish products may be predisposed to possible health hazards which are associated with the consumption of fish smoked using the plastic materials.

In general, Lates niloticus fish species recorded higher values of lead compared to Oreochromis niloticus, which might be influenced by its large size and feeding habit, being at the top of a food chain. Mercury and cadmium were not detected in any of the smoked fish samples suggesting that the firewood and charcoal used in the smoking process did not contain the toxic metals. This implies that the smoked fish products in Mara and Mwanza regions are safe for human consumption due to low levels of lead, mercury and cadmium observed. However, there should be frequent monitoring plans by the central and local government to make sure that the materials used to smoke fish around Mara and Mwanza do not contaminate the fish by harmful chemicals and heavy metals. This study also found out that the mean concentration of benzo(a)pyrene was slightly higher than the recommended level as set by the EU commission. The Lates niloticus recorded higher levels compared to Oreochromis niloticus which may be related to the size of the Lates niloticus which takes longer time to smoke and uses more smoking materials, allowing greater deposition of benzo(a)pyrene to the fish muscle. The levels of benzo(a)pyrene in smoked fish around Mara and Mwanza needs to be monitored frequently since the chemical has carcinogenic, teratogenic and mutagenic effects to the human body.

This involvement of women especially the youths in fish smoking in Mara and Mwanza is a valuable input to the fisheries sector. This calls for the government to formally address the needs and challenges of fish smokers by preparing a policy on fish post-harvest management. This will allow them to access loans and increase their capital so that they can use improved practices of fish smoking.

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# Low Mycotoxins Content at Harvest, High in Stored Maize: Harvesting and Storages Practices Implications in Two Agro Ecosystems of Tanzania

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**Abstract**

*A survey was conducted to establish association of pre-storage and storage practices on occurrence of multiple mycotoxins in northern highland and eastern lowland maize based agro-ecosystems in Tanzania. Four hundred (400) households from 80 villages, 40 from each of the two agro-ecosystems were randomly selected for semi structured interviews to establish maize harvesting and storage practices. From each household, approximately 1kg of maize was collected at maize maturity before they were harvested and another 1kg maize collected from at least 6 months storage. The five household samples from each village were reconstituted to make one composite sample representing a village. Standard procedure was used for mycotoxins extraction. Compound quantification was done using Ultra-high performance liquid chromatography/time-of-flight mass spectrometry (UHPLC/TOFMS). More than 70% of farmers in the Eastern lowland used grain hardness as an indicator of grain maturity. Delayed harvesting of 4 to 12 weeks after maturity was observed across the two agro-ecosystems. More than 60% farmers shelled maize mechanically by beating on floor, in bags and elevated platforms. Most important storage insect pests were confused flour beetle (Tribolium confusum Jacquelin du Val) (100%), followed by 80% larger grain borer (Prostephanus truncutus L). Fourteen fungal species were detected and only 12 were present in both agroecosystems. Penicillium brevicompactum and F. culmorum were not detected in samples from northern highland while F. tricinctum and F. equiseti were not detected in the eastern lowland zone. With exception of F. graminearum, all other species were more abundant in eastern lowland than northern highland. In eastern lowlands, aflatoxin contamination in samples stored for six months was ten times higher than in samples collected at harvest. Significant (p≤0.05) positive and negative correlations between mycotoxins and storage practices were obtained. The study suggests that pre-storage and storage practices applied by subsistence farmers in the two agro-ecosystems need to be fine-tuned to reduce mycotoxins risk the two maize based agro-ecosystems.*

***Keywords:*** Pre-storage, storage, subsistence farming, mycotoxins, agro ecological zones

## Introduction

Maize (*Zea mays* L.) is a major cereal used as a staple food and feed worldwide (Temu *et al.,* 2010). Under subsistence farming, maize has the simplest value chain comprising mainly the input supply and farmers who are consumers. Yet time from farm to folk is possibly the longest because after harvest, maize is usually stored for a year round until the next harvest cycle. Such storage of maize creates a man-made ecosystem in which the quality and nutritive value may change partly due to storage pests like insects and moulds (Magan, 2007). Apart from its inherent pre and postharvest vulnerability to mould infection, harvest and storage practices can exacerbate their effects (Miller, 2008). As a result fungal infection is of concern because it causes yield loss and contaminates maize with mycotoxins (Miller, 2008).

Mycotoxins are secondary metabolites produced by certain species of fungi. Depending on their adaptability to ecological conditions, the mycotoxin producing fungi are grouped as field fungi (*Fusarium* and *Alternaria* species) (Gallo *et al.,* 2016) and storage fungi (*Aspergillus* and *Penicillium* species) (Lasram *et al.,* 2016). Field fungi can colonize the ripening grains on standing crop in the field prior to harvesting while storage fungi are more dominant in stored products although in a very low percentage they may be found in grains before harvesting. Field fungi are usually arrested after harvest because they require high relative humidity for growth, normally above 95% (aw>0.95) (Mannaa and Kim, 2017). Storage fungi are adapted to grow under low moisture condition (relative humidity range 70 and 90% (aw<0.95) (Lasram *et al.,* 2016). This classification is not strict as the field fungi can grow in stores and storage fungi grow in the field provided the environmental conditions permit. Presence of storage fungi before harvest constitutes an inoculum transferred in stores.

Therefore, to minimize the effects of mycotoxin contamination, prevention is the best option because complete removal of toxigenic fungi in food systems is difficult, nearly impossible. In this context, availability of strategies to reduce pre-harvest contamination of mycotoxins through good agricultural practices (GAP) and Good Storage Practices (GSP) as recommended by Codex Alimentarius and is probably the best option to reduce mycotoxins in food systems in Africa. These recommendations however, need to be tailored to the local conditions and practices. Unfortunately, in Tanzania, reports to customize the GSPs based on Codex recommendations for producing maize are lacking. Lack of GSPs is possibly the cause of the high levels of fumonisin contamination in Tanzanian maize. Therefore, the need to customize effective post-harvest strategies to reduce mycotoxins in Tanzania is already a necessity which is not adequately addressed.

## Materials and Methods

### Description of study area

The study was conducted in Northern Highland (NH) and Eastern Lowland (EL) agro ecological zones of Tanzania. The eastern lowland ( 6°S and 8°S, and 36°30’E and 38°E) is characterized of flat plateaus (0-900 m a.s.l) in the eastern part. The northern highland (4°S and 25°S and 84°E and 45°E) sits on (1000 and 1500 m a. s. l.) .

### Sampling and inventory of pre-storage and storage practices

A two stage sampling was conducted in Kilosa (eastern lowland) and hanang’ (Northern highland districts, Morogoro and Manyara regions respectively. The sampling involved 40 villages of each district and from each village, five households were randomly selected to make a total of 400 households. From each household, approximately 1kg of maize was collected at maize maturity before harvested and another 1kg maize collected from at least 6 months storage (Orsi *et al.,* 2000). Immediately the samples were sent to the laboratory, followed by air drying to maintain field status and frozen for 24 hours to kill insects before they were kept at 4°C until analysis. A questionnaire was used to establish used harvesting and storage practices of maize and common insect pests. Questionnaires were supplemented by direct observations at each household where types of storage structures, method of construction, and symptomatic occurrence of moist environment, mould growth, insect infestation, and rodents were recorded. Identification of storage insect pests was done by the researchers based on available literature during the survey and on respondents’ description and ability to recognize the indicated pests from amongst other species in pictorial aids (Lever, 1976).

### Mycological assays and multi-mycotoxins quantification

For the purpose of isolating fungi from maize grains, surface sterilization, inoculation of maize grains into potato dextrose agar medium and purification of culture was done according to Landschoot *et al.* (2011). Morphological criteria (Leslie *et al.,* 2006) was used to distinguish the different fungal genera contaminating the grain. The obtained fungal isolates were categorized as *Fusarium, Penicillium, Aspergillus* or others based on macroscopic (colour, reverse colour and mycelium) and microscopic (conidiophores shape) characteristics. Polymerase Chain Reaction (PCR) techniques according to Nicolaisen *et al.* (2009), Luo *et al.* (2009) and Cruz and Buttner (2008) were used to identify species belonging to genus *Fusarium*, *Aspergillus* and *Penicillium* respectively. Quantification of mycotoxin was done according to Degraeve *et al.* (2016).

Sample preparation and subsequent mycotoxins extraction followed a Quick, Easy, Cheap, Effective, Rugged and Safe (QuEChERS) approach developed by Anastassiades *et al.,* (2003) and later modified for cereals (Rasmussen *et al.,* 2010; Rubert *et al.,* 2013). Mycotoxin standards, as solid pure extracts, of aflatoxin B1 (AFB1), aflatoxin B2 (AFB2), aflatoxin G1 (AFG1), aflatoxin G2 (AFG2), ochratoxin A (OTA), deoxynivalenol (DON), fumonisin B1 (FB1), fumonisin B2 (FB2), T-2 toxin (T-2), HT-2 toxin (HT-2) and zearalenone (ZEN) were supplied by Sigma-Aldrich (St. Louis, MO, USA). To establish a standard curve, mycotoxin free grounded maize samples were spiked with the toxins at eight concentration levels: 5 ppb, 10 ppb, 25 ppb, 50 ppb, 75 ppb, 100 ppb, 150ppb and 200 ppb and later analyzed for multi-mycotoxins (Ortiz *et al.,* 2013). Quantification of multi-mycotoxins in maize samples was done according to Degraeve *et al.* (2016).

**Data analysis**

The questionnaire was coded posting the data in the SPSS 16 followed by calculating descriptive statistics; means and standard deviations. Non parametric tests were used to determined mean differences of the storage practices applied in the two agro ecosystem. Differences in occurrence of multi mycotoxins in the two agro ecosystems for the samples collected at harvest and those collected from 6 months storage were calculated.

**Results**

**Determination of physiological maturity**

It was established that farmers in both agro-ecosystems used drying leaves, stalk and bending cobs as plant indicator of maize physiological maturity. No differences (p=0.13) between the two ecosystems were observed except the use of grain hardness which more than 70% of farmers in the Eastern lowland used as an indicator of grain maturity (Fig. 1).

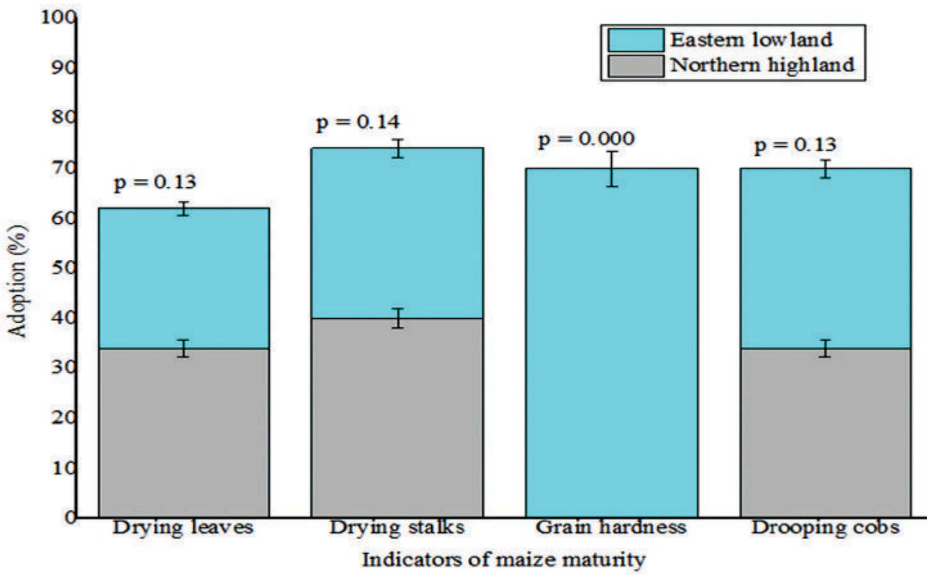


**Figure 1: Indicators of maize maturity as used by smallholder farmers in Northern highland and Eastern lowland**

**Timing of harvest after physiological maturity and the source of labor**

The Figure 2A indicates that between 35% and 50% of the farmers harvest maize 3 to 4 weeks after physiological maturity. Less than 10% harvested maize 12 weeks after physiological maturity. During harvesting, females were the main source of labor in eastern lowland, while 60% farming households in northern highland outsourced harvesting labor (Fig. 2B).

maize. While 40% farmers in Northern highland sorted and used damaged maize as animal feeds, 50%, 10% and 5% farmers in eastern lowland use the damaged maize as food, preparing local brew and sale respectively.

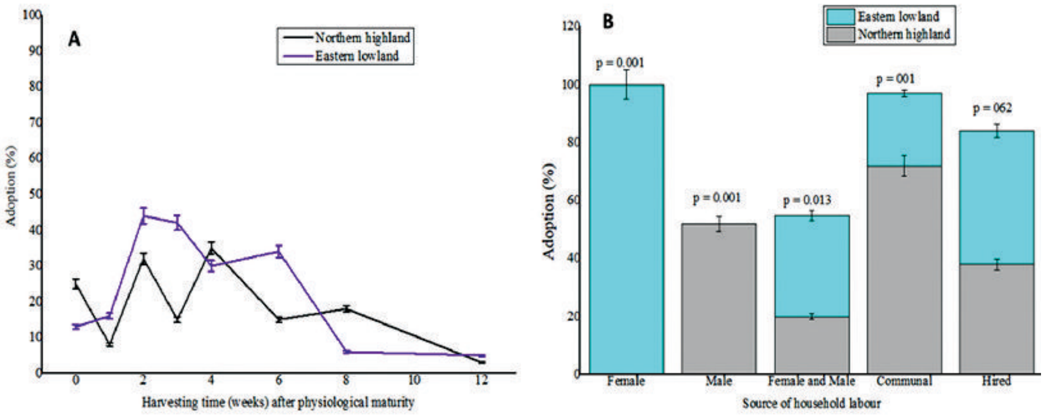


**Figure 2; Timing of harvest after physiological maturity in northern highland and eastern lowland**

## Sorting purpose before storage

Figure 3 presents results on sorting purposes. In these practices, significant differences (P≤0.05) between the two ecosystems were detected on the number of households involved. The results in Figure 4A, show that farmers in the two ecosystems sorted maize before storage. They differed in the utilization of damaged

## Drying and Shelling surfaces

Farmers in both ecosystems shelled maize mechanically by beating on elevated tunnels (Fig. 4A) and on floor (Fig. 4b). Handling of maize during beating varied significantly (P≤0.05) between agro ecological zones. The majority (80%) in Northern highland shelled maize by beating on a raised platform and

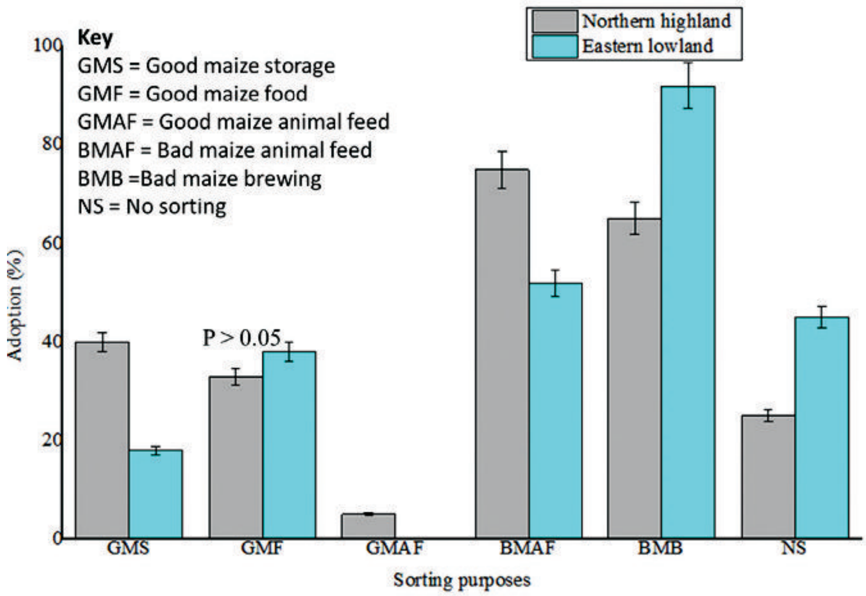


**Figure 3: Maize sorting purposes**

using motorized tractor operated engines. While 60% of the farmers in Eastern Lowland shelled maize by beating in poly bags, 65% of farmers in Northern highland shelled maize by beating on bare ground (Fig. 4B).

**Common pests**

In the two agro ecosystems the number of people who reported insect and bird pests as an important problem did not differ statistically ($p>0.05$). However half of the farmers in the eastern lowland ranked moulds as an important problem followed by rodents. The problem of insect and birds pests was equally ($p>0.05$) experienced by farmers in both agro ecosystems (Fig. 6).

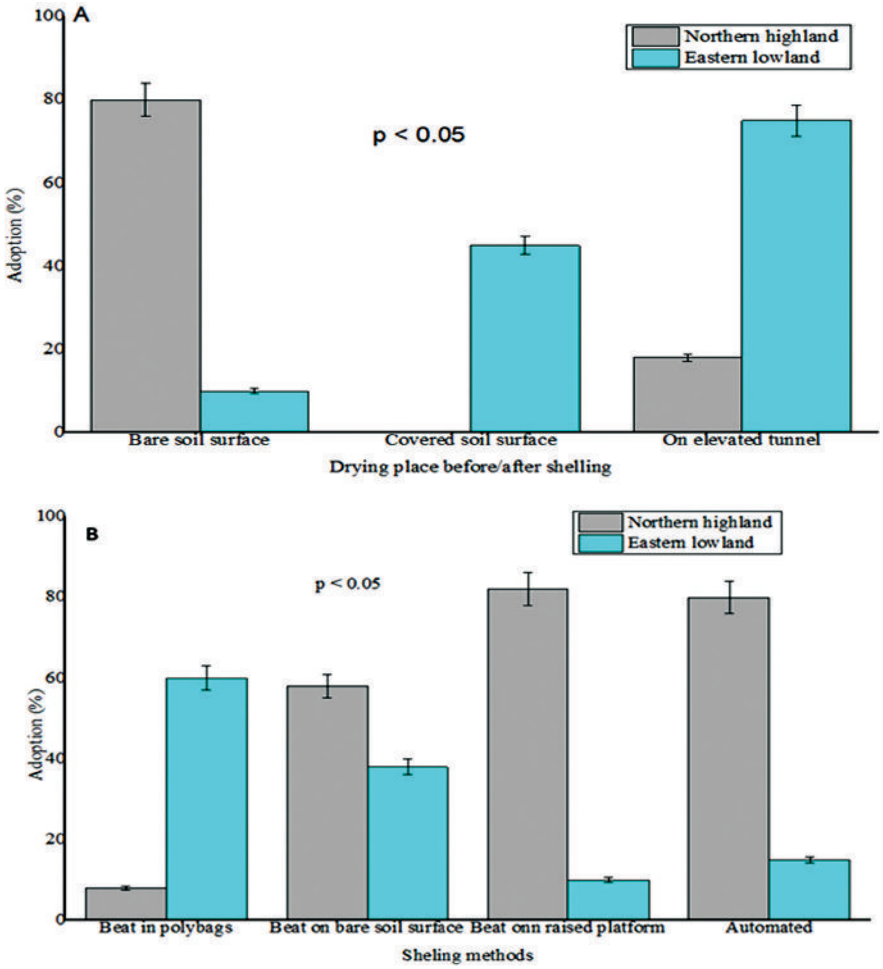


**Figure 4; Sorting, drying and shelling practices in Northern highland and Eastern Lowland Storage Facilities**

The differences between agro ecosystems on the practices involved in storage of maize were significant ($P\leq0.05$). In northern highlands close to 98%, 50%, 20% and 45% store maize in cribs, on floor, bags on floor and bags on raised platform respectively (Fig. 5). On the other hand, 5%, 40%, and 20% farmers in the eastern lowland store maize in Cribs (Fig. 5), and in bags placed on floor (Fig. 5) and raised platforms.

**Occurrence of insect pests**

Direct observation of this study revealed that eastern lowland had the greatest diversity of storage insect pests. These included; Confused flour beetle (*Tribolium confusum* Jacquelin

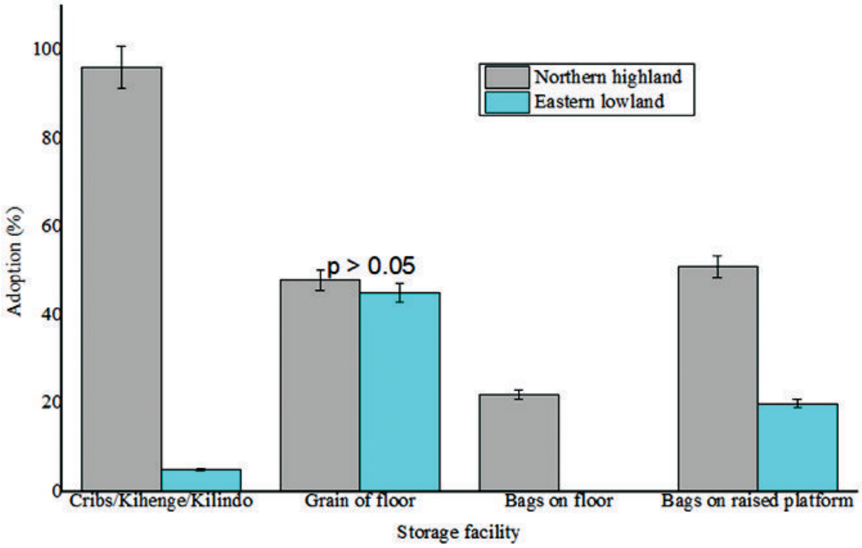


**Figure 5; Maize storage in bags placed of floor and cribs**

du Val) which occurred most frequently (100%), followed by 80% Larger grain borer (*Prostephanus truncutus* L), 78% Red flour beetle (*Tribolium castaneum* Herbst), 42% Laser grain weevil (*Sitophilus zeamais* L), 25% Areca nut weevil (*Araecerus fasciculatus* syn) and 14% Saw toothed grain beetle (*Oryzaephilus surinamensis* L.) (Fig. 7). The northern highland had the least diversity of identified storage insect pests, including 54% larger grain borer (*P. truncutus* L) followed by 22% Laser grain weevil (*S. zeamais* L).

**Occurrence of fungal species**

Of the 14 fungal species identified in this study, the occurrence of 9 fungal species varied significantly ($p<0.05$) between the two agro ecosystems. All the 14 species detected in this study only 12 were detected in each of the agro ecosystems. *Penicillium brevicompactum* and *F. culmorum* were not detected in samples from northern highland while *F. tricinctum* and *F. equiseti* were not detected in the eastern lowland zone. With exception of *F. graminearum*, all other species were more abundant in eastern lowland than northern highland (Fig. 8).

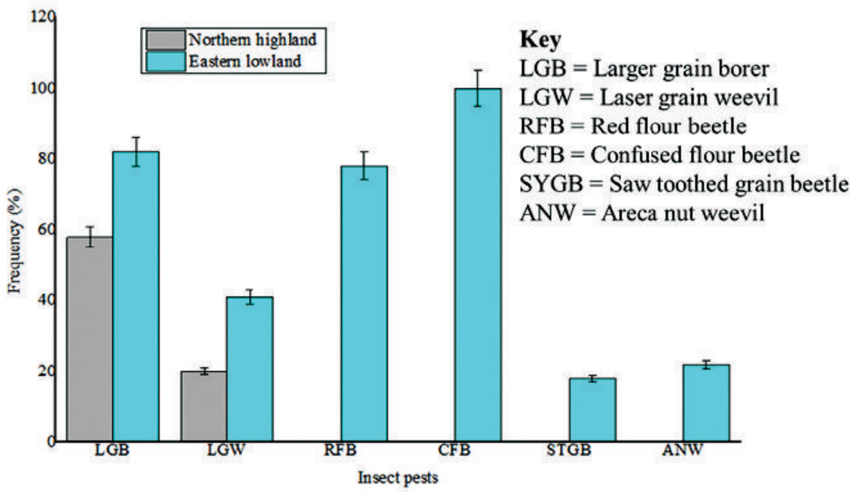


**Figure 6: Common pests in northern highland and eastern lowland agro ecosystems**

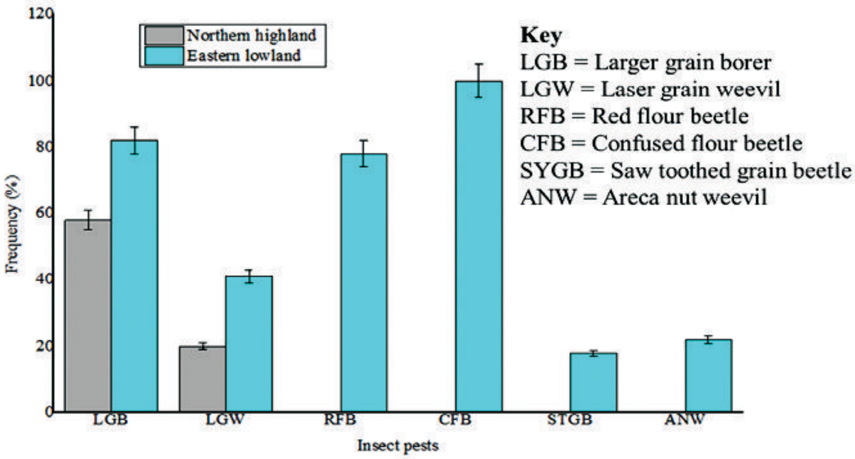


**Figure 7: Common insect pests of maize in northern highland and eastern lowland agro ecosystems**

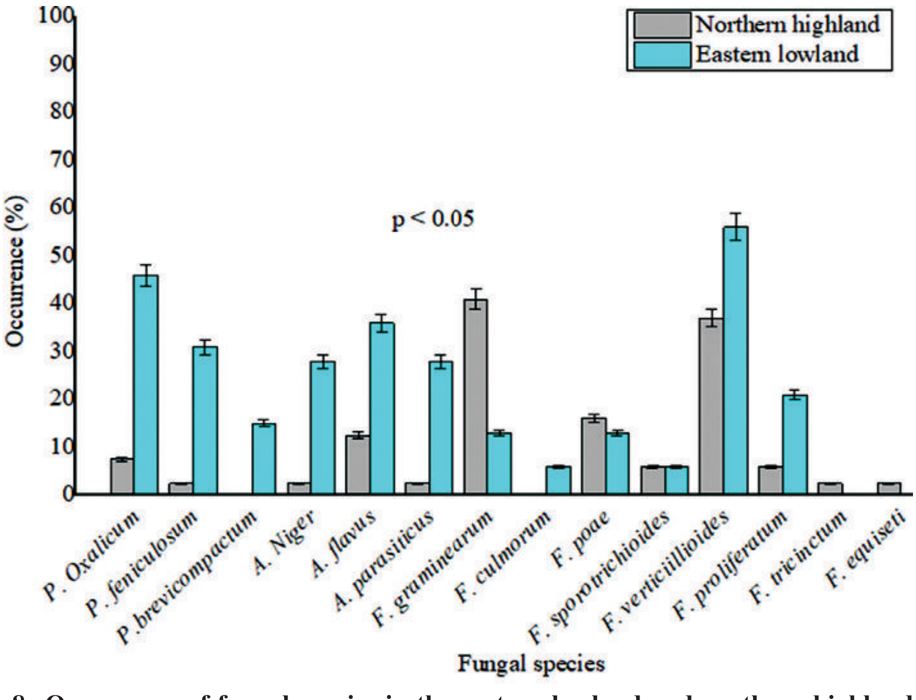


**Figure 8: Occurrence of fungal species in the eastern lowland and northern highland agro ecosystems of Tanzania**

**Occurrence of multi-mycotoxins at harvest and storage**

Six types of mycotoxins were detected in samples collected at harvest in both northern highland and eastern lowland (Table 1). Three more mycotoxins (HT-2, T-2, and OTA) were detected in maize of eastern lowland after 6 months of storage. At harvest, occurrence of FB1 in northern highland was 5 times higher than its occurrence in samples collected from 6 months of storage in the same location (Fig. 9). Similarly, DON was higher in both agro ecosystems than its occurrences in samples from 6 months storage. At harvest the occurrence of FB1 in Eastern lowland was lower by 45% than its occurrence in samples collected from 6 months of storage. Occurrence of FB2 in northern highland from samples collected at harvest was the same (42%) as its occurrence in samples from 6 months storage. However FB1

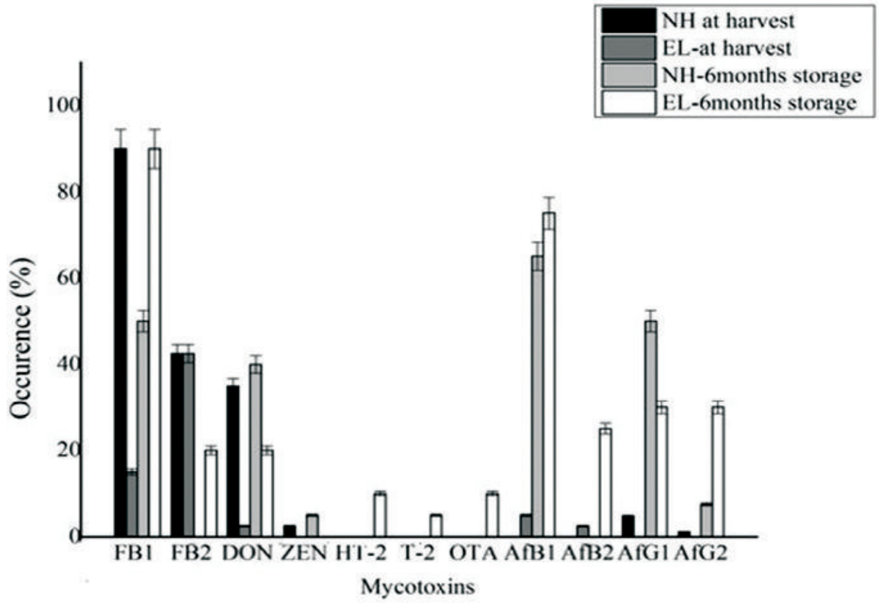


**Figure 9: Differences of occurrence of multi mycotoxins between samples at harvest and six months storage in Northern lowland and Eastern lowland; AFB1 = aflatoxin B1, AFB2 = aflatoxin B2, AFG1 = aflatoxin G1, AFG2 = aflatoxin G2, OTA = ochratoxin A, DON = deoxynivalenol, FB1 = fumonisin B1, FB2 = fumonisin B2, T-2 = T-2 toxin, HT-2 = HT-2 toxin and ZEN = zearalenone**

was not detected at harvest in eastern lowland although the detection was 20% after 6 months in the region. The storage samples had respectively 10%, 20% and 22% more AfB1, AfB2 and AfG2 than detection in samples collected at harvest in eastern lowland.

**Control of storage pests**

More than one third of the farmers in both ecosystems did not apply any measure to control storage pests. Significant differences (p≤0.001) between agro ecosystems were noted on practices applied to control storage pests. Close to 90% farmers in Eastern lowland applied ash to control storage pests while less than 10% farmers in Northern highland used this option. Fumigation (50% Northern Highland, 38% eastern lowland), removing remnants of previous crop in the store (22% Northern highland and 48% Eastern lowland), application of local herbs (35% in each location) and synthetic pesticides (40% Northern highland and 38% Eastern lowland) were the common practices (Fig. 10).

**Linking storage practices to mycotoxin contamination**

Linkage analysis established that there was a significantly positive correlations R=0.82, p=0.034 and R 0.47, p=0.043 among the number of households storing maize in synthetic polyethylene plastic bags and contamination of FB1 and FB2 respectively. Number of households which used the same storage method had significant negative correlation with DON R = -0.57, p=0.036. The correlation coefficients in Table 2 indicate that the number of households storing maize in cribs or (in Kiswahili *Vihenge*), had a significant negative correlation with FB2 (p=0.003), DON (p=0.002), AfB1 (p=0. 001), and AfG1 (p=0.003). The results point out that number of households which removed remains of previous crops in the store before introducing a new crop had a significant negative correlation with FB1 (p=0.012), FB2 (p=0.006), AfB2 (p=0.001) and AfG1 (p=035). Furthermore the number of households which were fumigating prior to storage had a significant negative correlation with FB2 (p=0.003), AfB1 (p=0.002), AfB2 (p=0.003), and AfG1 (P=0.004). The study has also established significant negatively

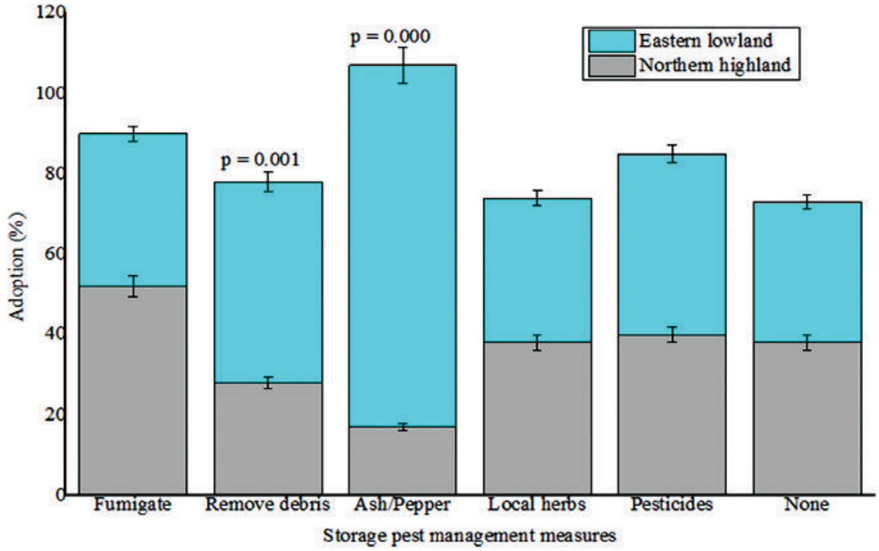


**Figure 10; Storage practices, storage pests, insect pests and pest control in Northern highland and Eastern lowland**

correlation between the number of households which sorted out maize before storage and FB1 (P=0.044), DON (p=0.005), OTA (p=0.049), AfB1 (p=003) and AfG2 (p=0.003). Significant negative correlations between number of farmers who controlled insect pests by applying ash or herbs like pepper and OTA (p=0.047), AfB1 (p=0. 045), AfB2 (p=0.038), AfG1 (p=0.036, and AfG2 (p=0.035) were noted. Contamination of AfB2, AfG1 and AfG2 were significantly negatively correlated ($p \leq 0.01$) with number of households which used synthetic pesticides to control storage insect pests. The link between number of farmers who used different storage structures, hygienic practices, approaches to control storage insect and contamination of ZEN, T2 and HT2 was insignificant or none existent (Table 2).

## Discussion

The current study established that majority of farmers delayed harvesting up to 12 weeks increasing the risk to pre harvest mycotoxin contamination of maize. The study linked the delay with farmers' practice of determining maize physiological maturity and time of harvesting using unreliable indicators such as leaf and stem senescence. According to Thomas (2013), for a healthy plant, drying leaves, stalk and drooping (bending) cobs is a sign of senescence as well as maturity but these indicators are not always reliable because they can occur as a result of abiotic and biotic stress factors (Degraeve *et al.* 2016; Madege *et al.* 2018). The grain hardness which was a maturity indicator used by the majority farmers in eastern lowland indicated that grains had dried enough for harvesting. However the rate at which the kernel dries is highly influenced by the variety used, agronomic practices as well as the prevailing weather condition (Parthasaranthi and Jeyakumar 2013). Therefore, reliance on this indicator can lead to early or delayed harvesting. Harvesting too early may result in immature seeds that have poor vigor and vulnerable to insect and fungal attacks that increase chances of mycotoxins contamination (Gu *et al.* 2017; Martinez-Feria *et al.* 2019).

In both agro ecosystems, after removing the crop from the field, they undergo sorting and drying before shelling. Farmers sorted out damaged or mouldy maize for various purposes including food, animal feed and brewing. Consumption of damaged or mouldy maize has been reported in Tanzania (Kimanya *et al.,* 2008) and Kenya (Lewis *et al.,* 2005) where it was associated with aflatoxicosis. Utilization of damaged or mouldy maize as animal feed is reported in Kenya (Bhat *et al.,* 1997) and is associated with food borne

**Table 1: Detected multi mycotoxins in maize samples collected at harvest and in storage after six months**

| Location | Range (µg/kg) | FB1 | FB2 | DON | HT-2 | T-2 | OTA | ZEN | AFB1 | AFB2 | AFG1 | AFG2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EL-H | Highest | 6590.18 | 4042.33 | 23582.51 | nd | nd | nd | 3663.32 | nd | nd | 2558.44 | 5.26 |
| | Lowest | 12.75 | 723.88 | 23582.51 | nd | nd | nd | 3663.32 | nd | nd | 20.28 | 5.26 |
| EL-6mS | Highest | 6946.97 | 270.47 | 585.81 | nd | 6.82 | 11.67 | 9.45 | 973.94 | 96.74 | 9.42 | 2.05 |
| | Lowest | 34.66 | 106.66 | 143.24 | nd | 5.56 | 11.67 | 9.02 | 7.38 | 0.69 | 0.58 | 0.59 |
| NH-H | Highest | 53540.52 | 42263.39 | 25651.42 | nd | nd | nd | 2031.55 | nd | nd | 5.21 | 1.79 |
| | Lowest | 544 | 18.55 | 156.49 | nd | nd | nd | 33.28 | nd | nd | 5.21 | 1.54 |
| NH-6mS | Highest | 197.04 | 197.04 | 770.19 | 16.91 | nd | nd | nd | 11.75 | nd | 1.12 | 1.18 |
| | Lowest | 11.41 | 11.41 | 32.85 | 16.91 | nd | nd | nd | 0.85 | nd | 0.56 | 0.61 |

*Key; EL-H= Eastern lowland sampling at harvest, EL-6mS = Eastern lowland sampling from 6months stored grain. NH-H = Northern Highland sampling at harvest, NH-6mS = Northern Highland sampling from 6months stored grain, nd = not detected.* ***AFB1 = aflatoxin B1, AFB2 = aflatoxin B2, AFG1 = aflatoxin G1, AFG2 = aflatoxin G2, OTA = ochratoxin A, DON = deoxynivalenol, FB1 = fumonisin B1, FB2 = fumonisin B2, T-2 = T-2 toxin, HT-2 = HT-2 toxin and ZEN = zearalenone***

**Table 2: Linkage analysis of mycotoxins to storage practices based on pearson correlation coefficients**

| PRACTICE | FB1 | FB2 | DON | HT-2 | T-2 | ZEN | OTA | AfB1 | AfB2 | AfG1 | AfG2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Polyethylene plastic bags | 0.82* | 0.47* | -0.57* | -0.30 | 0.09 | 0.09 | 0.59 | 0.40 | 0.39 | 0.33 | 0.37 |
| Cribs | -0.29 | -0.68** | 0.38* | 0.01 | -0.09 | -0.09 | -0.19 | -0.42** | -0.30 | -0.55** | -0.19 |
| Fumigating before storage | -0.32 | -0.54** | 0.12 | 0.04 | -0.02 | -0.02 | -0.27 | -0.43** | -0.44** | -0.38** | -0.30 |
| Removal of previous crop | -0.52** | -0.58** | -0.25 | -0.04 | 0.05 | 0.05 | 0.05 | 0.35 | -0.86** | -0.37* | 0.20 |
| Sorting before storage | -0.41* | 0.21 | -0.46** | -0.08 | 0.01 | 0.01 | -0.41* | -0.46** | 0.05 | 0.14 | -0.48** |
| Control pest by Ash /pepper | 0.43 | 0.09 | -0.29 | -0.03 | 0.03 | 0.03 | -0.39* | -0.48* | -0.57* | -0.51* | -0.59* |
| Use commercial pesticides | -0.36 | -0.09 | -0.31 | 0.07 | -0.03 | -0.03 | -0.03 | -0.04 | -0.97** | -0.75** | -0.38* |

*Key; **, * = Correlation is significant at 0.01 and 0.05 respectively.*

outbreak of mycotoxicosis. Saydenham *et al.* (1990) reported that consumption of mouldy maize either as direct food or via local brews is indicative of the magnitude of the problem of food insecurity in the rural places in many African countries. Previous studies have confirmed that sorting based on colour, visually by hand and based on weight by machine were more effective in reducing aflatoxins in peanuts than fluorescent sorting (Pelletier and Reizner, 1992). These results are further supported by findings regarding the use of near infrared transmittance kernel sorting technology which established negative correlation with fusarium kernel damage as well as fumonisins and deoxynivalenol (Kautzman *et al.,* 2015).

To allow maize dry after harvest, farmers in Northern highland heaped maize on a bare ground while farmers in eastern lowland dried maize on elevated tunnels. Drying maize before storage to reduce moisture content down to level not favorable for mould growth is common among smallholder farmers in East Africa (Lewis *et al.,* 2005; Kaaya *et al.,* 2006; Mwihia *et al.,* 2008). Previous reports show that, timely harvesting, sorting harvested maize-ears in the field, drying maize with and without husk on elevated bamboo tree platforms reduced postharvest fungal infection and risks of contamination of fumonisins (Ngoko *et al.,* 2003). These findings are also in agreement with the report that small holder maize in many tropical countries are subject to long pre harvest drying as well as long postharvest drying before they can be safely stored (Bodholt, 1985; Kaaya *et al.,* 2005). The majority of farmers shelled maize mechanically through beating maize in polybags, elevated tunnels and on covered and uncovered ground surfaces. Previous literature has established that mechanical shelling is known to cause kernel damage although the degree with which the grains are damaged would vary depending on the beating impact caused (Fandohan *et al.,* 2006). Hand shelling, although time consuming, can cause less damage than shelling using automobile power engines and beating (Chulze 2010). Vulnerability to damage in any shelling method may vary between maize varieties and degree of dryness (Nkakini *et al.,* 2007). Reports show that higher rate of grain damage due to mechanical shelling increases chances of mould growth particularly *Fusarium* and *Aspergillus* species (Diedhiou *et al.,* 2011; Fandohan *et al.,* 2006)

After shelling, the farmers adopted different storages methods such as polybags and traditional structures like vihenge, vilindo and cribs. These traditional storage techniques are common in many parts of Sub Saharan Africa especially on small holder farms (Udoh *et al.,* 2000; Armah and Asante, 2006; Nduku *et al.,* 2013;). Many traditional storage structures are perforated hence depending on environmental conditions, the storage practices could have been creating specific microbial ecosystems because they may avail different environmental conditions for growth as well as production of mycotoxins. Studies in Nigeria reported high aflatoxins in maize stores in polyethylene synthetic bags (Udoh *et al.,* 2000). This is probably because grains kept in synthetic polythylene bags provide suitable temperature for insects and mould growth as well as ad libitum food supply which allows insects to be reproduced haphazardly (Pantenius, 1988). To reduce risks of insect damage associated with storage of maize in bags, efficacy of multiple layer hermetic bags have been tested (Villers 2014; Maina *et al.* 2016; Mallikarjunan *et al.* 2016;). Research has established that storage of maize in ventilated facilities like bamboo granary have lower fumonisins content (Hell *et al.,* 2000; Fandohan *et al.,* 2005). This could be an explanation for the negative correlation of mycotoxins with numbers of cribs observed in the current study. Prior to storage few farmers fumigated as part of hygiene and it was ascribed to low mycotoxins contamination. These results are in agreement with scientific findings that use Ammonia fumigants inhibited growth of A. flavus in maize stores with subsequent significant reduction in AfB1 (Duncan *et al.,* 1994).

Before harvesting and after harvesting, the crop sufferes from various pest attacks including rodents, insects and moulds. The farmers knowledge on rodents as major field pests is in agreement with observation on rice farming systems in the same location that rice farmers had substantial knowledge on the presence and losses caused by rodents in their crop yield and general public health (Mulungu *et al.,* 2014). Similarly maize yield loss due to rodents, insect pests and mould has been reported previously (Mdangi *et al.* 2013; Liu *et al.* 2016; Danso *et al.* 2017). Attacks of these pests in stored maize have been associated with increased contamination of mycotoxins of maize (Degraeve *et al.* 2016; Madege *et al.* 2018; Madege *et al.* 2019). High infection of insects in stores of eastern lowland can be explained by the suitable growth factors created particularly relative humidity (60-80%) and temperature (25-30°C) which is typical characteristic of eastern lowland (Bakker-Arkema *et al.,* 1999). Increases of mycotoxins is related to insect attack because insects create wounds on maize kernels which become infection sites for fungi (Wu, 2006). Therefore, Storage practices that create optimal conditions for growth of mycotoxins producing fungi, predispose maize grains to biosynthesis of these toxins by *F. cerealis, F. poae, A. ochraceus, P. verrucosum, and P. nordicum* (Agriopoulou *et al.,* 2020).

The current study also established that the maize samples collected at harvest in the northern highland samples had the highest levels of Fumonisins and Deoxynivalenol which are commonly produced by *F. Verticillioides* and *F. graminearum*. During the same period the samples from the eastern lowland which were collected after six months storage had more than ten times higher contamination of aflatoxins than in maize samples collected at harvest. Aflatoxins are secondary metabolites of some *Aspergillus* species particularly of the section flavi; *A. flavus* and *A. parasiticus*. The observed differences in mycotoxins contamination between the two agro ecosystems can be associated with the ecological differences between the two zones that support different fungal growth and mycotoxins production potential. According to available literature, host susceptibility to fungal disease is directly influenced by ecological characteristics especially temperature and osmotic stress. These climatic variables determine infectivity, colonization, reproduction, survival, competitive ability, mycotoxicity and pathogenicity of both field and storage fungi (Drakulic and Ray 2017; Mannaa and Kim 2017). Temperature range of 15 to 30 and water activity ranging from 0.9 to 0.995 is optimum condition for production of Fumonisins in many cereals (Milani, 2013). The increase in aflatoxin levels from harvest, suggest that if conditions are permissive, aflatoxins can keep on increasing with storage duration in which case the public exposure is also acerbated. The increasing trend of aflatoxins along the maize value chain after harvest is reported in many countries in Africa (Kang'ethe, 2011; Asiki *et al.,* 2014; Nyangi, 2014; Akowuah *et al.,* 2015)

Strategies to reduce insect pest pressure using plant extracts, ash and pesticides were common on both northern highland and eastern lowland agro ecosystems. However, use of ash and herbs like *Tephrosia vogelii* L (or *utupa* in its Swahili acronym) leaves and fruits of Neem plant (*Azadracta indica* L) have been reported in some parts of Tanzania (Mihale *et al.,* 2009). However the efficacy of these herbs and many others are yet to be validated as reliable control strategies (Reddy and Muralidharan 2009). Application of ash in conjunction with cow dung and tobacco powder are also tested local alternatives of pest control (Mihale *et al.,* 2009).

## Conclusions and recommendations

It can therefore be conclusive that pre-storage and storage practices applied by subsistence farmers in the two ecosystems are linked to increasing mycotoxins contamination along maize value chain. The practices that are linked to to reduced risk of mycotoxins should be improved to reduce mycotoxin contamination in maize.

## Acknowledgement

The funding provided by VLiR-UOS to complete this study is highly appreciated.

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# Socio-economic Determinants of Smallholder Farmers Sisal Productivity and Profitability: A Case of Korogwe District, Tanzania

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**Abstract**

*Tanzania's sisal industry employs about 100 000 individuals with its current total production estimated at 40 000 tons per year. This follows efforts by theTanzania's Sisal Board (TSB) to promote smallholder farmers participation in the sisal industry. However, there is a lack of enough information on socio-economic determinants associated with smallholder farmers' sisal productivity and profitabilty. Therefore, the study was conducted to address the above. Specifically, the study aimed at identifying determinants of the smallholder farmers'sisal productivity and profitability in the study area. A cross-sectional research design was used in the research whereby data were collected from 150 randomly selected smallholder sisal producing households based on registers availed by estate managers in Ngombezi and Mwelya Wards. Primary data were collected through questionnaire with close and open ended questions. In addition, focus group discussions and key informant interviews were used to gather complementary data. Quantitative data from the questionnaires were analyzed using the IBM-SPSS software whereby descriptive (ie. ferequencies and percentages) and inferential statistics(through the use of simple linear regression) were determined. Qualitative data were analyzed using thematic content analysis whereby collected information were summarized based on themes and objectives of the study.Generally, study findings show that factors significantly associated with the smallholder sisal farmers' productivity were amount of land allocated to sisal production and amount of sisal harvested ($P \leq 0.001$) and amountof land owned by household ($P \leq 0.05$). On the other hand, factors associated with the sisal famers profitability included sex of the household head ($P \leq 0.1$), farm size ($P \leq 0.05$) and amount of sisal harvested ($P \leq 0.001$). Therefore, the study recommends that agricultural and investment banks should consider financing smallholder sisal farmers so as to enable them raise their incomes and capital needed for sisal production in order to increase sisalproductivity and profitability.*

***Keywords***: Sisal, socio-economic determinants, smallholder sisal farmers, productivity, profitability

## Introduction

Sisal (*Agave sisalana*) is a succulent perennial crop. It is a species of Agave originated from southern Mexico. It is a drought resistant plant that can grow well in the arid and semi-arid regions and rainfall amount suitable for its growth range from 1000 to 1250 mm. Sisal plant grows well in hot climate of temperatures between 10°C to 30°C. It can also tolerate temperatures of 40-50°C (Saxena *et al.,* 2011; Srinivasakumar *et al.,* 2013). Sisal was introduced in Tanzania by the German East Africa Company in 1893. The company was then largely focused with the development of the country thus, introduced sisal to the coastal areas as an alternative crop because the areas had hotter and drier conditions (FAO, 2013). In addition, the first sisal estates were located near the sea on tidal estuaries to support easy shipment of the sisal fibres and other products.

Generally, Tanzania used to be the world's leading sisal producer in the 1960s. Exportation of sisal contributed to more than a quarter of Tanzania's foreign income in the early 1960s however, by 1967 the production declined drastically. Currently, the production is a quarter of the 1960s production level (FAO, 2016). According to Kimaro *et al.* (1994) the decline of Tanzania's sisal industry was mainly caused by shrinking of the world market and the sisal price, nationalization of sisal estates, poor marketing arrangement and lastly, shortage of labour.

Currently, Brazil tops the list of countries producing sisal, followed by Tanzania then Kenya (Mwaniki, 2018). Over 281 000 tons of sisal was produced in the world, with Brazil producing 150 584 tons, followed by Tanzania which produced 34 875 tons in 2013. Other sisal producing countries include Madagascar, China, Guinea, Central Africa Republic, Ethiopia, Malawi, Mozambique, Angola, South Africa and Morocco (FAO, 2016). On the other hand, small-scale sisal production plays a crucial role in an overall contribution to the sisal industry globally. In Tanzania, the sisal industry employs over 100 000 people, with a total production of about 40 000 tons (TIC, 2016).

According to FAO (2013), small-scale sisal farmers in Tanzania are defined as farmers holding usually less or sometimes above 6 hectares of sisal land but, not more than 200 hectares. They are also referred to as emerging farmers and they are often characterized by lack of market experience, lack of access to resources and technology and limited use of agro-chemicals (Oxfam, 2013). In addition, small-scale sisal farmers in Tanzania's sisal value chain involve those in estates and smallholders growing sisal as a cash crop in non-estate areas (BOT, 2016).

Tanzania has for a long time been making efforts to improve production, productivity and commercialization of the crop sub-sectors (sisal included) under the Agricultural Sector Development Programme Phase Two (ASDP II). For example, financing agriculture and promoting good agricultural practices, improving extension services provided to smallholder farmers, training for updating skills and knowledge of farmers, improving agricultural mechanization and promoting contract farming (URT, 2016). Despite the above efforts (Kimaro *et al.,* 1994; Salum, 2012; BOT, 2016) sisal productivity among small-scale farmers is still low (FAO, 2013); according to TSB (2017) as cited by Senkoro and Mkorongwe (2018) production of sisal fibre per unit area in Tanzania is generally low i.e. 0.8 - 1.1 tones per ha for farmers and 2 - 2.5 tones per ha for estates.

Several studies have assessed the situation of sisal crop, for example Kimaro *et al.* (1994) examined sisal production and research in Tanzania; Salum (2012) who studied sisal production and henequen industry from the producers' perspective, and BOT (2016) an assessment of sisal contract farming schemes in Tanzania. Nonetheless, previous studies have not documented on the socio-economic determinants associated with small-scale sisal farmers' productivity hence, little is known on the same. Therefore, the study on which the paper is based aimed at determining socio-economic determinants of smallholder farmers' sisal productivity in Korogwe district, Tanzania.

Korogwe district constitutes the center of Tanzania's sisal industry. Sisal production in Korogwe district is mainly based on estates that are controlled and owned by the Tanzania Sisal Board (TSB). Currently, the board is in charge of five estates namely, Hale, Ngombezi, Mwelya, Magunga and Magoma. Nonetheless, the board still applies the Sisal Smallholders and Out-growers scheme (SISO) that gives small-scale farmers access to farms within these estates and also the market for their produce to both farmers working within the estates and out growers.

Generally, small-scale sisal farmers' productivity is determined by a number of socio-economic factors. According to Krugman (1994), productivity is the measure of efficiency in converting inputs into useful outputs. Sisal productivity is highly reliant on what the farm is used for and is highly determined by physical capital used for sisal production, human capital, training, experience and lastly, natural resources including land. But, for the case of this study, sisal productivity refers to sisal output in terms of the land input (i.e. tons/ha).

**Theoretical Framework**

The study is guided by the theory of production. The theory argues that the business firm decides how much of each commodity that it sells particularly its outputs and products it will produce, and how much of each kind of labour, raw materials and fixed capital goods that it will use (Kurz and Salvadori, 1995). The theory of production was relevant to this study because it emphasizes on creation of goods or services that are suitable for use or exchange in a market economy using suitable economic resources or factors of production. Thus, high productivity can be achieved through the availability of suitable factors of production. The link between the theory and the study is based on the key point that the availability and use of suitable economic resources can facilitate high sisal productivity among small-scale sisal farmers. The study assumed that sufficient availability and use of suitable factors of production mainly land; labour and capital by small-scale sisal farmers could lead to higher sisal yields thus, enabling households to generate more profits from sisal production. However, this is only possible with the support and readiness of policies, rules, regulations and social, political and economic spheres.

**Conceptual Framework**

The study's conceptual framework (Fig. 1) shows the interaction of the independent and dependent variables. The independent variables include the households' background variables (i.e. household head's age, sex, marital status, main occupation and education) and intermediate variables (i.e. policies and marketing conditions) which influence the dependent variable (small-scale farmers' sisal productivity). Generally, productivity is as an outcome of access to a number of crucial services required for production such as access to credit, extension services, land, inputs and transport facilities. On the other hand, the agricultural, marketing and investment policies can greatly influence smallholders' sisal productivity.

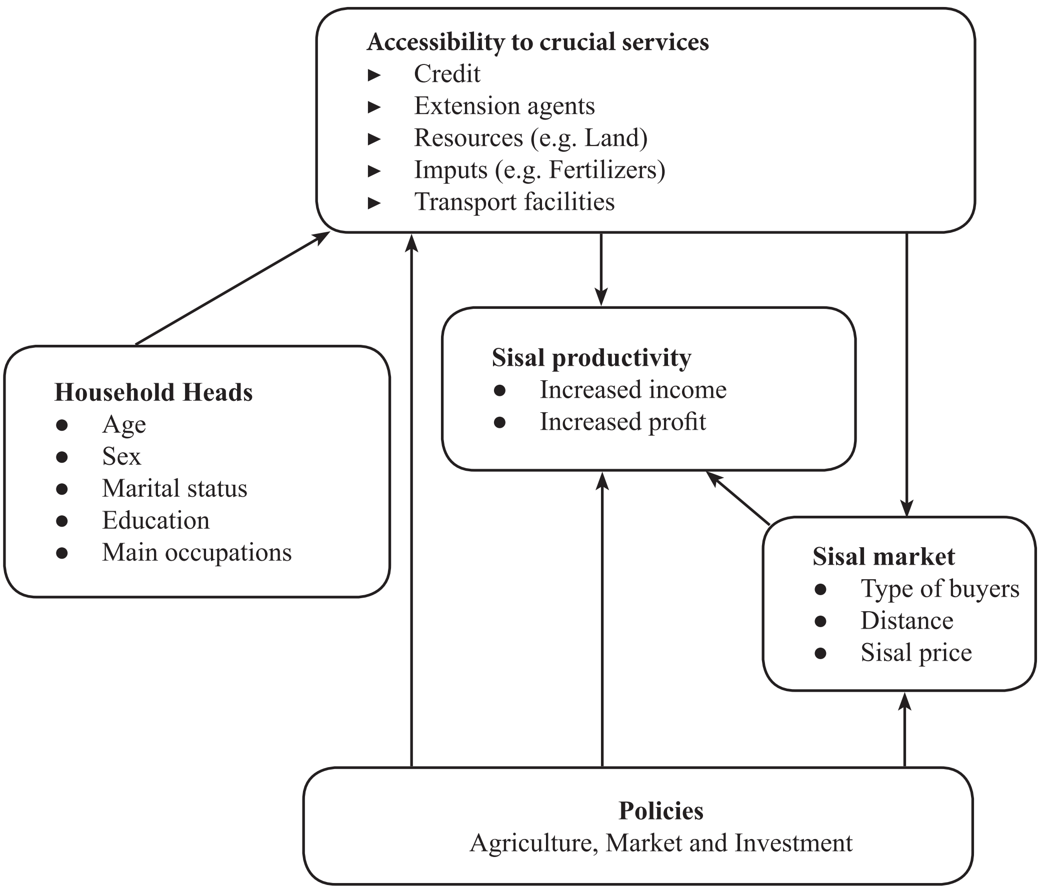


**Figure 1: Conceptual Framework (CF) for the socio-economic determinants of small-scale sisal farmers' productivity**

## Methodology

The study was conducted in Korogwe district, Tanga region, specifically in Ngombezi and Mwelya wards. Korogwe district was selected due to having many small-scale sisal producers relative to other areas. In addition, the district constitutes the center of Tanzania's sisal industry. According to TSB (2018) the district had 1207 small-scale sisal farmers in 2018 compared to Muheza district which had 49 small-scale farmers. The district lies between latitudes 4°15' and 5°15' South of the Equator and between longitudes 38°0' and 38°45' East of the Greenwich Meridian. Korogwe district borders Lushoto to the North, Muheza district to the East, Handeni district to the South and Lushoto as well as Kilimanjaro region to the West. The district's total area is 3 756 square kilometers (URT, 2013).

The variations in topography and climate in Korogwe District provide different cropping possibilities which can be divided into three major agro-ecological zones namely mountainous, low wetlands and semi-arid zone. An irrigational zone can also be identified along the major rivers (Agroberichtenbuitenland, 2018). Sisal is mainly cultivated in the semi-arid zone. Agriculture is the mainstay of the district's residents, employing 90% of the households. The crops grown are millet, cassava, beans, paddy, sisal, cotton, sunflower, and cashew nuts while domestic animals kept include goats, sheep, cattle, pigs and chickens.

The study adopted a cross-sectional research design whereby data were collected once (Setia, 2016).The approach allows one to collect data and determination of association between variables. In addition, it is cost effective and less time consuming while ensuring the appropriate quality of data (Kesmodel, 2018). Furthermore, the study adopted the mixed methods approach whereby both quantitative and qualitative data were collected to enable triangulation of findings. Primary data were collected using a structured questionnaire with open and close-ended questions from the 150 selected households. The questionnaire was used to collect data on households' demographic and socio-economic data. In addition, the questionnaire gathereed information on the households sisal production and marketing. On the other hand, qualitative data was collected through FGDs and key informant interviews: a total of 6 FGDs were conducted three in each ward and these involved a total of 67 participants; participants for the FGDs ranged between 7 – 9 and the sessions lasted for one to two hours. The FGD participants weresmallholder sisal farmers from the two wards covered by the study and were purposively selected based on the number of years they have been engaged in sisal production. Two key informant interviews were conducted with the managers of Mwelya and Ngombezi Sisal Estates. The key informants were purposively selected based on their experience in sisal production. Information collected from the FGDs and key informant interviews was mainly on general sisal production, existing oportunities and challenges faced by small-scale sisal producers.

The study's sample size was determined using the formula by Yamane's (1967) formula, which is $S=N\div[1+N(e)^2]$, where; S=sample size, N=population size and e=error term. Given N=1207, e=0.05 then S=1207/ [1+ 1207× 0.052] = 300.435. Therefore, the sample size for the study ought to have been 300 respondents. But the determination of sample size (S) in this study took into consideration all other important factors including time available for the accomplishment of the study, length of questionnaires, types of questions, analysis to be employed, availability of field helpers, manageability of data and funding available to accomplish the task (Chandler, 2017). Due to these factors, a sample size of 150 respondents was proportionally and randomly selected from the two wards.

Quantitative data collected through the questionnaire were coded and entered into the IBM SPSS software (version 20) for data cleaning and analysis. Linear regression was used to determine determinants for smallholder farmers' sisal productivity and profitability. The model is effective in determining impacts of independent variables on a ratio level measured dependent variable which for this study are sisal productivity and profitability. Qualitative data were analyzed using content analysis whereby emerging themes from the FGDs and key informant interviews were summarized based on themes and objectives of the study. Some of the emerged themes include smallholder sisal farmers' perception on the level of sisal production and the market situation of sisal within the district. Differences or association between variables were considered statistically significant if the p-value was ≤ 0.001, ≤ 0.05 and ≤ 0.1. The statistical model and the variables that were used are presented below.

The linear regression model for determining productivity of sisal smallholders was specified as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots b_nX_n + \varepsilon_i \text{ .......(1)}$$

Y = The expected or predicted sisal productivity (tons/ha)

$b_0$ = the value of Y when all of the independent variables ($X_1$ through $X_n$) are equal to zero.

$b_1$-$b_n$ = estimated regression coefficients

$X_1$-$X_n$ = predictor variables entered in the linear regression model.

$X_1$ = Years of experience in sisal production,

$X_2$ = Education of the household head (Primary and above 1, 0 otherwise)

$X_3$ = size of land cultivated with sisal in hectares, $X_4$ = Amount of labour used (total number of people used in production by a household), $X_5$ = Crops produced as first choices (Sisal 1, 0 otherwise),

$X_6$ = Household main source of income (Agriculture 1, 0 otherwise),

$X_7$ = Sex of the household head (Female 1, 0 Male),

$X_8$ = Type of inputs used (Advanced inputs 1, 0 otherwise),

$X_9$ = Number of support given

Likewise, the linear regression model for determining profitability of sisal smallholders was specified as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots .b_nX_n + \varepsilon_i \text{ ......(2)}$$

Y = The expected or predicted profitability

$b_0$ = the value of Y when all of the independent variables ($X_1$ through $X_n$) are equal to zero.

$b_1$-$b_n$ = estimated regression coefficients

$X_1$-$X_n$ = predictor variables entered in the linear regression model.

$X_1$ = Household head's age measured in years,

$X_2$ = Household head's sex (Female 1, 0 male),

$X_3$ = Amount sisal harvested (tons),

$X_4$ = Years of experience in sisal production,

**Table 1: Expected impact of each predictor variable on sisal productivity.**

| Predictor variable | The expected impact |
|---|---|
| Years of producing sisal | Number of years a farmer has been engaging in sisal production would positively influence sisal productivity. |
| Household's head education | The level of household's head education would have a positive impact on the level of sisal productivity. |
| Land allocated to sisal | Number of hectares allocated to sisal production would positively affect sisal productivity. |
| Amount of labour used | Amount of labour used by a household in production would affect sisal productivity positively. |
| Producing sisal as a first choice crop | Producing sisal as a first crop would positively affect sisal productivity. |
| Household's main source of income | Household's main source of income would positively affect sisal productivity. |
| Household head's sex | Male household heads were expected to report a higher sisal productivity. |
| Type of equipment used | Use of advanced equipment was expected to positively affect sisal productivity. |
| Support provided | Type and frequencty of support provided to smallholder sisal producers was expected to affect sisal productivity. |

$X_5$ = Household head's marital status (Married 1, 0 otherwise),

$X_6$ = size of land cultivated with sisal in hectares,

$X_7$ = Household head's main occupation (Agriculture 1, 0 otherwise),

$X_8$ = Type of sisal products sold (Processed fibres 1, 0 otherwise),

$X_9$ = Household head's education level (Primary and above 1, 0 otherwise)

Table 2 below presents the assumed relationship of the independent variables and profitability of smallholder farmers' sisal production.

husbands who could not be available during the interviews. Moreover, the study used random sampling which ensures an equal chance for all the individuals in the study population to be included in the sample. Therefore, the study randomly picked the sample from the ward estate registers. In addition, women mostly cultivate crops which involve light manual work while sisal requires great labour intensity as it involves a lot of activities which are very intense. The study finding conform to findings by Kavita (2018) who argue that women mostly cultivate crops which involve light manual work unlike men who can cultivate all crops even those involving intensive tasks requiring the use of machines such as sisal.

**Table 2: Expected impact of eachpredictor variable on sisal profitability**

| Predictor variable | The expected impact |
|---|---|
| Household head's sex | The sex of the household head specifically male sex would positively affect sisal profitability. |
| Household head's occupation | Occupation of the household head would positively affect sisal profitability. |
| Household head's marital status | Households whose heads were married were expected to report a higher sisal profitability. |
| Years of producing sisal | Farmers' years of engagement in sisal production was expected to be positively associated with sisal profitability. |
| Amount of labour used | Amount of labour used by a household in production was expected to positively or negatively be associated with sisal profitability positively. |
| Land allocated to sisal | Number of hectares allocated to sisal production was expected to be positively associated with sisal profitability. |
| Household's main source of income | Sisal production as a households main source of income was expected to be positively affect sisal profitability. |
| Sisal products sold | It was expected value addition of harvested sisal would be positively associated with sisal profitability. |
| Tons of sisal harvested | Tons of sisal harvested was expected to be positively associated with sisal profitability. |

## Findings and Discussion

### Respondents socio-demographic characteristics

The households' major socio-economic characteristics are as shown in Table 3. More than a half (60%) of the household heads were males. The lower number of female headed households (FHHs) was probably caused by the fact that fewer women are generally involved in sisal cultivation. Moreover, even some of the female respondents were only representing their

The age of the household heads ranged from 26 to 85 years. Nevertheless, the majority (55.3%) were in the age range of 36-60 years (Middle aged household heads) followed by those above 60 years of age (42.7%). The findings (Table 3) generally suggest that middle aged and older household heads were actively involved in cultivation of sisal. However, the findings also suggest that youth household heads

**Table 3: Demographic and socio-economic characteristics of household heads (n=150)**

| Characteristic | | Frequency | Percent |
|---|---|---|---|
| Age | 20-35 | 3 | 2.0 |
| | 36-60 | 83 | 55.3 |
| | 61 and above | 64 | 42.7 |
| Sex | Female | 60 | 40.0 |
| | Male | 90 | 60.0 |
| Education level | Primary | 98 | 65.3 |
| | Secondary | 35 | 23.3 |
| | University | 17 | 11.3 |
| Occupation | Agriculture | 144 | 96.0 |
| | Employed | 5 | 3.3 |
| | Business | 1 | .7 |
| Marital status | Single | 6 | 4.0 |
| | Married | 134 | 89.3 |
| | Divorced | 10 | 6.7 |

were less involved in cultivation. This is because many youth lack patience when it comes to sisal production; unlike other crops, sisal requires much time for its cultivation and its production costs are high. One of the interviewed farmers reported that:

*"Many youths prefer to engage in production activities that pay them shortly and with less production costs too. But, sisal cultivation takes time as it requires a number of years for it to be ready for harvesting while incurring various costs of production during all these years of waiting. So, this hinders many youth to get involved in sisal production"*

A high proportion (65.3%) of household heads had primary school education level (Table 3). This suggests that the level of literacy in the study area was high and this could easily help farmers to adapt various farming programmes intended to raise their level of productivity and also understand instructions on inputs such as chemical fertilizers and pesticides (Lugamara, 2017).

Findings from the study (Table 3) further show that, almost all the surveyed household heads depend on agricultural production as their main occupation. The above is supported by Korogwe district socio-economic profile which shows that, agriculture employs over 90% of district residents (URT, 2016).

**Level of Sisal Production in Korogwe District**

Sisal as a crop was very important to many sisal cultivating households in Korogwe district and this was clearly identified during the household survey and focus group discussions whereby 99.3% of household heads ranked it as the most important crop to the household (Table 4). Both the FGDs and the interviewed farmers pointed out it was a great source of households' income. Most of the household heads who ranked sisal as the number one crop based their arguments on its importance both as their main source of income earnings, its minimum maintenance requirements, ability to withstand many agro-ecological conditions and lastly, its ability to produce continuous fibres for many years. The above is emphasized by the quote below:

*'...sisal has fewer complications when compared to some other crops because it sustains many climatic conditions unlike other crops and its production and maintenance activities become less as years pass by and this gives farmers ample time to focus on other household's income earning activities"* (Mwelya Estate Manager, Mwelya ward, Korogwe, 21st February, 2020).

The greater importance of sisal crop to the farmers was based on the quantitative estimates of sisal output and the area cultivated with sisal.

Table 4 shows that an average of 0.64 tons/ha (i.e. sisal yield) was reported for households in Mwelya ward which was relatively higher than the average reported for Ngombezi ward. The findings further show that average farm size allocated to sisal by all households was 8.6 ha. However, households in Ngombezi ward allocated relatively more land to sisal i.e. 9.97 ha. The observation that yields are highest in Mwelya, where average farm size is slightly smaller than Ngombezi suggests that larger farms are not as productive as smaller farms. However, other factors might be involved on the sisal yield differences noted. The study's observation conforms to Wickramaarachchi and Jeevika (2018) who found that smaller farms were more productive as their operators apply more inputs, particularly labour hence, resulting into higher output.

**Table 4: Respondents households sisal cultivation characteristics (n = 150)**

| Characteristic | | Frequency | Percent | Overall (n=150) |
|---|---|---|---|---|
| Sisal's rank among crops cultivated by household | Fist | 149 | 99.3 | - |
| | Second | 1 | 0.7 | - |
| Households' sisal production-2018/2019 | Ngombezi | | | |
| (nN = 75) | Mwelya | | | |
| (nM = 75) | - | | | |
| Sisal farm as a single unit | Yes | 5 (6.7) | 23 (30.7) | 28 (18.7) |
| | No | 70 (93.3) | 52 (69.3) | 122 (81.3) |
| Average households' sisal production (tons) | 5.54 | 4.55 | 5.04 | |
| Average households' sisal yield (tons/ha) | 0.61 | 0.64 | 0.625 | |
| Average farm size under sisal production (ha) | 9.77 | 7.42 | 8.6 | |

*NB: nN and nM refers to number of households from Ngombezi and Mwelya respectively*

**Costs of Sisal Production**

The costs incurred by small-scale sisal farmers during sisal production were divided into two phases. The first phase involved the costs that farmers incurred during the early stages of production and which were paid directly by the farmers themselves. These costs included farm preparation, seed preparation, planting and weeding costs. The second phase involved harvesting, transportation and lastly, processing and decortications costs. Unlike the former, the latter were at first paid by the buyer and then farmers would be obliged to wait until fibres have been processed and purchased by a buyer, then and only then the second phase's costs would be cut directly from the farmers' money during payments by cooperatives. One smallholder farmer said:

*'Unlike other cash crops where buyers support farmers from farm preparation to harvesting, in sisal a farmer incurs all necessary costs all by himself. However, during harvesting season a buyer provides harvesting and transport services whose costs are later borne by a farmer but, in this way a buyer earns control over the sisal fibre quality"*

**Market Situation of Sisal in Korogwe District**

Table 5 shows that all farmers (100%) sold their sisal produce to a tenderer who happens to win a particular sisal selling season's tender. The tendering process is overseen by cooperatives unions under guidance of the Tanzania Sisal Board (TSB). The observation that all farmers relied upon one buyer per selling season suggests that there is a limited market for sisal produce and that prices offered could be low due to lack of competition. The observation conforms to BOT (2016) who reported that presence of few buying companies impairs competition, leading to low prices. Table 5 also shows that type of sisal product sold mostly by small-scale farmers of sisal was processed sisal fibres (97.3%). This also suggests that there is a limit in range of type of products sold by small-scale sisal farmers hence, lower profitability to small-scale farmers. The quote below emphasizes the above:

*"There is a good number of sisal products that farmers could offer to the market and some of them are handy made including ropes, in this way farmers could increase their profitability rate. However, since many farmers are obsessed with selling of sisal fibres only therefore, sisal production remains less profitable to them'* (Mwelya Estate Manager, Mwelya ward, Korogwe, 21st February, 2020).

**Table 5: Sisal marketing by surveyed households (n=150)**

| Sisal marketing | | Frequency | Percent |
|---|---|---|---|
| Buyer | Winning tenderer | 150 | 100 |
| | Others | 0 | 0 |
| Type of product sold | Raw leaves | 4 | 2.7 |
| | Processed sisal fibres | 146 | 97.3 |

**Factors Determining Sisal Productivity of Small-scale Sisal Farmers**

Linear regression analysis results (Table 6) show that there was a significant (P≤0.001) association between sisal productivity and amount of land (ha) allocated to sisal. This implies that amount of land allocated to sisal production plays a bigger part in influencing and determining its productivity. According to literarature (e.g. Savastano and Scandizzo, 2017) there is usually an inverse relationship (IR) between farm size and productivity whereby there appears to be a smooth tendency of land productivity to decline with farm size. The quote below emphasizes the above:

*"...Amount of land determines productivity however, in traditional agriculture, smaller farms have been associated with greater productivity because it is often perceived that less land allows farmers to use more inputs such as fertilizer, use the land more intensely and adopt more technology unlike in larger farms. Also, farmers with smaller farms usually employ family members, only hiring the more expensive low-hourly workers when family labour potential is exhausted unlike farmers with larger farms who have to employ expensive non-family labour"* (Ngombezi Estate Manager, Ngombezi ward, Korogwe, 20th February, 2020).

Table 6 further shows there was a slightly significant (P≤0.1) association between sisal productivity and it being produced as a first choice crop. This means that the expectation that sisal is a great source of household income than other crops gives it an advantage of being highly prioritized by households. Therefore, much attention and higher priority including the use of more inputs and better technologies will be directed towards it thus, eventually leading to higher output. The results above conform to those of Mwaniki (2018) that, cultivating sisal as a source of income is a major factor encouraging uptake of the crop's cultivation in the rural households.

Further to the above, Table 6 shows existence of a significant association between sisal productivity (P≤0.05) and households' source of income. This means that a household's source of income can influence a household's sisal productivity whereby households with sufficient income sources are more likely to obtain higher productivity because they can afford to adopt better technologies and purchasing the same on time. The finding conforms to that of Ruiz (2014) who reported that improved access to finance can increase farmers' investment choices and provide them with more effective tools hence, improved productivity. The study is also in line with the theory of production by Kurz and Salvadori (1995) which states that suitable economic resources or factors of production, capital included, determine profitability.

**Table 6: Factors determining sisal productivity of small-scale sisal farmers**

| Independent Variable | Unstandardized Coefficients | | Standardized Coefficients | T | Sig. | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | | | Tolerance | VIF |
| (Constant) | 0.880 | 0.105 | | 8.386 | 0.000*** | | |
| Year of producing sisal | -0.003 | 0.004 | -0.063 | -0.803 | 0.423 | 0.932 | 1.073 |
| Household head education | 0.048 | 0.058 | 0.068 | 0.840 | 0.403 | 0.869 | 1.150 |
| Land allocated to sisal (ha) | -0.012 | 0.003 | -0.384 | -3.721 | 0.000*** | 0.533 | 1.875 |
| Amount of labour used | -0.046 | 0.103 | -0.045 | -0.444 | 0.658 | 0.548 | 1.823 |
| Sisal produced as first choice | -0.076 | 0.040 | -0.152 | -1.883 | 0.062* | 0.871 | 1.148 |
| Household's main source of income | -0.057 | 0.029 | -0.154 | 1.985 | 0.049** | 0.949 | 1.053 |
| Household head's sex | -0.003 | 0.037 | -0.007 | 0.088 | 0.930 | 0.898 | 1.113 |
| Type of equipment used | 0.008 | 0.024 | 0.031 | 0.354 | 0.724 | 0.755 | 1.325 |
| Number of support given | 0.008 | 0.022 | 0.029 | 0.376 | 0.708 | 0.934 | 1.070 |

*NB: ***, **,* are significance levels at 1%, 5%, and 10% respectively.*

## Factors Influencing Small-scale Sisal Farmers Profitability

Linear regression results (Table 7) show a significant association between a household's head's sex and profitability. This implies that male headed households cultivating sisal are more profitable unlike female headed households. The observation suggests that the intensive nature of sisal cultivation forces women to use more of hired labour to help them perform the intensive cultivation tasks that cannot be performed by them. Thus, incurring more production costs unlike men who can perform all the intensive activities by themselves hence, saving the money they could have been paid to hired labourers. The study's observation conforms to what has been reported in literature with regards to a household's sex and its productivity in general. For example, Kapoor (2019) argues that male-headed households have greater assets endowments which also lead to better livelihood outcomes. In addition,

**Table 7: Linear regression results on Factors determining profitability of small-scale sisal farmers**

| Independent Variable | Unstandardized Coefficients | | Standardized Coefficients | T | Sig. | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | | | Tolerance | VIF |
| (Constant) | 14.649 | 0.781 | | 18.753 | 0.000*** | | |
| Sex of the household head | -0.204 | 0.107 | -0.118 | -1.911 | 0.058* | 0.791 | 1.264 |
| Occupation | 0.157 | 0.202 | 0.045 | 0.779 | 0.437 | 0.909 | 1.100 |
| Household head's marital status | 0.186 | 0.149 | 0.072 | 1.250 | 0.213 | 0.915 | 1.093 |
| Year of producing sisal | -0.011 | 0.011 | -0.059 | -1.045 | 0.298 | 0.953 | 1.049 |
| Amount of labour used | 0.021 | 0.015 | 0.112 | 1.418 | 0.159 | 0.489 | 2.043 |
| Land allocated to sisal (ha) | -0.030 | 0.012 | -0.246 | -2.427 | 0.016** | 0.295 | 3.388 |
| Household's main source of income | 0.194 | 0.124 | 0.090 | 1.570 | 0.119 | 0.915 | 1.093 |
| Sisal products sold | -0.347 | 0.311 | -0.066 | -1.115 | 0.267 | 0.853 | 1.173 |
| Tone of sisal harvested | 2.591 | 0.281 | 0.916 | 9.220 | 0.000*** | 0.307 | 3.256 |

***NB:** ***, **,* are significance levels at 1%, 5%, and 10% respectively.*

Gebre *et al.* (2021) based on a study conducted in Ethiopia have reported that male-headed household's maize productivity to be 44.3 % higher than that of the female counterparts due to the latter's lack of resources.

Table 7 further shows a significant (P≤0.05) negative association between amount of land allocated to sisal production and its profitability. This means that the more land a household allocates to sisal production the less profit it gets. Therefore, suggesting that small farms are more profitable compared to bigger farms. The observation is in line with that of Yu *et al.* (2015) who found that subsidizing farmers to rent land without helping them to become better-equipped could result in resource misallocation towards larger farms using less-efficient labour technologies.

Findings in Table 7 further show there was a significant association (P≤0.05) between amount of sisal harvested and profitability. This implies that the more sisal produced by the small-scale sisal farmers the higher the profit and vice versa. Also, based on economies of scale, small-scale farmers with more produce are more profitable as their production costs become lowered through spread of costs over a large number of their harvests. This observation conforms to what has been reported by Kenton (2020) that individuals and companies can achieve economies of scale by increasing production and lowering costs because this enables costs to be spread over a large number of goods.

## Conclusions and Recommendations

The paper has assessed the socio-economic determinants for smallholder farmers' sisal productivity and profitability of the same. Based on the findings it can be concluded that a household's choice to produce sisal as its first/major crop is associated with the crop's higher productivity. It is also concluded that a household's main source of income determines its sisal productivity. On the other hand, the study assessed the factors that determine household's sisal profitability. It is hereby concluded that a household head's sex determines small-scale sisal profitability with households headed by men profiting more than those headed by women. Moreover, the intensive nature of sisal cultivation forces women to use more hired labour unlike men who can perform most if not all the tasks by themselves. It is further concluded that farm size is highly associated with sisal profitability. Lastly, it is concluded that amount of sisal harvested (tones) determines sisal profitability of the sisal cultivating households with those producing more getting higher profits due to exploittation of economies of scale.

Based on the study findings and conclusions it is recommended that smallholder sisal farmers should prioritize more on cultivating sisal than other crops as this will help them directthe use of inputs and better technologies more on sisal hence, enabling them to raise their productivity and eventually lead to higher profit.Tanzania's Agricultural Bank and other formal financial institutions should work with farmer groups (i.e. Savings and Credit Cooperative Societies and Agricultural Marketing Cooperatives) to avail affordable loans to the smallholder sisal farmers. This will help farmers to raise their incomes and capital needed to cover all sisal production costs.Smallholder sisal farmers need to improve their sisal productivity level in order to raise the profitability. This can be done through the use of modern farm inputs and better technologies and the government through provision of extension services to smallholder farmers by the Tanzania Sisal Board and local government autorities as the need appropriate knowledge and skils to raise their sisal productivity and profitability.

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# Trypanosomes Infection in Rodents and their Zoonotic Potential from Ruaha Ward in Kilosa District, Tanzania

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**Abstract**

*Zoonotic haemoparasites are among of the public health problems that affect human population and are capable of being transmitted from wildlife reservoirs. Study on trypanosomes infection in rodents from Ruaha ward in Kilosa district, Tanzania was carried out on March 2020. The total of 99 individuals of rodents were captured from different localities in Ruaha, using Sherman live traps. Blood samples were collected from supraorbital vein of captured individuals, both thick and thin smears were made, dried and stained with Giemsa at the ratio of 1:10. After washing and drying they were observed under microscope at 100 magnifications with oil immersion for trypanosomes infection. Out of 99 rodents captured there were, Rattus rattus 22 (22.22%), Mastomys natalensis 72 (72.73%), and Aethomys chrysophilus 5 (5.05%). Among the captured rodents, 62 (62.63%) were males and 37 (37.37%) were females. Rattus rattus appeared to be predominant species in resident areas, while Mastomys natalensis followed by Aethomys chrysophilus bieng dominant in fallow and cultivated land areas. The infectious agent (Protozoa) belonging to genus Trypanosoma was found infecting the rodent population. Rattus rattus (n=3/99, 3.03%) were shown to have high prevalence compared to Mastomys natalensis (n=1/99, 1.01%), meanwhile Aethomys chrysophilus (n=0/99, 0.00%) were found not infected with any trypanosomes. The overall prevalence of trypanosomes were (n=4/99, 4.04%), however, captured female rodents were not infected. It is concluded that zoonotic agent (Trypanosoma spp.) are prevalent to rodents in Ruaha ward, hence it is recommended that more survey of trypanosomes infections in rodents are crucial for disease surveillance as the way toward ending Trypanosomiasis by 2030.*

***Keywords***: Prevalence, Rodents, Zoonoses, Public health, Trypanosoma spp.

## Introduction

Rodents are the most frequent and important mammals on the earth, because they tend to adapt themselves with different locations and environmental changes (Seifollahi *et al.,* 2016). However, rodents are hazardous, as they can amplify pathogen from environment and from reservoirs of (zoonotic) disease (Gratz 1994; Meerburg *et al.,* 2009), and they spread the diseases through two different ways as described by Meerburg *et al.* (2009). These two ways include, direct route that rodent can transmit pathogen to human (example, by biting or breath on germs that are present in rodent excrements), and indirect route, in the sense that rodents can serve as amplifying host of pathogens and can bring into direct contact with humans by means of ectoparasitic arthropod vectors (mites, ticks, flies).

The infections with zoonotic haemoparasites are widespread in wild rodents (Korbawiak *et al.,* 2005; Katakweba *et al.,* 2012), they include Borrelia, Trypanosomes, Bacilli, Plasmodia and Coccobacilli (Silayo 1992; Gratz 1997; Juha *et al.,* 2003; Powelczyk *et al.,* 2004; Katakweba *et al.,* 2012). There are five groups of protozoan haemoparasites recognized, one group of euglenozoan flagellates including trypanosomes and four groups of apicomplexan parasites (O'Donoghue, 2017), where they tend to infect all terrestrial vertebrate groups including rodents.

Trypanosomes parasites are of medical and veterinary importance which mainly transmitted by tsetse fly (Glossina genus) to a wide range of vertebrate hosts (Morrison, 2011), where rodents are considered as reservoirs of these pathogens (Meerburg *et al.,* 2009; Seifollahi *et al.,* 2016). In addition, according to Han *et al.* (2015), out of 2277 extant rodent species studied only 217 species were found to be reservoirs harboring 66 zoonoses caused by viruses, bacteria, fungi, helminthes and protozoa, also they found 79 species of rodents were hyper reservoirs carrying between 2 and 11 zoonoses.

Trypanosomiasis have unbearable impact on human and animal health worldwide particularly in developing countries (Swallow *et al.,* 2000). Most outbreaks of rodent borne diseases in humans are commonly related to socio-economic deficiencies such as poor housing, poverty and overcrowding (Katakweba *et al.,* 2012), that are more prevalent in developing counties like Tanzania. Given the damage of rodents to humans and economic loss and due to health importance, parasitological studies on rodents seem necessary (Seifollahi *et al.,* 2016).

Rodents are well adapted to leave with or in close proximity to humans hence man are quite vulnerable to the potential spread of any pathogens carried by rodents (Dada, 2016). The close association between rodents and humans especially in rural areas facilitated the spread of zoonotic agents (Hamed *et al.,* 2003; Gholipoury *et al.,* 2016). In many settlements there is a relatively little awareness that rodents can transmit diseases, consequently little emphasis is directed towards the management of rodents and associated disease vectors (Katakweba *et al.,* 2013). Some rodent species such as Mastomys natalensis play more important role in distribution of zoonotic diseases like bubonic plague (Bastos *et al.,* 2005)

Human activities that change the ecosystem of rodents' living place have an important role in the epidemiology of zoonotic disease. These activities among others are agricultural fields and agroforest which provide food and shelter; yet, these are the most critical factors that influence rodent's distribution (Hieronimo *et al.,* 2014).

Generally, there is under-reporting of rodent-borne zoonoses and insufficient attention is paid to the diagnosis of these important diseases in sub-Saharan Africa (Katakweba *et al.,* 2012). As far as there is frequent rodent-human interactions, could increase the potential for contracting some zoonotic diseases like Trypanosomiasis in which (at critical stage) its treatment requires drugs that can cross the blood-brain barrier to reach the parasites. Therefore, this study was conducted to collect some informative data about trypanosomes infections in rodents from rural areas, where rodents are in close association with human settlements.

## Materials and methods

### Study Site

The study was conducted at Ruaha in Kilosa district Morogoro, Tanzania. Kilosa which is located at latitude 5º55' to 7º53'S and longitude 36º30' to 37º30'E, and its elevation is variable, Ruaha is situated at elevation 400 M above the sea level. The area is consisted with Ukaguru and Rubeho Mountains which is part of Eastern Arc Mountains (EAMs) that is recognized as global biodiversity hotspot and the mountains lies along western side of the district. The area experience bi-modal rainfall with short rains range from November to January, and long rains range from March to May with its peak in April. Annual mean rainfall of the area ranges from 1000 mm to 1400 mm in Southern part of the district, and temperature of the district varies with altitude. The mean annual temperature is 25ºC with coldest month (19º) and hottest month (30ºC) being July and March, respectively.

### Study Design and Rodent Trapping

A cross sectional study design were used whereby different areas were selected and designed for trapping rodents within the ward. The traps were placed in 30 human residence (inside houses), fallow and cultivated areas. Rodents were captured by using Sherman LFA live traps (7.5*9.0*23.0 cm: HB Sherman traps, Inc, Tallahossee, FL) and locally made live-traps (wire cage), whereby peanut butter which mixed with maize flour was serves as bait Three Sherman traps and two local traps were placed inside houses for three consecutive nights, at strategic points (corridors and kitchen) in order to increase capture rate. In both fallow and cultivated areas, traps were placed in line transect whereby each line trap had 10 traps that were situated 7 m apart within the line and 5 m apart between line traps. Traps were inspected every morning to collect and identify the captured rodents using (Kingdon, 1997), as described by (Mulungu *et al.,* 2008; Herbreteau *et al.,* 2011). Captured rodents were identified for sex (male or female) whereby perforated and unperforated vagina indicate female active and not active females, respectively while with scrotal or abdominal as male active and not active, respectively.

**Blood Sample Collection and Smears Preparation**

Captured rodents were anaesthetized by Ethyl ether soaked in cotton wool and 1-2 mls of blood were drawn from supraorbital vein using a glass capillary. Thin and thick blood smears were prepared from each blood sample on microscopic glass slides. The smears were left to dry in air for 5 minutes, and then fixed with methanol for 3 minutes. Each capillary was used for one animal only in order to reduce the chance of transmitting haemoparasites from one animal to another and to ensure accurate results (Ameen *et al.,* 2012). The blood smears were immersed in 10% Giemsa stain solution (1:10 dilution) for 30 minutes (Katakweba *et al,* 2012). Then smears were then flushed with water (tap water) to remove excess stain for 10 second, and allows to dry completely before fixation into pure methanol for 1 minutes then dried again (Olubunmi, 2013; Dada, 2016). The blood smears were examined under the light microscope (Olympus CX21) at 100x magnification with oil immersion and the haemoparasites were identified using the information and structures on parasitized red blood cells (WHO, 1991).

**Haemoparasites identification**

The blood smears were examined under the light microscope (Olympus CX21) at 100x magnification with oil immersion and the haemoparasites were identified using the information and structures on parasitized red blood cells (WHO, 1991).

**Data Analysis**

Data obtained was recorded and entered in Microsoft Excel, whereby Trypanosomes infections was compared between rodent species and sex. The estimation of prevalence was done through the formula; Prevalence (N)=N1N2*100%, Where N=Percentage prevalence, N1=Number of rodents infected, N2=Total number of rodents examined for the parasite.

**Results**

**Captured rodents**

All 99 rodents were captured from different localities around Ruaha ward, including; *Rattus rattus* 22 (22.22%), *Mastomys natalensis* 72 (72.73%), and *Aethomys chrysophilus* 5 (5.05%). Among the captured rodents, 62 (62.63%) were males and 37 (37.37%) were females as indicated in Table 2. Out of three species of rodents captured, *Rattus rattus* was dominant species in resident areas, while *Mastomys natalensis* and *Aethomys chrysophilus* were dominant in fallow and cultivated land (Table 1).

**Table 1: Species composition and relative abundance of rodents captured**

| Rodent species | Total captured | Sex | | Relative abundance (%) |
|---|---|---|---|---|
| | | Male | Female | |
| *Rattus rattus* | 22 | 18 | 4 | 22.22 |
| *Mastomys natalensis* | 72 | 40 | 32 | 72.73 |
| *Aethomys chysophilus* | 5 | 4 | 1 | 5.05 |
| **Total (3-species)** | **99** | **62** | **37** | **100** |

**Table 2: Localities where rodents were captured/trapped for detection of trypanosomes infection**

| Species | Inside house | Fallow land | Cultivated land |
|---|---|---|---|
| *R. rattus* | 22 | - | - |
| *M. natalensis* | 2 | 21 | 49 |
| *A. chrysophilus* | - | - | 5 |
| **Total** | **24** | **21** | **54** |

**Haemoparasites detection**

There was a very low prevalence of trypanosomes in the study area. Out of 99 blood samples screened, only 4 (4.04%) samples were positive for trypanosomes infection, whereas 95 (95.96%) samples were not infected (Table 3). Regarding the sex, all of infected rodents were male (100%) compared to that of female (0%). The detected *Trypanosoma* spp. in rodents is mainly zoonotic in nature.

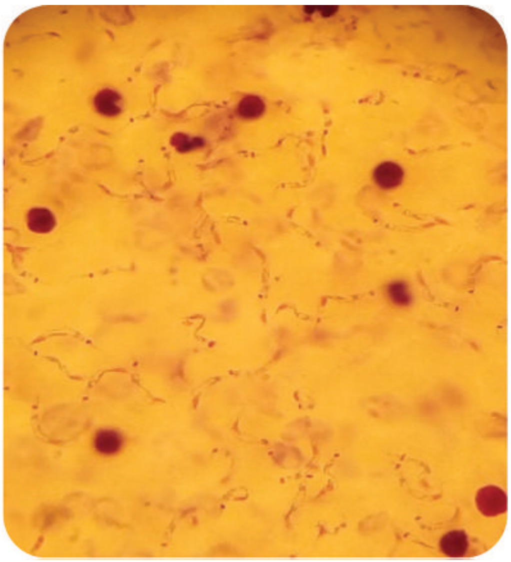

**Plate 1: Trypanosoma spp. viewed in thick blood smear**

**Discussion**

The present study was carried out to determine the trypanosomes infection in rodents and their zoonotic potential from Ruaha in Kilosa district, Tanzania. The rodent species captured in this study are often found in close association with people in dense settlements. Rattus rattus (22.22%) shows moderate abundant and were captured inside houses. This finding is in line with Belmain *et al.* (2002), that R. rattus is rarely to be trapped in the bush or in farmers' fields, and the species appears to be predominantly confined to areas of human settlement due to their nesting behaviour. Also, similar finding has been reported by Katakweba *et al.* (2013). The availability of food in human settlements provide an ideal environment for rodents' infestation particularly *Rattus rattus*.

Mastomys natalesis and *A. chrysophilus* were captured from cultivated area and fallow land. However, few Mastomys natalensis were found in houses, this concurrent with katakweba *et al.* (2012). Meanwhile within cultivated areas were high amount of food and guaranteed availability of water, hence, push growth rate of these two species. This also have been described by Boutin, (1990) and elsewhere. Mastomys natalensis (72.73%) shown to be more abundant compare to other species captured, this attributed to their nesting behaviour. Belmain *et al.* (2002), reported similar finding that *M.*

**Table 3: Prevalence of trypanosome infection in captured rodents**

| Species | No. captured | No. infested | Prevalence (%) |
|---|---|---|---|
| *Rattus rattus* | 22 | 3 | 3.03 |
| *Mastomys natalensis* | 72 | 1 | 1.01 |
| *Aethomys chrysophilus* | 5 | 0 | 0 |
| **Total** | **99** | **4** | **4.04** |

*natalensis* show more prevalent in the area where houses are isolated from each other (500-1500 m), this means areas with fallow and cultivated land. Also, Hubbard. (1972) and, Timbuka and Kabigumila. (2006), reported that Mastomys has generally been regarded as the most adaptable and the most widespread rodent in East Africa.

The importance of adequate housing and sanitation for the maintenance of health has long been a topic of scientific and public health policy discussion. In this study houses with disrepair indicators and poor sanitary conditions accounted for higher rodent captured when compared with those without evidence of disrepair. Therefore, the current study agreed with Dada (2016), that crowded, unsanitary and dilapidated housing conditions exacerbate rodent infestation.

This study has demonstrated the presence of trypanosomes in the blood smears of rodents, with *R. rattus* accounting for the majority of positive cases. This phenomenon has been reported elsewhere (Katakweba *et al.,* 2012; Katakweba *et al.,* 2013). The Trypanosome spp. observed in the blood smears of rodents was expected, since this genera of haemoparasites are commonly found associated with rodents as described by Dada, (2016). In addition, the current study shows higher infestation on male rodents than females. This concurrent with Linardi and Botelho, (2002). Furthermore, this study concurrent with Katakweba *et al.,* (2013), that presence of the trypanosomes in the blood of a large number of R. rattus raises a public health question whether this commensal rat could be a potential reservoir and vector of human or animal pathogenic trypanosomes such as *T. rhodesiense*, *T. gambiae* or others. The observed trypanosomes were not further characterized to determine their species or pathogenic significance in infected animals.

The current study shows that the overall prevalence of trypanosomes to be relatively low (4.04%), with 3.03% and 1.01% prevalence in *R. rattus* and *M. natalensis* respectively. Low prevalence may be attributed to geographical difference and distribution of vector in the study area. Also, Abdullah *et al.* (2019), reported that occurrence of haemoparasite is determined by abundance of the vector responsible for the transmission. Further, environmental factors (rainfall, temperature, relative humidity) have effects on the occurrence of vectors responsible for transmission on the area.

Rodent infestations in dense urban settlements are expected and unfortunately human health risk is not known. In the current study commensal rodents (*M. natalensis* and *R. rattus*) were found infected. Unfortunately, it is reported that world urban population is set to raise by 2.1 billion by 2030 (Taylor *et al.,* 2008), and by 89 million Tanzania in particular by 2035 (MNRT, 2020), such population explosions will inevitably favour commensal rodents. With ongoing urbanization in Ruaha ward the situation creates high risk of not only trypanosomes transmission but also other rodent-borne zoonotic disease transmission.

Therefore, this study is not totally conclusive due to small samples collected from the area of study because of time limit, meanwhile this study was conducted during wet season so, there is open room for further investigation on characterizing trypanosomes spp. in rodents across seasons.

## Conclusion

This study shows Trypanosomes infection in commensal rodents (*R. rattus* and *M. natalensis*), whereby *R. rattus* was highly infected and in term of sex, males were mostly infected. Despite of the small sample size included, nevertheless the study suggests that *R. rattus* act as main rodent reservoir of trypanosomes parasites in the area. Also, it is revealed that houses with disrepair indicators and poor sanitary conditions accounted for higher rodent captured when compared with those without evidence of disrepair. So far, human-rodent interaction facilitates not only trypanosomes transmission but also other rodent-borne parasites which may become more serious in human health. Therefore, this finding is a critical step in estimating and assessing the status of rodent infestation in the study area. In view of this, community wide rodents control strategies with strong emphasis on community participation must be employed to prevent rapid spread of rodent population. As reported by

Belmain *et al.,* (2008) that involving the local communities in management of rodents has been shown to be effective in reducing commensal rodent infestations.

**Recommendations**

As the way toward ending trypanosomiasis (to zero transmission) by 2030, more surveys of trypanosomes in rodents are crucial for disease surveillance and control. Also, better planning of urban (and developing rural) housing scheme is much encouraged to reduce human-rodent interaction.

**Acknowledgements**

We thank Sokoine University of Agriculture for providing introductory letter as secure to entrance permission in Ruaha ward, Kilosa district to carry out this research. We are grateful to Mohamed A. Samiji who provided financial assistance by sponsoring Samiji during his BSc study on Wildlife Management at SUA. More thanks go to Dr. Christopher Sabuni and others staffs of SUA Pest Management Center for their support on preparation to the field work. Lastly but not least, we would like to thanks Mr. Salim Omary for his support in laboratory work and more thanks to College of Veterinary Medicine and Biomedical Science at SUA for providing laboratory during this study. Without forgetting all villagers of Ruaha for their nice cooperation during data collection.

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# The Relevance of Formal and Informal Institutions in Local Chicken Genetic Resource Conservation: A Case of Igunga District, Tanzania

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**Abstract**

*Understanding the relevance of institutions for local chicken (LC) genetic resource conservation forms the basis for the management of Animal Genetic Resource (AnGR). A qualitative study was conducted to assess the relevance of formal and informal institutions on LC genetic resource conservation in rural and peri-urban areas in Tanzania using Igunga district as a case study due to its substantial number of crossbred LC with exotic breeds. Primary data were collected through in-depth interviews with fourteen key informants, ten focus group discussions (FGDs) with farmers as well as documentary review of the existing formal institutions. Atlas.ti (version 7.5.7) computer software was used in the content analysis of data solicited from the key informants and FGDs. Findings show that, formal institutions have low relevance because they are inclined to LC and/or AnGR production rather than its conservation. On the other hand, existing informal institutions such as norms, beliefs, traditional healing and sacrifice have a moderate relevance because they may serve as incentives for the conservation of LC genetic resources. The study therefore suggests that, the government should formulate or improve the existing formal institutions for effective management of AnGR.*

***Keywords***: AnGR management, local chicken conservation, regulatory frameworks, Igunga

## Introduction

In many developing countries Tanzania included, local chicken (LC) play an important role to rural livelihoods and they contribute significantly to social cultural, food security and income of smallholder farmers (Padhi, 2016; Singh *et al.,* 2018). More importantly, the scavenging behaviour, disease resistance and ability to thrive under harsh environment are considered as potential genetic attributes of LC (Okeno *et al.,* 2013; Ngeno *et al.,* 2015; Gebremariam *et al.,* 2017). However, the growing chicken demand coupled with limited knowledge on chicken husbandry has led farmers to perceive LC as non-productive and relatively inferior to the high yielding breeds (Biscarini *et al.,* 2015; Zidane *et al.,* 2018). Consequently, this has accelerated the problem of indiscriminate crossbreeding. According to Scherf (2000), out of the 7,000 livestock breeds including chicken registered in the FAO global database, more than a third are susceptible to extinction.

This study uses the term LC genetic resource conservation interchangeably with AnGR conservation to refer to all human activities including strategies, plans, policies and actions undertaken to ensure that the diversity of LC are maintained to contribute to food production (FAO, 2007b). Globally, two AnGR conservation methods are broadly grouped as; in-situ, in which animals are maintained within the environment where they have conventionally been raised and ex-situ, in which animals are maintained away from their environment where they were raised (Oldenbroek, 1999; Rege and Gibson, 2003).

The Interlaken Declaration (FAO, 2007a), where a Global Plan of Action (GPA) for AnGR was internationally agreed upon spells out the needs for improved productivity and drawing of long term and sustainable breeding programmes; which are currently mostly non-existent for the local livestock breeds. The GPA identifies four strategic priority areas: i) characterization, inventory, monitoring of trends and associated risks ii) sustainable use and development iii) conservation and iv) policies, institutions and capacity building. The latter emphasizes the strengthening of all institutions involved in AnGR management (Zonabend *et al.,* 2013). In developing countries where sub-Saharan Africa falls, AnGR are a very crucial constituent of biodiversity (FAO, 2003); as such effort to improve food security in these countries lies in wise use of AnGR (Philipsson, 2011). Nonetheless, literature shows that, limited resources and infrastructure are some of the obstacles hindering governments to formulate policies for AnGR conservation (Boettcher and Atkin, 2010). For example, in Tanzania existing animal breeding infrastructures such as the National Artificial Insemination Centre (NAIC) and Tanzania Livestock Multiplication Units (TLMUs) mainly concentrate on breeding and conservation of large animal species such as the Mpwapwa cattle rather than LC (Njombe, 2013). On the other hand, specific studies on LC conducted in Tanzania have concentrated on characterization of the chickens in terms of their physical, production and genetic attributes (Msoffe *et al.,* 2005; Guni and Katule, 2013; Lyimo *et al.,* 2013; Pius and Mbaga, 2018; Mwambene *et al.,* 2019). However, these studies have not shown how the characterized LC can be conserved in wake of existing formal and informal institutions. The knowledge on how the institutions relate to management of AnGR is a key entry point for farmers, decision makers and policy makers to learn on how LC genetic resources can be conserved. Therefore, the study on which the paper is based aimed to uncover the relevance of both formal and informal institutions towards LC genetic resource conservation in Igunga district and Tanzania at large.

Institutions are defined differently by different scholars based on the perspective in which they are inferred: as organizations (Stinchcombe, 1997), as rule of the game (North, 1990; Nootboom, 1996), as set of rules by a set of individuals to manage repeated actions whose consequence not only affect those individuals but also others (Ostrom, 1992), as shared values and rules and actions focused at enforcing those values (Peters, 2019). These definitions are different but, have one collective insight, that institutions impact individuals. The paper is guided by the definition of institutions by Helmke and Levitsky (2004), that is, institutions are rules and processes (both formal and informal) which configure social relations by restraining and permitting actors' behaviour. By contrast, informal institutions as defined by Mahonge (2010) as unwritten rules, customs, conventions and norms that govern resource use practices and relevant social relations among the resource users. Mahonge's definition is adopted by the paper to refer to community based norms and customs serving the purpose to govern relationships among specific LC users and forms the basis for their actions towards LC genetic resource conservation. Therefore, it can be said that effective AnGR conservation depends on the relevance of formal and informal institutions and how its operationalization is perceived by stakeholders (farmers and regulators). Therefore, the paper aims to unveil relevance of existing institutions towards LC genetic resource conservation. The following questions are answered: (i) what formal institutions are relevant for governing LC genetic resource conservation? (ii) What informal institutions are relevant for LC genetic resource conservation at practice level? (iii) To what extent are the existing institutions relevant to LC genetic resource conservation?

**Theoretical Review**

This study draws insights from two theories; the Institution Theory (IT) by North (1990) and the Perception-In-Action (PIA) Theory by Gibson (2002). The first theory examines the humanly devised constraints that structure human interactions. In consequence, they structure incentives in human exchange whether political, social or economic. The main argument of the theory is that, the processes by which the structures, including schemes, rules, norms and routines become established as authoritative guidelines for social behaviour. This scenario creates an enforcement mechanism which directly and indirectly influences the motives guiding individual behaviour. This implies that the relevance of formal institutions as established by the government depend on the interaction with the society as being bounded by its informal constraints. Lack of interactive environment is one of the key enforcement obstacles. The theory thus requires the government to strategize the integration of farmers in the effort towards sustainable LC genetic resource conservation. This study applies the theory in assessing the relevance of formal and informal institutions in conservation of LC genetic resources.

On the other hand, Perception-In-Action Theory is based on the fact that human perception and actions are mutually dependent. It asserts that human perception is a necessary property of a living action; and that without perception action would be unguided, and without action perception would serve no purpose. This implies that before an action is undertaken, a series of events must occur. For example, the perceiver (farmer) has to acquire information based on their ability to see, hear or become aware of the institutions through their senses. Then the perceiver has to process the information in order to gain more insight about it (understand) and lastly take action. Thus, it is assumed that farmers are driven by incentives in order to act towards LC genetic resource conservation. In this study, the term incentive is used to mean the social, cultural or economic values anticipated by farmers in order to keep LC. The study applied the theory in ascertaining whether there are incentives behind the LC genetic resource conservation. Therefore, the two theories complement each other by deriving from the possibilities that coordination between the government and the farmers is vital for enhancing sustainable LC genetic resource conservation.

**Conceptual framework**

According to the study's conceptual framework (Fig. 1.), institutions relevant for AnGR conservation have been shown. These include formal institutions such as policies,

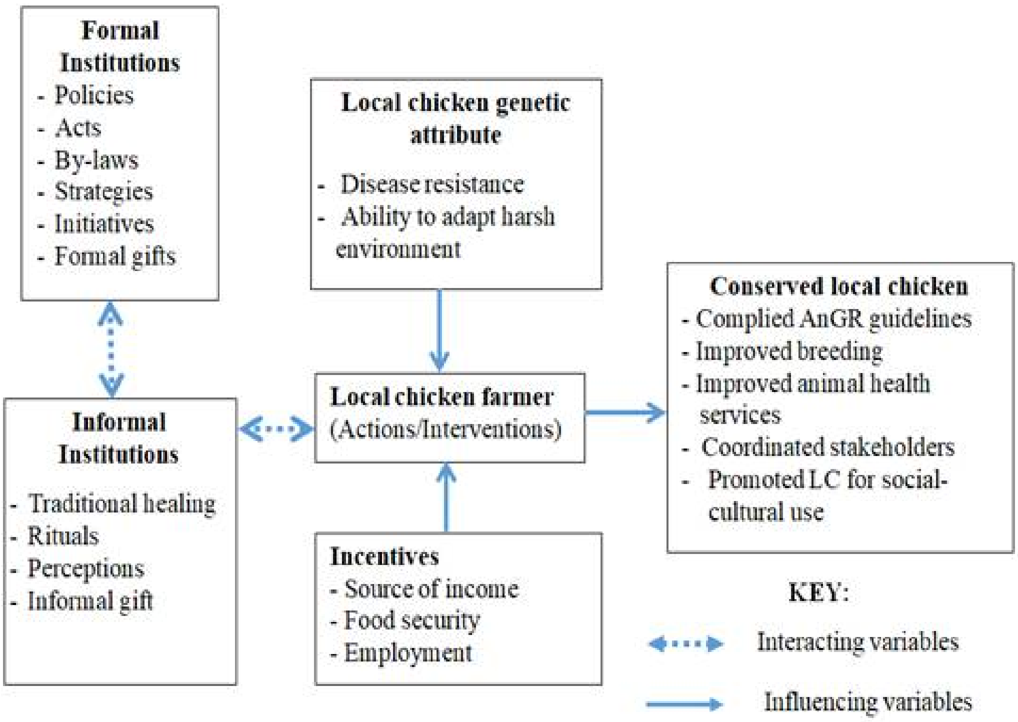


**Figure 1: Conceptual framework for the study**

acts, initiatives and strategies whereas informal institutions include gifts, beliefs, traditional healing and sacrifice. Specifically, this study conceptualizes that formal institutions can directly influence LC genetic resource conservation. As such, well organized and assenting formal institutions should be focused on governing LC genetic resources. However, there should be recognition, determination or willingness by the responsible government officials, agencies or actors, to prioritize and make formal institutions operational. On the other hand, the study assumes that LC farmers also have their own institutions (informal) which challenge, influence and interact with the formal institutions. In consequence, both formal and informal institutions may interact with farmer's perceptions and actions (interventions) relevant for LC genetic resources conservation. As such, the interaction may motivate (incentivize) or de-motivate farmers to conserve LC genetic resources depending on its contribution to their livelihoods in terms of income, food security, employment and cultural issues. Equally, this study further assumes that, farmer's willingness to conserve LC genetic resources can be influenced by genetic reasons such as ability to thrive under harsh environment, disease resistance and the low input use. The attributes signifies the relevance of conserving LC genetic resources in favour of resource poor farmers residing in rural areas where it is mostly kept. In this study, the conserved LC genetic resources is an outcome for variables such as controlled breeding, access to animal health services, improved LC management practices, stakeholder's coordination and promoted LC use for social-cultural reasons. These outcomes are measured based on two levels prescribed as follows; i) Low relevance when the institutions focused on LC production rather than conservation and ii) Moderate relevance when the institutions advocated for LC production but with some key aspects on its conservation.

## Methodology
### Description of the study area

The study was conducted in Igunga district, Tanzania. The scope of application of formal institutions that were reviewed was based at both the local and national levels; whereas actual practice was investigated in Igunga district, Tabora Region, Tanzania. The district lies between latitude 3”51' and 4”48' to the South of Equator and longitude 33”22' and 34”8'East of Greenwich. Igunga district was used as a case study because it has a history of implementing institutions (by-laws and Chicken Passing on the Gift rule) which has influence on LC genetic resource conservation. From the district, two wards (Igunga and Mbutu wards) wherein ten villages (5 villages in each ward) which were impacted by the four years chicken-based interventions (2015 to 2019) were purposively selected. The rationale for selecting the villages was twofold. First, the interventions donated chickens (one exotic cock and four LC hens per farmer) for crossbreeding purpose; together with training on good chicken husbandry practices. Second, the interventions (HITz, 2019), introduced a formal institution referred to as chicken pass on the gift (POG) which is based on the rule that, each livestock assisted farmer or family helps another farmer in obtaining the same benefits as received from the donor (Windig *et al.,* 2012). In this situation, the POG was applied to produced crossbred chicks which were distributed amongst the farmers (each farmer received one cock and four hens) within the study villages.

### Study population and data collection

A qualitative multi-methods research approach was employed whereby primary data were collected through key informant interviews (KIIs) and focus group discussions (FGDs) that were guided by checklist of questions and FGD guide respectively. An audio recorder was used where consent from the study's participants was sought before interviewing and tape-recording their responses. The KIIs and FGDs were conducted in Kiswahili, the language that all participants were familiar with for easy communication. The transcription of the audio records was done in Kiswahili and later translated into English for analysis. Primary data were also sought through reviewing of formal institution documents such as Acts, policies, by-laws, strategies, plans and initiatives concerning AnGR conservation. The review was conducted by showing the types, roles, responsibilities and the operationalization of the institutional documents in relation to LC genetic resource conservation.

**Key informant interviews**

The researcher shared introductory letter which highlighted the research objectives to the livestock practitioners in the relevant offices including the livestock research and training institutes. The selection of key informants (KI) based on their animal breeding skills and experience, which are relevant for AnGR conservation as stipulated by FAO guidelines (2007). The aim was to get participants with experience on chicken breeding and conservation. Key informant profiles were established for the purpose of identifying their capability and/or skills relevant to the subject matter under investigation. The study involved fourteen KIs categorized into three groups as follows; eight representatives were sought from the local government, government research and training institutions, four representatives from the private and livestock development partners, and two representatives from traditional healers (one from each ward). The study combined the diverse categories of KIs in order to gather insight son the relevance of institutions from various actors on LC genetic resource conservation. Key informant interviews explored views about the operationalization of formal and informal institutions relevant to LC genetic resource conservation in the study area. Existing opportunities and constraints were also included during the interview.

**Focus group discussions**

A total of ten focus group discussions (FGDs) were conducted with farmers in ten villages (one FGD in each village). Each FGD involved 7 – 10 participants. The ten FGDs were conducted as insights on the relevance of institutions varied with geographical location of farmers (rural/ peri-urban). In order to capture various opinions from farmers about the relevance of institutions for LC genetic resource conservation, farmers for FGD were selected based on: i) sex because the relevance of institutions for LC genetic resource conservation varied due to gender roles on chicken rearing responsibilities; ii) type of chicken breed kept by farmers because it determines the influence of institutions in governing LC genetic resources; iii) type of chicken management adopted by farmers because relevance of institutions especially for in-situ LC genetic resource conservation depend on good chicken husbandry practices. The participation of farmers in the study was voluntary; therefore prior consent was sought before one could participate in the study. Focus group discussions with farmers explored both formal and informal institutions in relation to the findings from the literature as well as government officials' views on the practices of AnGR/LC genetic resource conservation. A trained research assistant facilitated all the FGDs and the researcher probed and asked follow up questions while recording and taking notes.

**Documentary/Desk Review**

Secondary data were obtained from various reports related to AnGR conservation. The reports were collected from Igunga district, livestock department office; while the AnGR conservation guideline was sourced from the internet (FAO, 2007b). The researcher read all the collected reports whereby identified sections or statements relevant to AnGR conservation were highlighted for analysis. The main reports were from the chicken – based intervention's reports (EPOG and Igunga-Eco village) which evidenced the extent to which institutions for LC genetic resources are relevant at practice level. A report on the State of the World's AnGR (SoW-AnGR) for food and agriculture by FAO (2007b), was used as a global guideline for gauging the relevance of existing institutions for LC genetic resource conservation.

**Data analysis**

Content analysis method was used in data analysis. First phase involved institutional analysis, a qualitative approach which was done by highlighting the parts (written rules or formal institutions) related to AnGR conservation including aspects such as compliance with global AnGR guidelines, genetic improvement with LC flocks, access to animal health services, socio-cultural use and stakeholder coordination. The highlighted parts were drawn out of the documents to form the basis for discussion on their relevance towards LC genetic resource conservation. Findings were supported by quotes drawn from the selected section of the formal institutions such as policies, Acts, by-laws, initiatives and strategies in relation to their relevance on LC genetic resource conservation.

The unwritten rules (informal institutions) were analyzed in the second analytical phase which involved qualitative data from KIs and FGDs recorded in the field notes and recorded audio conversations. The data were transcribed, categorized, coded and thereafter grouped into themes with reference to study objectives. The Atlas.ti (version7.5.7) computer software facilitated the data analysis solicited from KIs and FGDs. The findings are presented basing on two main themes including the institutional operationalization (governance) and social-cultural use of AnGR for LC genetic resource conservation. The themes were supported in the quotes from the statements made by the key informants and consensus made by farmers during the FGDs.

## Results and discussion

Investigations on the relevance of formal and informal institutions in LC genetic resource conservation in the study area and Tanzania at large identified five main themes including three for the formal and one for the informal institutions respectively. The themes identified were compliance with formal institutions to global guidelines, LC crossbreeding, animal health services, stakeholder participation and socio – cultural uses. The latter theme represents informal institutions within which four sub-themes including traditional healing, rituals, perceived tastes and preferences, and informal gift are discussed.

### Compliance with guidelines

According to FAO (2007a), conservation of LC genetic resources is required to meet the Global Plan of Action (GPA) guidelines for conservation of AnGR. Documentary review finding identifies four GPA's strategic priority areas entailing; i) characterization, inventory, monitoring of trends and associated risks on conservation ii) sustainable use and development iii) conservation and iv) policies, institutions and capacity building. Tanzania government is cognizant of the priority areas as pointed out on section 2.4 of the National Compact Strategies and Action Plan (NCSAP) (URT, 2019). Furthermore, section 2.3.1 of the NCSAP clearly points out weaknesses under which, the lack of animal breeding act creates unfavourable enforcement environment to the pointed out activities under each of the NCSAP priority areas. Also, under challenges, the NCSAP mentions "long term investment to realize genetic improvement, unreliable sources of improved genetic materials, occurrence of endemic and epidemic diseases, seasonal supply of feed resources, low number of specialized professionals, weak implementation of mitigation to climate change, low levels of involvement in breeding programme by the private sector and indiscriminate crossbreeding". In general, this section highlights both finance and non-finance as obstacles causing failure of the government to comply with the GPA guidelines. Based on the literature, Hoffmann and Scherf (2010) urge that, development of the action plan is the first step in the implementation of the GPA. However, Hoffmann (2009) further emphasizes that; implementation of GPA guidelines requires substantial financial resources whereby countries should make effort to provide support in order to effectively manage AnGR. Thus, conservation of LC genetic resources in Tanzania will primarily need to address the obstacles so as to operationalize the existing action plan and meet the GPA guidelines. Commenting on the weaknesses in relation to LC genetic resource conservation, one key informant declared that: "…monitoring activities on LC breeding practices do not occur mainly due to dwindling financial support and lack of focus on LC genetic resource conservation" (National AnGR coordinator, MoLFD key informant, July 2020). In regards to monitoring of chicken breeding and hatchery activities by the government, another key informant explained that:

*"On average I sell about 300 hatched chicks per month. The chick breeds are not from the same parents because the eggs are*

*locally sourced from various farmers who keep different types of chicken breeds. Interestingly, I have never seen government officials visiting my business for monitoring or regulation purpose"* (Entrepreneur, Igunga village, key informant, July, 2020).

A further institution finding review revealed that, the Tanzania Livestock Research Institute Act (TALIRIA) (URT, 2012) is authorized to conduct research activities on AnGR. In regulatory perspectives, only section 38 (2d) mentions that "regulating the utilization by specific institutions engaged in livestock research or livestock industry…in livestock conservation, or in the management, collection or use of livestock or livestock products". This section indicates weakness of the government since the regulation activity is research based. Thus, it does not address regulatory activities to other actors such as farmers and/or hatchery operators. Similarly, section 63 (1j) of the Animal Welfare Act (AWA) number 19 of 2008 (URT, 2008) regarding the power of the minister mentions making regulations "for the breeding of an animal including the method of breeding and the species of animals to be used". This assertion implies that the AWA, as the name indicates, is principally highlighting welfare issues related to productivity rather than local AnGR conservation issues. Therefore, this rule of the game does not comply with local AnGR conservation guidelines as an animal welfare issue.

Despite the deliberate effort by the government in developing the CNSAP, TALIRIA, and AWA, findings from the KIIs with the government officials suggests non-compliance of national AnGR conservation with global guidelines. Lack of financial resources is one of the obstacles attributed to this non-compliance resulting into lack of LC genetic resource conservation measures. Since the national government has limited financial resources, government agencies such as TALIRI, responsible for undertaking livestock research activities, are equally affected. This implies that the regulatory authority can be affected by factors beyond its control. Based on this, their technical capacity can be utilized effectively if they get support from the national government and/or development partners. Research findings by Mahonge (2012) and Zonabend *et al.* (2013) indicate that laws enforcement may become unsuccessful due to the lack of capacity of enforcers. Thus, the financial incapability can lead to unsuccessful LC genetic resource conservation. On the contrary, an in-depth interview with the hatchery entrepreneur has revealed the lack of government control on chicken breeding and hatchery operations resulting into indiscriminate LC crossbreeding. In developing countries like Tanzania where breeding services are not well developed and/or managed indiscriminate crossbreeding of local AnGR with exotic breed is a common practice (Olaniyan, 2015). As such, there is no clear evidence whether the existing LC in a study area evolved from their natural habitats. The introduction of exotic LC breed without meeting breeding guidelines is one of the sources that can cause genetic erosion on existing LC.

**Genetic improvement**

Indiscriminate crossbreeding involving LC with exotic breed was reported during the FGD with farmers in the study areas. FGD finding in Mwabakima village showed that;

*…the use of exotic chicken to crossbreed with LC is a threat to the existing LC diversity… as a result the produced chicken flocks in the community are becoming less resilient to harsh environment and diseases…*this may be largely attributed to indiscriminate crossbreeding. (FGD1, Mwabakima village, June. 2020).

Complementing the observation from the FGD, Section 7c of the village by-laws in Igunga district (IDC, 2017) also emphasizes enforcement on donation of various resources including crossbred chicks. Although the POG enforcement promotes chicken rearing activities among farmers, it does not consider indiscriminate crossbreeding as a problem to farmers. Similarly, the Tanzania Livestock Modernization Initiative (TLMI) (URT, 2015) seeks to promote sustained genetic gains in Tanzania livestock breeds (local AnGR). For example, in the section on improving the Tanzania poultry industry, priority action area mentions on the "identification of key dual-purpose breeds (egg and meat) suitable for

Tanzania free range conditions". This priority action area promotes LC because of the dual-purpose nature and their ability to thrive under free range (harsh) environment. However, it does not clearly point out strategies on how to conserve the LC breeds. Also, the National Livestock Policy (NALIPO) (URT, 2006a); section 1.3 states that "low genetic potential of the indigenous livestock coupled with limited supply of improved livestock has led to poor production and productivity of the livestock industry". This section suggests that local AnGR have lower genetic value which is contradicted by TLMI on the basis of suitability of LC thrive on harsh environment. The findings indicate limited recognition on the extent to which LC can perform better in their local context. When commenting on LC genetic performance as compared to other breeds, FGD participants argued:

*Local chicken are rich in genetic diversity, we are able to select stocks and/or develop new breeds in response to changing conditions including climate change or disease outbreak…* this is something we have not experienced in exotic or crossbred chickens (FGD 2, Mwabakima village, June. 2020).

Furthermore, section 3.1.3 (i) of the National Livestock Policy (NALIPO) states that "poultry industry is divided into traditional and commercial production system. Traditional system is the largest contributing over 70% of the flock, consisting of LC breeds (*Gallus domesticus*) such as Kuchi, Kishingo, Sukuma, Kinyafuzi, and Kiduchu". This section signifies LC recognition and population dominance but conservation measures are not effective due to the extensive nature of production system. This also suggests that breeding practices cannot be easily controlled. Commenting on the traditional production system in relation to LC genetic improvement, the FGD pointed out that:

*Since the LC are mainly reared extensively there is no control in chicken breeding; this may result into genetic erosion/dilution due to indiscriminate crossbreeding practices* (FGD 3, Mgongoro village, June. 2020).

Further investigation on institutions revealed that, the Livestock Identification, Registration and Traceability (LIRTA) Act number 12 of 2010 (URT, 2010b), recognizes the treasure of livestock on the basis of "appropriate identification, registration and traceability for the purpose of controlling animal diseases and livestock theft, enhancing food safety assurance, to regulate movement of livestock, improve livestock products and production of AnGRs".

Nonetheless, in this rule of the game, the aspect of local AnGR conservation is not addressed indicating that the value of LC genetic resource conservation is underestimated. In view of the concern, a study by Hoffmann (2009) connotes that in-situ conservation of poultry genetic resources is not necessarily dependent on high technological approaches or facilities but, mainly on skills and recording. Farmer's views on their ability to keep LC performance records indicated that:

*The majority of us especially in rural areas do not know how to read and write, this situation impedes the effort towards LC genetic resource conservation* (FGD 4, Ibutamisuzi village, June, 2020).

On the contrary, observations from the in-depth interviews with government officials especially those from the national AnGR advisory committee indicated uncertainty on the efficiency of documentation of LC genetic resources to the level that the information can be used to conserve LC genetic resources. For example one of the government official interviewed said:

*"…the current information of LC is inadequate to justify conservation initiatives… it is imperative to undertake characterization of the environment and LC genetic resources in the country to determine their physical and genetic diversity and uniqueness in such breed-types…the gathered information may serve as a benchmark towards effective LC genetic resource conservation measures"* (National AnGR coordinator, MoLFD key informant, July 2020).

The FGD findings indicate factors that cause erosion of LC genetic resources. Such factors include development partner's pressure (depicted from the chicken-based interventions) to improve LC performance, prevailing extensive production system and inability of farmers to document LC genetic performance.

The presented FGD findings are in agreement with findings by Magothe *et al,* (2015) that LC upgrading programs implemented in Kenya between 1976 and 1996 resulted into loss of important LC genetic traits for generations. Also, the findings from the present study are in line with findings by Mahoro *et al.* (2017) that LC mate freely due to extensive (scavenging) nature of LC production systems. By contrast, the in-depth interviews showed that lack of information on LC necessitates characterization, documentation and inventory of LC genetic resources. A study conducted in southern and eastern Africa on infrastructure for sustainable use of AnGR showed that there is little documentation on AnGR and such information are mainly research based stations (Hoffmann *et al.,* 2013). The state of the World's Animal Genetic Resources for Food and Agriculture (SoW-AnGR) highlights that inventory, characterization and monitoring should include the identification, quantitative and qualitative description, documentation of breed populations and the natural habitat and production systems in which they are embedded (FAO, 2007a). Therefore, the uncertainties by the key informant from the national AnGR advisory committee are genuine due to the existing limited LC genetic resource information.

**Animal health services**

Conservation of LC genetic resources is a function of appropriate animal health management systems (Asmara, 2014). Limited access to veterinary extension services addressing animal health services was identified by the study as the cause of LC losses. An FGD with farmers affirmed this:

*Limited access to animal health services is an obstacle…if the access was readily available, chicken losses due to disease outbreak such as ubaba (Newcastle Disease) would have decreased; in that way LC genetic resources could have been conserved.* (FGD 5, Mbutu village, June. 2020).

The observation from the FGD clearly shows that farmers have limited access to extension services in mitigating chicken health challenges. By contrast, the Livestock Sector Development Strategy (LSDS) of 2010 (URT, 2010a) as per section 2.1.4 regarding animal disease control under the productivity of poultry illustrates that "Introduction of heat stable vaccine against Newcastle Disease (NCD) and improved housing and feeding through the PADEP and DADPs programmes in some regions (for example Lindi and Mtwara) has reduced mortalities to 4%". Tanzania government is committed towards improving the animal health by imposing animal disease control measures to prevent LC losses; if scaled up, it can contribute significantly towards LC genetic resource conservation. A study conducted in rural areas of Lindi and Mtwara in southern Tanzania on NCD outbreaks indicated that NCD control using locally produced heat stable NCD-I2 vaccine protected 73.3% of the LC sampled in the region (Komba et al., 2012). Other than animal health (vaccination) interventions, the Animal Disease Act (ADA) number 17 of 2003 (URT, 2003) is cautious on restricted animal movements as a bio-security intervention. Section 43 (b) of the ADA states that: "no person shall move an animal on foot or by the use of a vehicle outside the inspector's area of jurisdiction without a permit". This implies that ADA is at the forefront in preventing spread of chicken diseases through movement restriction which also results into reduction of LC losses.

**Stakeholder coordination**

Successful conservation of AnGR observed in this study requires involvement of all stakeholders particularly farmers, public, private and development actors. Findings from key informants, who are the government officials, indicated that the existing institutions have mentioned LC genetic resource conservation without clearly pointing out coordination of stakeholders in the poultry sub sector. For example, two of the key informants remarked:

*"National livestock policy has mentioned the contribution of LC in the poultry sub-sector but it has not clearly pointed out coordination of stakeholders in regards to LC genetic resource conservation initiatives"* (LITA Dar es Salaam, July 2020).

**Another key informant added:**

*"…the Tanzania Livestock Research Institute Act (2012) mentions TALIRI as a government agency responsible for coordinating all livestock related research matters including AnGR conservation… … … if the agency is supported well, it can enhance LC genetic resource conservation strategies…. . it has also mentioned the issue of ensuring property right of newly discovered animal breed but the Act did not cover clear guidelines on conservation of existing AnGR (such as LC) under threat for genetic erosion…"* (TALIRI Naliendele Key informant, July 2020).

According to the Tanzania Livestock Research Institute Act (TALIRIA), the government does not recognize stakeholders especially farmers on matters related to AnGR. For example, Section 25 (1) states that, "where as a result of any research carried out by or on behalf of the institute anything is discovered, the discovery shall become the property of the institute; (2) the institute may, for the purpose of commercial exploitation of any discovery which the institute considers important for the improvement of animal production, arrange with any person to buy, sell, take or grant patent rights in the discovery, subjects to such terms and conditions as the board may determine". The section has not addressed the role of farmers as individuals, associations and/or cooperatives on aspects such as breed discovery as well as participation in research as a means towards conservation and utilization of AnGR in their natural habitat (in-situ conservation).

In-depth interviews and the reviewed institutions have clearly indicated that there is lack of stakeholder coordination on AnGR management implying that, existing institutions for AnGR/LC genetic resource conservation are focused on the government actions. They do not spell out the roles and responsibilities of other stakeholders along the LC value chain other than the government in relation to local AnGR conservation. Since stakeholders such as farmers, development practitioners and animal breeding societies are not regulators, they lack control for managing LC genetic resources. Based on that, some scholars have urged policy makers to consider integrating farmers' concerns into development policies agenda as a way to mitigate livestock issues such as LC genetic resource conservation (Elias and Abdi, 2010). A study conducted in Indonesia regarding in-situ conservation of LC (Sentul chicken) indicated that other stakeholders, besides the government, are important in conservation programs; such stakeholders include research institutions, universities, private companies and farmer groups (Asmara, 2017). Therefore, the holistic approach regarding stakeholder engagement is vital for conservation of LC genetic resources.

**Socio-cultural uses of local chickens**

In general, LC crossbreeding using exotic chicken was not supported by farmers interviewed during FGDs. There were of the view that existing informal institutions could be appropriate for conservation of LC genetic resources. The farmers were not in favour of the high producing chicken breed because the existing LC were associated with their social cultural landscapes basing on four sub-themes comprising; traditional healing, traditional sacrifice, LC tastes and preference and informal gift. These sub-themes are presented along with the farmers' views on LC genetic resource conservation.

**Traditional healing**

The use of LC in traditional healing is a common social-cultural practice in the study areas. Since farmers are exposed to the breeding technology using exotic chicken, the population of LC is under threat due to uncontrolled breeding. Commenting on the status of LC availability for use in traditional healing, FGD participants said:

*…When compared to exotic or crossbred chicken…LC is important for social-cultural obligation…as such it may involve travelling to distant villages in search for specific LC type to cater for traditional healing.* (FGD 6, Makomero village, June. 2020).

Also, from another focus group discussion it was said:

*A successful traditional healing must involve local chicken… apart from that, the healing is considered ineffective.* (FGD 7, Ibutamisuzi village, June. 2020).

The FGD finding demonstrates that, traditional healing incentivizes farmers in a study area to keep and conserve LC. The finding is in agreement with that reported in Indonesia by Asmara (2014) in a study that looked at the social-cultural values of LC. The study indicated that stronger social cultural values such as traditional healing supported the existence of Pelung and Kedu LC breeds.

**Rituals**

In a study area there is a ritual locally termed as *Maholelo* or *Ndagu* in Sukuma vernacular which literary means a kind of pact made with the help of a local specialist (divine-healer or traditional healer) in divination and healing in which someone promises something that is precious for him or her to the witches or ancestors, like his/her own body part or even one's child in return for the success in their business or other line of work. In practice, divine-healers prefer blood collected from a red, black or white LC in making the pact. A key informant from one of the traditional healers in the study area said:

*"…in our community, I use a black, red or white local chickens to cleanse ritual misfortunes, and or to condemn or curse social offenders in order to ensure that my clients are successful in their businesses or at workplaces"* (A traditional healer key informant, June, 2020).

The key informant finding indicates that as long as certain plumage colours are preferred for sacrificial reasons, the pointed out LC with black, red or white plumage colours are likely to undergo conservation. Although exotic chicken may have same plumage colours, they are not used for rituals because they are considered foreign and are believed to lack ancestral connection. These findings are in agreement with that reported by Guèye (2007) who indicated that in Africa, a black LC cock is sacrificed to obtain protection from evils such as diseases and war, while white cock is used when community members want to thank God. Also, in agreement with those reported by Mugittu (2016) who indicated that the preference for plumage colour reinforces the interest to keep LC where colour variation is possible.

**Perceived tastes and preferences**

During the FGDS, it was pointed out that consumer's preference on LC taste and organic nature were key aspect considered to influence LC genetic resource conservation. Although some farmers had crossbred stocks, their expression on breed preference was inclined towards LC. This is because consumers think that the crossbred or exotic chicken are genetically modified and or are fed on veterinary drugs to increase their performance. Talking on this account, focus group discussion with farmers who are no longer keeping crossbred chickens said:

*"Crossbred or exotic chickens are mostly not preferred by customers because they are perceived as inorganic and tasteless"* (FGD 8, Mwan'halanga village, June. 2020).

A further discussion with farmers on price factor revealed that:

*"Farmers are interested with rearing LC because they can be sold at a premium price… as such the value of one LC can be equivalent to selling three exotic/crossbred chickens"* (FGD 9, Isugilo village, June, 2020).

Both FGDs and KIIs findings, show that factors such as taste, organic and price are the key factors appealing farmers to keep and conserve LC. The findings are in agreement with Kyarisiima *et al* (2011) in a study that looked at perceived tastes and preferences of chicken meat in Uganda. The study observed that customers believed that crossbred/exotic chicken are fed on growth promoters. The finding implies health risk to consumers and hence promotes LC to premium market price. Gary (1996) found that even though the price may alter consumers' preferences, the choice of food by consumers greatly depends on childhood, social interactions and social influences. Therefore, the arguments enhance conservation of LC genetic resources.

**Informal gift**

During the FGDs, gifts offered in a study area were examined. In relation to LC genetic resource conservation, an informal gift, commonly referred to as kubebhya in Sukuma vernacular which means "give a chicken gift" was identified. It is a norm whereby one farmer voluntarily donates a chicken upon request from another farmer or neighbour within the community. The request is put forward based on trait preferences such as egg and weight performance, taste and mothering ability. Thus, the given LC is used to crossbreed with other chickens aimed at acquiring similar traits. However, this form of institution (kubebhya) has evolved over time hence; its impact on preserving LC has also changed with time. This change has been contributed by the chicken based interventions which enforced the beneficiary farmers to donate crossbred chicks (Chicken POG) to other farmers within the community. Unlike kubebhya, the POG practice contradicts LC conservation effort because breeding practices involves exotic breed and yet, are not controlled. Thus, comparing kubebhya in the past with the POG practice, focus group discussion with farmers revealed that:

*"…Passing on crossbred chicken as a gift is disruptive to the existing LC diversity, it also promotes the perception that LC are unproductive…however, LC may still perform better if chicken management practices (e.g. housing, feed, vaccination) are improved"* (FGD 9, Bukama village, June. 2020).

According to the study findings, farmers view POG as an enforced practice; but that is a chicken-based intervention trying to ensure that many farmers benefit from it. However, one would argue why could farmers not devise a mechanism such as changing the existing by-law (IDC, 2017) whereby they themselves would promote pass-on-gift using local chicken instead of exotic chicken. Meanwhile, they seem to accept it, on the one hand, and lament, on the other hand. Consequently, the finding is in agreement with that reported by Okeno *et al* (2012) in a study that looked at LC breeding. The study indicated that LC breeding programmes (schemes) involving chicken exchanges/gifts should focus on improvement within LC breed families, in so doing it will help maintain the LC attributes which are preferred by farmers and avoid genetic erosion and dilution and contribute to their conservation. Vincent (2014) further added that, the choice of local breeds should meet the requirements of the livestock production typologies and community preferences, these features are important for community engagement in LC genetic resource conservation (in-situ conservation).

According to the findings, formal institutions at national level have low relevance because they are more aligned towards improving LC production rather than conservation. On the other hand, relevance of informal institutions is prescribed as moderate because the studied social-cultural obligations of the community members regarding the use of LC are somehow in favour of its conservation at the practice level.

**Policy implications**

From the study findings, existing institutions are generalized with limited focus on AnGR conservation. The relevance of existing institutions is categorized into low (formal institutions and moderate (informal institutions). In general, the institutions reviewed regard LC as one of the potential livestock resources in attaining the national development objectives pointed out in the Tanzania Development Vision 2025 (2010c). This is mainly because LC is the driver for the growth of the poultry sub-sector; therefore, its conservation requires deliberate efforts. Since most of the farmers especially in rural areas are involved with LC rearing, it is natural for them to have vested interest on specific types of LC breed kept within their local environment. This underscores the fact that their participation in LC genetic resource conservation is vital; because LC is an integral part of the farmer's livelihoods. Therefore, if LC genetic resources are conserved, it can contribute to food and income security, as well as creating youth and women employment opportunities. However, lack of appropriate policies impacts farmers, especially in rural areas where it is mostly kept. The unregulated LC crossbreeding practices with high yielding breed underestimates the global AnGR conservation efforts. This indicates that Tanzania is falling behind in the formulation of appropriate institution that can regulate the practices.

Furthermore, the spelled out GPA guidelines underscores policies, institutions and capacity building (FAO, 2007), as key strategies for governing AnGR conservation. Since policies are the basic principles by which the government is guided, this study suggests that the existing formal and informal institutions can be effective; only if a policy tailored to animal breeding is available and meets stakeholder's objectives. Therefore, this study has provided supplementary information on existing institutions which is important for policy makers on whether to formulate a new policy or amend the existing ones so that LC genetic resources can be formally recognized, their breeding practices regulated and hence conserved.

**Theoretical implications**

The study was guided by Institution Theory (IT) and Perception-In-Action (PIA) Theory. According to IT theory, the main argument of the theory is an argument that institutions both formal and informal constitute constraints that human beings devise to shape human interaction but also becomes relevant if there is an enforcement mechanism. The study findings have shown that, institutions do not have enforcement mechanism to enhance LC genetic resource conservation. The study have also shown that there is a lack of interaction between the government as a designer of the written rules and the farmer as the implementer who is also bounded by its informal constraints. Based on the findings, this study confirms the IT based on the argument that institutions are irrelevant when they are not interactive and enforced.

Further study findings have indicated farmers keep LC not only for economic reasons but also for social-cultural reasons. Besides the resilience nature of LC to harsh environment and diseases attributes makes it possible for them to implement actions (interventions) relevant for its conservation. Therefore, this study confirms PIA Theory because the moderate relevance of the informal institutions suggests mutual dependence between farmer's actions and perceptions which enhances LC genetic resource conservation.

**Conclusions and recommendations**

The study findings conclude that there is low and moderate level of formal and informal institutions. Further findings indicate that the low relevance is concentrated at focusing LC genetic resource productivity rather than its conservation. On the other hand, moderate conservation is based on socio-cultural values including traditional healing, rituals, perceived tastes ad preferences as well as informal gift; which are inclined towards LC genetic resources conservation. It is also concluded that the knowledge generated through this study provides insights that can be used for improving existing formal institutions and/or formulation of appropriate AnGR management institution such as the Animal Breeding Act (ABA). From this end, potential opportunities may arise from the interactions between the appropriate formal and the informal institutions to effectively govern LC genetic resource conservation in the study area and in other areas in Tanzania with similar conditions. Based on the conclusions, it is also recommended that there is a need for co-management arrangements between the government (livestock sector), non-governmental organization (development sector) and the community (farmers) for sustainable conservation of LC genetic resources. In this way, the institutions will become more relevant for effective LC genetic resource conservation.

**Acknowledgements**

Authors are grateful to the government officials at different levels as well as farmers and key informants from the study villages within Igunga and Mbutu wards for their participation in this study; their time devoted in this study is highly appreciated.

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# Trade Development of Medicinal Plants Products in Tanzania: An Overlooked Research Area?

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**Abstract**

*The existence of trade of products of medicinal plants reflects their significance on health care and the local economy. Consumption trends have shifted medicinal plants from local consumptions to economic contexts. However, the engagement of medicinal plants products within the market economy necessitates the understanding of the trade system and management for economy, health and biodiversity securities. This paper used a systematic literature review to assess information on trade of medicinal plants in order to explore its structure and identify research gaps. About 377 research articles were identified where 46 of them were reviewed. The literature indicate the contexts of the trade are natural forests and health sectors which influence supply and demand sides, respectively. The supply chain differ among literatures. The results indicate that, despite the importance of the medicinal plant trade in Tanzania, its understanding rely on isolated bits and pieces of information from other research articles, the evidence of an overlooked research area. The identified research gap was lack of information on the trade like value chain and trade mechanisms. The study recommends further research to combine ethnomedicine, conservation and economics research domains which can ensure sustainable use of scarce resources of medicinal plants to meet the limitless demand of the healthy community.*

***Keywords***: medicinal plants, herbal medicine, trade, Tanzania

## Introduction

Tanzania has a wide diversity of flora and fauna ranked fourth in Africa after the Republic Democratic of Congo (DRC), South Africa and Madagascar (Fokunang *et al.* 2011). Tanzania is believed to have more than 1000 species of medicinal plants, compared to about 6000 throughout Africa (Hilonga *et al.* 2019; Delbanco *et al.* 2017). These species of medicinal plants are consumed and processed into various products which are found in different rural and urban markets in the country (Pereus *et al.* 2019; Otieno *et al.* 2015). The markets play important roles in the availability and accessibility of medicinal plants products through various trade chains (Nahashon, 2013). The existence of trade reflects the significance of medicinal plants products on health care and the local economy (Veldman *et al.* 2020; Abihudi, 2014). On health side, medicinal plants products constitute about 95% of traditional medicine (Kayombo *et al.,* 2013). The traditional medicine is used by about 80% of the population for treatment of various illness (Vats and Thomas 2015; Otieno *et al.,* 2008). The use of medicinal plants products in traditional medicine practices dates well before colonial period (Stangeland *et al.,* 2008) and developed later for other uses some of which is the novel source of modern medicines (Mahunnah and Mshigeni, 1996). About 75% of people living with HIV/AIDS and 60% of children with fever use medicinal plants products (McMillen, 2012).

On local economy side, medicinal plants have shifted from local gifts to traded products which contribute to household income and whereby different supply chains have evolved (Veldman *et al.* 2020; McMillen, 2012). For example, about 400 plant species have been identified to be traded in various markets throughout Tanzania (Hilonga *et al.* 2019). In addition, the quantity of traded non-wood medicinal plants at Kariakoo Market alone in Dar es Salaam in 2017 was more than 30 tons valued to more than USD 200,000 (Posthouwer *et al.,* 2018). Furthermore, the trade in medicinal plants products involves a large number of people in production and processing (Heinrich, 2015). These people include collectors, processors, transporters, and seller (Andel *et al.,* 2015). Therefore, traded products of medicinal plants play significant roles to ensure access, income generation and health improvements of communities in Tanzania.

The engagement of medicinal plants products within the market economy necessitates proper understanding for economy, health and biodiversity securities (Posthouwer, 2015). However, the trade of products of medicinal plants is rarely mentioned in the popular research agenda of products of medicinal plants regarding quality, efficacy and safety (Street *et al.,* 2008). The products of medicinal plants involved in the trade always transit several levels of stakeholders and organizations from cultivation to processing and distribution, before it reaches the final consumers (Heinrich, 2015). Therefore, along this path, there is a possibility that value adding activities and trading processes can affect the quality, efficacy and safety of products of medicinal plants (Andel *et al.,* 2015). This strengthens the need to understand the existing trade practices as one of the efforts to identify areas for improvement in aspects of quality, efficacy, safety and sustainability hence increase the viability of products of medicinal plants.

It is from this context that a systematic review of the literature was done to assess the existing information from previous studies on the trade of products of medicinal plants in Tanzania. This review aimed to explore the conduct of the trade in order to provide an overview and conceptualization of the area, including identifying any knowledge gap. The generated information can be used to clarify hypotheses in the field of trade of products of medicinal plants which can subsequently be explored further in order to understand the trade dynamics in the traditional medicine industry for the improvement of both health and the national economy in general.

This paper is structured into the following sections: the introduction, followed by the methods used in literature search and selection process as section two, results and discussion are presented in section three while section four presents the research gap. The conclusion and recommendation are presented in section five.

## Methods

### Literature Search Strategy

A systematic literature search was conducted from June to September 2020 and included published scientific literature, thesis and dissertations, and conference proceedings specific for Tanzania and only reviewed papers outside Tanzania. The databases used were LibHub (discovery tool of scholarly literature) and SUAIR (Sokoine University of Agriculture Institutional Repository) of Sokoine National Agricultural Library (SNAL) of Sokoine University of Agriculture – Tanzania. These databases were sought as the focus in Tanzania. However, to widen understanding and facilitating comparison, the following specific journals were also targeted: African Journal of Traditional and Alternative Medicine, Economic Botany, Journal of Ethnopharmacology, and South African Journal of Botany. These journals were selected after tracking references of the earlier reviewed different research papers. The search in specific journals was limited to studies conducted within Sub-Saharan Africa (SSA).

In the articles search process, the following search terms were included (singular or plural forms when necessary): medicinal plants products trade, botanical products trade, ethnobotanical products trade, ethnomedicine trade, ethnopharmacology trade, herbal products trade, indigenous medicine trade, phytomedicine trade, and traditional medicine treatment. The search was repeated with the term trade replaced with production, industry, commercialization and value chain to increase the access of economic view of the publications. Each search term was followed by Tanzania and SSA to limit the outputs to researches done in the focus area. Searches from SUAIR were confined to some databases terminology and topic categories while the LibHub were not. The articles were also searched by examining references. In the literature search process, the names of the databases searched, the keywords used and the search results collected were used to create the potential reference collection.

**Study Selection and Information Extraction**

The selection criteria for the article from the potential reference to be included in the reference collection were at least one content of trade parameters of medicinal plants products. These parameters were commodity descriptions, trade actors, factors that influence consumptions, prices, and exchange process without limiting the time of publication.

The exclusion factors were studies that focused solely on medicinal plants researches without any focus on the trade aspects such as documentation of the medicinal plants used for specific diseases or in specific areas, determination of the active chemical compounds and microbial activities which are mostly based on laboratory aspect, and unavailability of the full article. Article selection from reference collection to be included in the reviewed list was based on two steps. The first step was the review based on the title and abstract of the article. In this aspect, three selection options were considered: the article was included, excluded or undecided. For undecided articles, the second step of full article review was conducted and was either included or excluded. The articles that met the inclusion criteria were included in the review list. The articles were then summarized based on the explanations of the medicinal plants trade aspects they covered (See Fig. 1).

**Results and Discussions**

**Study characteristics**

In the course of the review, 377 articles were identified whereby 46 of them were qualified for this study (Fig. 1). The reviewed studies were categorized into seven groups

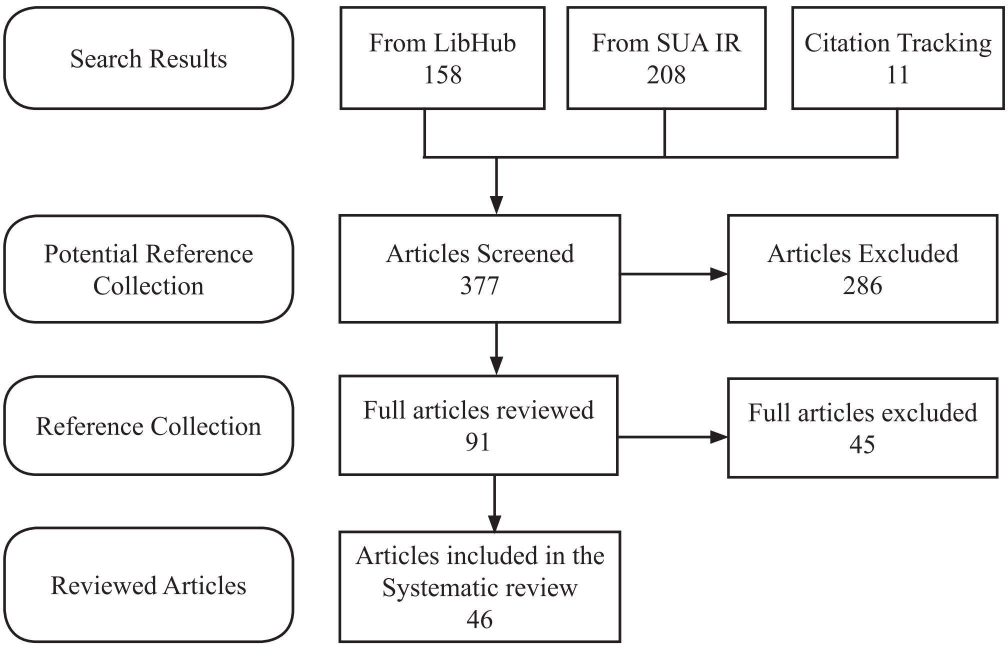


**Figure 1: Identification process of 46 articles included in the systematic literature review**

based on the themes of the research objectives; ethnomedicine, conservation, anthropology, modern health, policy issues, commercialization and information (Fig. 2).

***Ethnomedicine:*** These articles comprised of studies on the use of medicinal plants, chemical compounds and microbial analysis.

***The conservation:*** These articles comprised of studies on the conservation of medicinal plants with respect to biodiversity and climate change.

Anthropology: These articles comprised studies on knowledge and historical use of medicinal plants.

***Modern health:*** These articles are based on use of medicinal plants for known diseases in parallel to modern medicines.

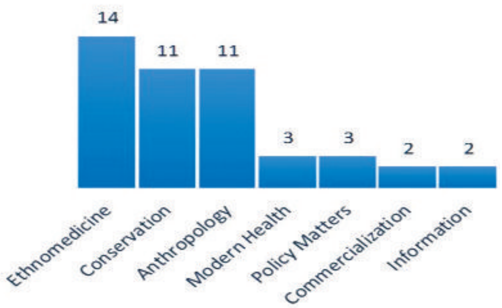


**Figure 2: Categories and number of articles reviewed**

***Policy issues:*** These articles comprised of studies that focused on the development and regulation of traditional medicines.

***Commercialization:*** These articles are focused on markets and exchange of medicinal plants.

The information category: These articles are focused on information technology application on traditional medicine and WHO 2019 Global Report on Traditional and Complementary Medicine.

The ethnomedicine articles were the largest part of the reviewed literature (14 research articles) while commercialization and information were the least (2 research articles each) (Fig. 2). Conservation and anthropology studies used methods of market survey, interview with practitioners and questionnaires while ethnomedicine studies were dominated by the laboratory works. The coverage of the studies was fairly distributed throughout Tanzania. The distribution of the articles based on the research themes was the first indicator of the scarcity of the research on the trade of products of medicinal plants.

The following sections explore and discuss the trade aspects of medicinal plants products presented in the reviewed articles. The discussion is based on the supply and demand contexts, supply chain and actors involved, nature and status of the traded products, consumers and access to products, and factors leading to consumption of medicinal plants products.

**Supply and Demand Contexts**

The literature describes products of medicinal plants in two aspects either on the biodiversity side or on the treatment side (Otieno et al. 2008; Mahonge *et al.* 2006; Augustino and Gillah, 2005). Medicinal plants constitute about 95% of traditional medicines components (Kayombo *et al.,* 2013) and about 98% of medicinal plants are wild sourced; from natural forests and bushes (Hilonga *et al.,* 2019). The observed role of medicinal plants in traditional medicine and their sources implies that trade in products of medicinal plants operates under health and natural forests contexts of Tanzania. The health context influences the demand side while the context of natural forests influences the supply side. The literatures are highly fragmented on the effect of each context on the trade of products of medicinal plants. This part synthesizes literature to explain those contexts as explained in various articles.

Tanzania health sector operates the pluralism system which is the combination of the traditional and modern medicines systems (Vähäkangas 2015; Mbwambo *et al.* 2007). Traditional medicine was the only health system of health in Tanganyika before Germany rule in 1882 (Vats and Thomas, 2015; Alexander, 2012; Mhame, 2000). The modern medicine was then introduced to some parts of Tanganyika by missionaries and colonial governments (Vähäkangas, 2015). The little coverage and inaccessibility of the modern health facilities made other parts to continue using the traditional medicine systems (Stangeland *et al.,* 2008). The introduction of modern health facilities went in parallel with detrimental traditional medicine system (Vats and Thomas, 2015). The negative perception of traditional medicines was carried out by modern health practitioners and some religious leaders, specifically Christians, which still impact the consumption of medicinal plants products hence their trade (Mbwambo *et al.,* 2007). However, even in the areas with modern facilities, the use of both health systems were reported even before and after independence (Feierman, 1981; Swantz, 1979). The situation of using both health systems still exist (Vats and Thomas, 2015).

On natural forests, as the sources of medicinal plants as another context of medicinal plants products trade in Tanzania, literature condemn the trade as the main source of degradation (Hilonga *et al.,* 2019; Pereus *et al.,* 2019; Otieno *et al.,* 2015; Abihudi, 2014). Although other sources of biodiversity degradation like climate changes, agricultural activities and human settlements have been mentioned in the literature, the medicinal plant products trade has been presented as the major cause (Mahunnah *et Al.,* 2012). The literature acknowledges the traditional practitioners' role in the conservation of biodiversity (Kayombo *et al.,* 2013) although they are part of the trade. The initiatives taken to reverse degradation on a trade perspective were to identify the most traded medicinal plants in various parts of the country (Veldman *et al.,* 2020; Posthouwer, 2018). Various initiatives have been proposed on the conservation of biodiversity both in situ and ex situ (Nahashon, 2013; Alexander, 2012) with little initiatives on the improvement of the trade. The arrangement to access the medicinal plants in reserve forests has received little attention in the literature. They mention harvesters or collectors to access medicinal plants through payment to village governments (McMillen, 2012). The effect of conservation strategies could affect the medicinal plants products availability, price and quality (Veldman *et al.,* 2020). Therefore, the literature on medicinal plants conservation in relation to trade presume sustainability as a scientific problem and nothing as an economic problem on scarce resources which need to be managed along the value chain. The economic initiatives like increasing efficiency in the processing system also could serve the purpose of medicinal plant conservation more than banning harvesting where most of the time were ineffectively implemented or encouraged switching to other medicinal plants (Otieno *et al.,* 2008).

**Supply Chain and actors of Products of Medicinal Products**

The literature differs on the supply chains and actors of trade of products of medicinal plants. The actors and supply chains are highlighted in conservation studies of medicinal plants which used the market survey. The number of identified actors and their supply series are as follows: McMillen (2012, 2008) identified four actors namely: harvesters, healers, vendors and customers. Nahashon (2013) identified five actors: harvesters, traditional healers, vendors, exporters and customers. Abihudi (2014) identified four actors: collectors, middlemen, vendors and customers while Hilonga *et al.* (2019) identified four actors: harvesters, middlemen, vendors, and traditional healers. The difference could be attributed to the differences of the local-urban places where studies were conducted. The nature of the studies left aside the value addition activities to further describe other features such as facilitating and regulating activities and their implication to trade and conservation.

The key actors found in the literature were traditional healers. The literatures refer to the traditional healers as the custodian of the knowledge, practices and materials used in traditional medicines and in trade of products of medicinal plant (Kayombo *et al.,* 2013). However, literature recognizes different types of traditional healers with different names in various studies. They have been mainly categorized into three types such as diviners or charlants, herbalists or medicine men, and sooth-sayers or witch doctors or ritualists (Vähäkangas, 2015; Vats and Thomas, 2015; Alexander, 2012). The herbalists are defined as those responsible to describe medicinal plant products to patients. The diviners are responsible to diagnosis and describing the source of diseases. The ritualists are for religious and foretelling aspects. However, during the colonial period, all the three categories were put in one basket hence brought confusion to traditional medicines practices (Stangeland *et al.,* 2008). The distorted roles have blunted practices of traditional medicines. This is due to the fact that types of traditional healers responsible for the trade of medicinal plant products are not explained in the literatures.

The exchange process and actors relations explanations are missing in the literature. Most of the authors have termed the whole medicinal plants products as informal trade operating in the hidden economy (Veldman *et al.,* 2020; Posthouwer, 2018; McMillen, 2008) without further explanation neither on the trade exchange process nor the value chain. Further, the medicinal plant products have been condemned to fall short of information on quality, efficacy and safety and traded at consumers' risk (Sife *et al.,* 2015), which again poses the question of why they are still consumed and the trade flourishing and ever increasing in the country (Posthouwer *et al.,* 2018). The situation necessities understanding of the medicinal plants trade structure and mechanism in more details.

**Nature and status of the traded medicinal plants products**

Medicinal plants products have been widely used in different ways such as medicine components in traditional medicines, novel sources of modern medicines specifically to chronic diseases such as cancer and HIV/AIDS, and as an industrial ingredient in aromatic industries (Runyoro *et al.,* 2006). In the case of traditional medicine, the medicinal plants products constitute about 95% of it (Kayombo *et al.,* 2013), the extent of making most literature to use the medicinal plants products interchangeably with traditional medicines (Sife *et al.,* 2015; Kira and Komba, 2012; Stangeland *et al.,* 2008). However, these are two different concepts.

World Health Organization (WHO) defines traditional medicine as the sum total of the knowledge, skill and practices based on the theories, beliefs and experiences indigenous to different cultures, whether explicable or not, used in the maintenance of health as well as in the prevention, diagnosis, improvement or treatment of physical and mental illness (WHO, 2019). Medicinal plants products, mostly referred to as herbal medicines, include herbs, herbal materials, herbal preparations and finished herbal products that contain active ingredients, as parts of plants, other plant materials or combinations thereof, where sometimes can include inorganic active ingredients that are not of plant origin e.g. animal and mineral materials (WHO, 2019; Vats and Thomas, 2015). The medicinal plant products have been given different names such as customary medicines, local medicines, indigenous medicines and natural medicines (Alexander, 2012).

The literature puts narrow separation on medicinal plant products and their accompanied services in the medicinal plants products trade. These services include diseases diagnosis and medicinal plants products descriptions because these services have been taken by a single person (Vats and Thomas, 2015; Alexander 2012). Faith healing has been included in traditional medicine (Vähäkangas, 2015), which again impact the medicinal plants trade. The result has been the weaknesses associated with the diagnostics methods of traditional medicines such as ramli (indigenous way of diseases diagnosis using spirits), which has been attached to medicinal plants products trade (Ngoma *et al.,* 2003).

The literature explains different status of the medicinal plants products found in the markets. Some have been traded at raw state (leaves, barks, and roots), unprocessed fragmented materials (chips, slices), semi-processed materials (powders, extracts, and teas), and processed materials (lotion, soaps, tinctures, tablets, and syrups) (Hilonga *et al.,* 2019; Otieno *et al.,* 2015; Posthouwer *et al.,* 2018; Abihudi, 2014). The semi processed and processed materials have been a combination of two or more medicinal plants (Otieno *et al.,* 2008). The value chain of the products found in the market is not described in the literature.

The relative prices of the medicinal plants products assessed through traditional medicine services with a comparison of modern medicines services are reported to be cheaper than the modern health services with flexible payments modalities (Mahonge *et al.,* 2006). However, for the market traded products of medicinal plants and specifically for chronic diseases, information on their pricing policies and mechanisms is lacking in the literature.

**Consumers and Access to Medicinal Plants Products**

The WHO explains that about 80% of the population in the developing countries uses traditional medicine consequently medicinal plants products (WHO, 2019). Furthermore, about 75% of people living with HIV/AIDS and 60% of children with fever were claimed to use medicinal plants products (Nahashon, 2013; McMillen, 2012). The information portrait the uses of medicinal plants products base in primary health care (Stanifer *et al.,* 2015). Therefore, the use of medicinal plants products is across all socio-economic statuses in communities in both rural and urban areas (Hilonga *et al.,* 2019; Alexander, 2012). However, the literature portraits another group of users that comprised the chronic diseases such as epilepsy, mental health, diabetics, and cancer (Mwanri *et al.,* 2017; Thomford *et al.,* 2016; Winkler *et al.,* 2010; Ngoma *et al.,* 2003; Witte *et al.,* 2000). Also, the literature reveals other uses such as sexually transmitted diseases, gynecological disorder and gastrointestinal afflictions (Alexander, 2012). Another use of the medicinal plants products in ritual practices was also cited in literature although it receives little attention (Posthouwer, 2015). The uses of medicinal plants products explained in the literature expand beyond primary health care as described by WHO (2019), but also as the first level of personal health care (WHO, 2019).

Moreover, about the access points of the medicinal plants products, literature have described to be of vendors at different market places both in rural and urban areas and traditional healers' home or clinics (Amy 2018; Vuorela *et al.,* 2002). However, the literature does not explain among different users of products of medicinal plants who are the dominant customers for the trade. The way customers accessing information about products is depicted in the literature as personal communication and information spread as "concentric ripples in water starting with a word of mouth" as stated by Vähäkangas (2015).

**Factors Leading to Consumption of Medicinal Plants Products**

The factors leading to the consumption of medicinal plants products found in literatures can be categorized into two; pull factors implying those which attract people to use medicinal plants products and push factors implying those which force people to use medicinal plants products (see Table 1).

These factors are also synthesized into two attributes; internal and external attributes derived from the pluralism health system operating in Tanzania. The internal attributes are those inherent to medicinal plants products while external attributes are those outside medicinal plants products. These factors as presented in Table 1 have been summarized from Hilonga *et al.,* 2019; Posthouwer, 2015; Stanifer *et al.,* 2015; Vats and Thomas, 2015; Bignante and Tecco, 2013; Mbwambo *et al.,* 2007; and Ngoma *et al.,* 2003.

According to the literatures, most people use medicinal plants products as outcome of the push factors with external attributes (Table 1). This implies that the increase of medicinal plants products consumptions sprouted in the weakness of the modern medicine. Therefore, the modes in which the medicinal plants products trade capitalize in these weaknesses, and is not depicted in the literature.

Furthermore, the literature differs widely on when a person uses traditional or modern medicine systems. Some literatures claim that people do start with traditional medicines, literally consumption of medicinal plants products, before going to modern health facilities (Vats and Thomas, 2015; Stangeland *et al.,* 2008) while other literatures claim that people start with modern health facilities before embarking to traditional medicines (Kayombo *et al.,* 2007).

However, other literatures went further claiming simultaneous use of both medicinal plants products and modern medicines (Thomford *et al.,* 2016; Kayombo *et al.,* 2007). Therefore, with pluralism of health system in Tanzania and increase of modern health facilities, it was expected to decrease uses of traditional medicine and consequently reduction of the trade of medicinal plant products.

**Table 1: Summary of factors leading to consumption of medicinal plants products**

| | Internal Attributes | External Attributes |
|---|---|---|
| **Pull Factors** | The credibility of medicinal plants products/ Perceived little side effects | Flexible payment model in traditional medicines services |
| | Perceived effectiveness of medicinal plants products to some of the chronic diseases | Lack of bureaucracies in access of medicinal plant products |
| | Easy accessibility of the medicinal plants products | Change of lifestyle inclined towards natural products consumption |
| **Push Factors** | Cultural attachment to traditional medicines | Low coverage of the modern health facilities |
| | Low cost of medicinal plants products | Diseases failed to be treated in the modern health facilities |
| | | High costs of modern health facilities |
| | | Only available health care system |
| | | The Continual increase of human population |

However, that is not the case and the literatures report different scenario, where there is an increase in both modern health facilities and medicinal plant products trade (Veldman *et al.,* 2020; Peter *et al.,* 2014).

**Research Gap**

Despite the importance of the medicinal plant trade in Tanzania, its understanding relies on isolated bits and pieces of information from other research articles. The main sources of information were from themes of ethnomedicine, conservation, anthropology, modern health, policy matters, commercialization and information whereby the issue of trade was not their main objective. None of the studies focused on improvement and promotion of the medicinal plants products trade, which evident that medicinal plants products trade is an overlooked research area.

The trend of the research led to a lack of key information in medicinal plants trade like the value chain of the medicinal plants products and its business models. Further, the declared informal status of medicinal plants products trade demands more studies to determine the nature of the informality and initiatives to formalize it. The information will facilitate the development and improvement of medicinal plants products trade which can then inform policy and the practitioners on the best way to benefit from the trade in a sustainable manner.

**Conclusion and Recommendation**

This review was conducted in order to explore the conduct of the trade in products of medicinal plants products so as to provide an overview and conceptualization of the area, including identifying any knowledge gap. The relevance of the review was based on the importance of this trade in biodiversity conservation, health and economy of Tanzania.

The literature were crystal clear on the existence of the medicinal plants products trade all over the country. The supply chain was characterized by a different number of actors who were described to work in the informal sector. The structure of supply and demand operated in the context of natural forests and health contexts, respectively. The forestry nature of supply-side determined the status nature of the products found in the market, which indicate inadequate of value addition in the middle. This could be the reason that the factors leading to the consumption of medicinal plants products be dominated by the push factors on the external attributes.

Based on both the importance of medicinal plants products trade and identified research gap, the following are recommended: Conducting a business and economics research on medicinal plants products to fill the existing information gaps such as value chain and trade business models. The studies will help to identify value addition activities that are important in the improvement of products and shifting it to formal trade. Further, the perception of medicinal plant trade as a major source of biodiversity degradation demand more economical intervention in additional to environmental conservation. The conservation could be contributed through efficient use of the traded raw materials, an area which emerges to be another domain of agricultural economics in medicinal plants product research. The combination of ethnomedicine, conservation and economics could ensure sustainable use of scarce resources of medicinal plants to meet the limitless demand of the healthy community.

**Acknowledgement**

This study was sponsored by Green Resources for Livelihood Improvement (GRILI) -DANIDA Project.

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# Natural Occurrence of Moulds and Mycotoxins in *Synadenium glaucescens* Extracts (SGE) under Different Storage Conditions

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**Abstract**

*Fungal growth and mycotoxin contamination in value-added medicinal plants products are quality and safety attributes that negatively affect entry to the market. This research aimed at investigating the occurrence of spoilage fungi and mycotoxins in Synadenium glaucescens extracts (SGE) from different plant parts and storage conditions. Laboratory whole water extraction method was used to prepare SGE from root-wood, root bark, leave, stem-bark and stem-wood. SGEs were subjected to storage temperature (25°C and 4°C refrigeration) and light (light and dark) conditions for 21 days. Samples were evaluated weekly to enumerate the occurrence of spoilage fungi and identified. In a follow-up experiment, pure cultures of Fusarium moniliforme and Aspergillus flavus were inoculated in SGEs and incubated for 14 days to allow production of mycotoxins. Aflatoxin and fumonisins were quantified using LC-MS/MS. It was established that 70% of samples of SGE contained Fusarium moniliforme and 60% Rhizopus spp. SGE samples stored under full light illumination were spoiled by Rhizopus species (35%), F. moniliforme (30%), F. pallidoroseum (3%), Cladosporium leguminicola (5%), C. sphaerospermum (2%), Alternaria alternate (6%) and Curvularia lunata (4%). The highest isolation frequency of F. moniliforme was in SGE from root wood (42%) and stem (42%). The highest (38%) isolation frequency of Rhizopus sp. was in SGEs from stem wood followed by root bark (32%) and 30% in both stem and root. Aflatoxin B1 was not detected in any sample. Fumonisin B1 (FB1) was detected in 80% of the samples and the concentration varied from 0.01µg/Kg to 6.33 µg/Kg. Among the samples contaminated with FB1, SGEs made from roots were contaminated by FB1 in a range of 0.03 to 0.04 µg/Kg, stem wood from 1.52 to 6.33 µg/Kg while in the root bark varied from 0.01 to 1.83 µg/Kg. SGE made from stem bark had FB1 ranging from 1.03 to 4.04 µg/Kg. Since fungal contamination was noted after 21 days of incubation, the source of spoilage fungi could be from the environment during postharvest handling. Therefore, it can be recommended that SGE safety can be ensured if good manufacturing practices (GMP) are maintained during preparation. Moreover, the Leaf SGEs were less vulnerable to fungal growth and fumonisin contamination at room temperature. Therefore, where the efficacy is the same, the leaf of S. glaucescens is possibly a better source of SGE formulations. These findings provide a benchmark of future investigations for more innovative GMP and safety measures to protect consumers against risks of exposure to mycotoxins.*

***Keywords***: *Synadenium glaucescens* syrup, fungi, spoilage, aflatoxin, fumonisin

## Introduction

Mycotoxin contamination of food and feed is a worldwide safety concern in public health (Miedaner, Gwiazdowska, and Waśkiewicz 2017). The presence of mycotoxins in the food and feed chain causes great fear over human health because mycotoxins can induce severe toxicity effects at low dose levels (Eskola *et al.* 2020). The toxins are produced by some toxigenic fungal species that belong mainly to genera *Aspergillus, Fusarium, Claviceps, Penicillium, Stachybotrys,* and *Altenaria*

(Rocha-Miranda and Venâncio 2019; Wild and Gong 2010). The proliferation of toxigenic fungi and production of mycotoxins on food and feed occur at any point along the product chain from farm to folk (Gaddeyya *et al.* 2012). Some of the most common mycotoxins are aflatoxins, fumonisins, and patuline. Liquid extracts of plants like edible fruits and medicinal plants are among the substrates that are likely to favour the growth of mycotoxigenic fungi and the production of mycotoxins.

Like many other sub-Saharan countries, Tanzania has been using medicinal plants for many centuries (Elsie *et al.* 2016; Suma *et al.* 2018). The people of Tanzania believe herbal products are closer to nature and free of any side effects. There is a wide variety of herbs in Tanzania due to her rich biodiversity in varied ecological conditions. Synadenium glaucescens (Euphorbiaceae) is one among many medicinal herbal plants that are indigenous to East Africa including Tanzania (Elkarim *et al.,* 2020; Mabiki *et al.,* 2019). The plant is known to be of great importance to mankind, especially cherished for its effectiveness in the treatment of both animal and human illnesses such as excessive menstruation, skin conditions, sickle-cell, diabetes, hypertension, sores and wounds (Mabiki *et al.,* 2013). Medicinal decoctions are prone to deterioration due to impurities that can cause attack by biological contaminants including fungi. It has been established that whether used fresh or dried, some of these medicinally important plants are facing serious problems of attack by various phytopathogens.
Various phytopathogens adversely affect medicinal plant parts and decrease the medicinal value of the part. It may be harmful to the human body while using these infected parts as a medicine. Previous studies have revealed significant contamination of *A. niger*, *Penicillium janthinellum, Aspergillus flavus, Aspergillus brassicae, Aspergillus pullulans, Drechslera* sp. and *P. janthinellum* in various species of medicinal herbal products (Probst *et al.* 2011; Chilaka *et al.* 2016; Adetuniji *et al.* 2014; Chilaka *et al.* 2017). Discolourations, quality deteriorations, reduction in commercial values as well as in therapeutic potential and mycotoxin production have been linked to mouldy contaminated herbal drugs (Gautam and Bhadauria 2009; Rocha-Miranda and Venâncio 2019).

The contamination of herbal products with mycotoxins does not only cause health hazards but also results in economic losses, especially for products meant for export. The mycotoxins most commonly found in fresh and their processed plant products are aflatoxins, fumonisins, ochratoxin A, and patulin (Rocha *et al.* 2009). Toxins produced by *Alternaria* sp. Include alternariol, alternariol methyl ether and attenuate (Rocha *et al.* 2009). These toxins may be found in syrups resulting from the use of contaminated raw material or invading toxigenic fungi in the final manufactured product.

To protect consumers against these toxins, over 100 countries globally including Tanzania established maximum tolerable limits (MTL) for different food and feed products (Kimanya *et al.* 2008; Kimanya *et al.* 2012). In Tanzania, the ministry of Health, Community Development, Gender, Elderly and Children (MoHCDEC) through its council for Traditional medicine has set a condition that a registered traditional medicine should be free from aflatoxins (Kheir *et al.,* 2020). To limit, mycotoxin contamination below the MTL, preventive measures like good agricultural practices (GAP) and good manufacturing practices (GMP) are forefront strategies (Amoa-Awua *et al.* 2007). The practices must aim to create unfavourable conditions for the growth of fungi and the production of mycotoxins. Under storage conditions, fungal proliferation and production of mycotoxin are favoured by certain environmental factors such as humidity, illumination, and temperature, as well as certain biotic conditions like the type of substrate.

Even with such numerous studies regarding the processing and storage of plant extracts of Synadenium glaucescens, findings of occurrence of fungi and their mycotoxins in Synadenium glaucescens extracts from different parts of the plant are currently lacking in the literature. The present study aimed at optimizing storage conditions for good quality and safety of extracts prepared from Synadenium glaucescens plant parts.

## Methodology

### Source of *Synadenium glaucescens* extract (SGE)

Twenty (20) samples (10ml each) of SGE were obtained from the chemistry laboratory of the College of Natural and Applied Sciences (CoNAS), Sokoine University of Agriculture. Of the 20 samples, 5 samples were extracts from each of the five plant part categories (root-wood, root bark, leaf, stem-bark and stem-wood). Harvesting of Synadenium glaucescens from the wild, sample preservation, preparation of extract from different parts of the plant were as per Mabiki *et al.* (2013).

### Experimental design

A triplicated completely randomized design experiment involving two storage temperature conditions (4°C and 25°C) and illumination (dark and light) was established under laboratory conditions. The experiment aimed to determine the influence of these factors on the growth of mycotoxin producing fungi and the presence of mycotoxins in SGE from root-wood, root bark, leaf, stem-bark and stem-wood. In a follow-up experiment, pure cultures of Aspergillus flavus and Fusarium moniliformin were artificially inoculated in the SGEs from root-wood, root bark, leave, stem-bark and stem-wood to evaluate growth and production of aflatoxins and fumonisins, respectively. Extracts for natural and artificial inoculation were kept in sterile glass petri dishes (90mm) for seven days before they were subjected to mycological analysis and quantification of mycotoxins.

### Observation of spoiled SGE

After seven days, observations were made to identify spoiled SGE and data counts were recorded including the nature of spoilage. The observation was made for 21 days, three times at 7 days interval. After 21 days, spoiled and unspoiled samples were subjected to mycological and mycotoxin analysis.

### Identification of Spoilage fungi

After 21 days of observation, the SGE samples were transferred to the African Plant and Seed Health laboratory of the Sokoine University of Agriculture for mycological analysis. To develop pure cultures for fungal identification, one milliliter (1ml) of each of the tested SGE was transferred aseptically into sterilized petri dishes using a heat sterilized isolation loop. The petri dishes contained 12-15ml of glucose Czapek's Agar medium with the following compositions per litre; 2g $NaNO_3$, 1g $K2HPO_4$, 0.5g $MgSO_4.7H_2O$, 0.5g Yeast extract, 10g glucose and 15g Agar (Menaka *et al.,* 2011). Before inoculation, the media was autoclaved at 121°C, 15pa for 15 minutes and cooled to just above solidifying temperature before they were dispensed into petri dishes. While adding the SGE, the dishes were rotated by hand in broad swirling motion so that the SGE is dispersed in the agar. The plates were incubated at room temperature for 7 days and sub-cultured to a fresh medium for culture purification using a method described in Degraeve *et al.* (2016). Where possible, fungi were identified to species level directly from colonies on Potato Dextrose Agar (PDA) media using well-established techniques of macroscopic and microscopic examination and standard reference books for the identification of moulds using lactophenol blue stain (Gautam and Dill-Macky 2012; Popovski and Celar 2013). A portion of the obtained culture was placed and teased out into a clean glass slide upon a drop of lactophenol cotton blue using sterile inoculating needles and covered with a clean coverslip (Morufat and Muhammad 2018). The light microscope depended on studying the morphological characteristic and microscopic characteristics which was compared to the mycological atlas for confirmatory identification (Ahmad *et al.* 2014). The relative density (RD) and isolation frequency (Fr) of species were calculated as per equations 1 and 2, respectively.

$$RD = \frac{Number\ of\ isolates\ of\ a\ species\ or\ genus}{Total\ number\ of\ fungal\ isolates} \times 100 \quad (1)$$

$$Fr = \frac{Number\ of\ samples\ with\ a\ species\ or\ genus}{Total\ number\ of\ samples} \times 100 \quad (2)$$

### Artificially inoculated fungi in SGEs

A follow-up experiment was performed to find out mycotoxigenic fungi's ability to produce mycotoxins in SGEs under artificial inoculation. Pure cultures of F. moniliforme and

A. flavus were artificially inoculated in SGEs maintaining uninoculated samples as control. The pure cultures of the fungus were sub-cultured on potato dextrose agar slants and kept in the laboratory at 25±2°C. Such mother culture slants were preserved at 5°C in the refrigerator. Further, these cultures were sub-cultured once in a month and used for future studies. To inoculate in SGE, petri plates containing 20 ml of PDA medium were inoculated with 9 mm mycelial disc from 10-day old culture of different isolates. Disks of mycelium were cut with a flamed corkborer and transferred to petri dishes containing PDA media. These plates in triplicate were incubated at 25°C for 10 days.

**Mycotoxin analysis**

For the quantification of mycotoxins in SGE, samples were sent to an ISO accredited laboratories of the Tanzania Bureau of Standards (TBS) (ISO 9001:2015 Certified). A method developed by Arroyo-Manzanare *et al.* (2015) for the determination of mycotoxin in cereal syrup was used with little modification. In sub sections 2.6.1 to 2.6.4 below, we describe the used chemicals and reagents, instruments and equipment, sample treatments and the LC-MS/MS used for quantification of fumonisins and aflatoxins in SGE.

**Chemicals and reagents**

Fumonisin and Aflatoxin standards were obtained from Supelco (Bellefonte, PA). Ethyl acetate was obtained from Merck (Darmstadt, Germany), n-hexane and perchloric acid from JT Baker (Deventer, Netherlands). Acetonitrile was bought from LGC Promochem (Wesel, Germany), acetic acid from Carl Roth (Karlsruhe, Germany), sodium hydrogen carbonate from Alkaloid (Skopje, Macedonia), and sodium sulphate anhydrous from Lach-ner (Neratovice, Czech Republic). Ultrapure water was produced by GenPure Water Purification System (Thermo Scientific, Thermoelectron LED, Langenselbold, Germany).

The reagents used were of analytical grade. Solvents were of HPLC grade and standard aflatoxins and fumonisins were of analytical grade. Formic acid was used as a mobile phase additive for HPLC methanol (MeOH), ammonium formate and individual standards of aflatoxins and fumonisins were obtained from Sigma Aldrich (St Louis, MO, USA). For sample treatment, formic acid (analysis grade) was procured from Merck (Darmstadt, Germany), and an HPLC grade acetonitrile (MeCN) from Panreac (Madrid, Spain) were used. Ultrapure water (18.2 MO cm1, Milli-Q Plus system, Millipore Bedford, MA, USA) was used throughout the analysis. Mycotoxin extraction kits; SampliQ QuEChERS consisting of either buffered QuEChERS extraction packed (4 g $MgSO_4$, 1 g NaCl, 1 g sodium citrate and 0.5 g disodium hydrogen citrate sesquihydrate) or non-buffered QuEChERS extraction packed (4 g $MgSO_4$, 1 g NaCl) were acquired from Agilent Technologies Inc. (Wilmington, DE, USA). Acrodisc 13 mm syringe filters with 0.2 lm nylon membrane (Pall Corp., MI, USA) were used for filtration of extracts prior to the injection into the chromatographic system.

**Instruments and equipment**

Mycotoxin analyses were carried out using an Agilent 1290 Infinity LC (Agilent Technologies, Waldbron, Germany) furnished with a binary pump, online degasser, autosampler (5 lL loop) and a column thermostat. The MS measurements were performed on a triple quadrupole MS API 3200 (AB SCIEX, Toronto, ON, Canada) with electrospray ionisation (ESI). As chromatographic column, the A C18 Zorbax Eclipse Plus RRHD (50 2.1 mm, 1.8 lm) was used. For sample preparation, a Universal 320R centrifuge (Hettich Zentrifugen, Tuttlingen, Germany), a vortex-2 Genie (Scientific Industries, Bohemia, NY, USA) and an evaporator System (System EVA-EC, from VLM GmbH, Bielefeld, Germany) were used. Instrumental data were collected using the Analyst Software version 1.5 with Schedule MRM TM Algorithm (AB Sciex).

**Sample treatment**

Two grams of each sample of Synadenium glaucescens extract (SGE) and 8 mL of 30 mM $NaH2PO_4$ pH 7.1 were placed into a 50 mL screw-cap test tube with conical bottom, which was shaken by vortex for 10 s. Subsequently, 10 mL of 5% formic acid in MeCN was added to the tube, and it was shaken again by vortex for 2 min. Agilent SampliQ EN QuEChERS extraction kit (4 g $MgSO_4$, 1 g NaCl, 1 g sodium citrate and 0.5 g disodium hydrogen citrate sesquihydrate) was added and the tube was quickly shaken vigorously for 1 min. Then, the samples were centrifuged at 4500 rpm for 5 min followed by transferring 2 mL of the upper MeCN layer to a vial which was evaporated to near dryness under a gentle stream of nitrogen and reconstituted with 1 mL of MeOH:$H_2O$ (50:50, v/v). The samples were filtered with a 0.2 lm filter before injection and aflatoxins and fumonisins were determined by LC-MS/MS.

**LC-MS/MS analysis**

The chromatographic method was used for the determination of the selected mycotoxins involved UHPLC separations which were performed in a C18 column (Zorbax Eclipse Plus RRHD 50 2.1 mm, 1.8 lm). The separation performance used a mobile phase consisting of 0.3% aqueous formic acid solution with 5 mM ammonium formate (solvent A), MeOH with 0.3% formic acid and 5 mM ammonium formate (solvent B) at a flow rate of 0.4 ml min-1. The eluent gradient profile was set as follows: 0 min: 5% B; 1 min: 50% B; 2 min: 72% B; 4 min: 80% B and 6 min: 90% B. Lastly it was back to 5% B in 0.2 min and maintained for 1.8 min for column equilibration. The temperature of the column was 35°C and the injection volume was 5 lL (full loop). The MS worked with ESI in positive mode and under the multiple reaction monitoring (MRM) conditions which were optimized as in Arroyo-Manzanares *et al.* (2015). The ionisation source parameters were: source temperature 500 C; curtain gas (nitrogen) 30 psi; ion spray voltage 5000 V; and GAS 1 and GAS 2 (both of them nitrogen) were set to 50 psi.

**Statistical analysis**

The data were statistically analysed using the Xlstat (version 2017.5) and the SPSS software (version 20). Descriptive statistics and the ANOVA calculates whereby if the test revealed a significant effect (significance level $\alpha$=0.05), a posthoc Tukey test was performed.

**Results**

**Fungal spoilage of stored SGE**

The incidence of fungal growth in SGE samples stored under refrigeration and room temperature were significantly different (p=0.001) (Fig. 1). SGE samples stored at room temperature (25°C) had higher (35%) spoilage incidences compared to 0% spoilage of samples under refrigeration (4°C) (Fig. 1A). Whether the SGE samples were stored under light or darkness, findings in Figure 2 show that these factors had no significant (p=0.001) influence on the spoilage incidence (Fig. 1B). Spoilage frequency also varied (p=0.001) with parts of *Synadenium glaucescens* plant from which SGE was obtained. Root wood, stem bark, and root bark had spoilage incidence between 38-40% while all other parts had spoilage incidence less than 20% (Fig. 1C). Combined analysis shows that all combinations involving refrigeration storage did not show fungal spoilage symptoms while all combinations with room temperature storage showed contamination at varying frequencies depending on whether they were exposed to light or darkness and also regardless of the type of plant part used (Fig. 1D)

**Occurrence of Fungal species**

**Effects of temperature**

The results in Table 1 shows that the temperature conditions in which SGEs were stored significantly influenced on the occurrence of fungal species (p=0.001) No fungal species were isolated from samples stored under refrigeration but numerous of them were recovered from SGEs stored at room temperature. About seven in every ten samples of SGE contained *Fusarium moniliforme* (relative density = 40%), while about 60% of these samples had *Rhizopus* species (relative density = 35%). Isolation frequency of less than 10% was observed for *F. palidoroseum*, *C. sphaerospermum*, *Curvalaria lunata* and *Alternaria alternate* while *Cladosporium leguminicola* had an isolation frequency of 13.81% (relative density 9%).

**Effects of light**

Observations in this study show that darkness significantly initiated the growth of spoilage

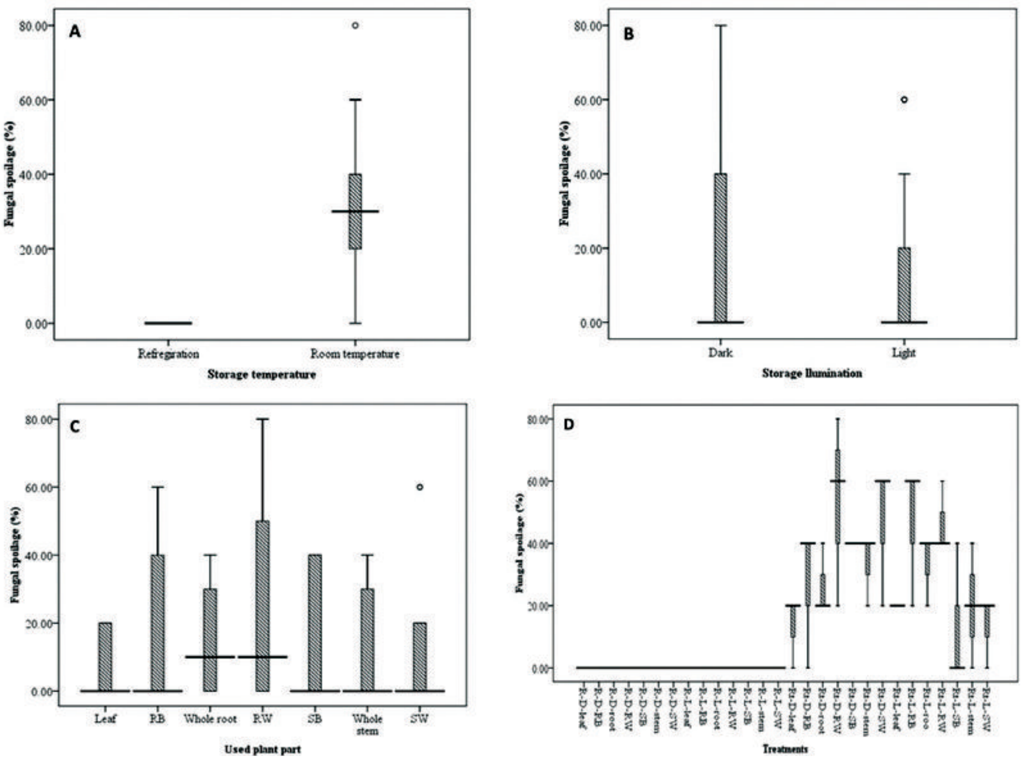


**Figure 1: Effects of temperature (A), illumination (B), plant parts (C) and treatment combinations on the incidence of fungal spoilage of SGE (D) interaction of the three factors: R=Refrigeration, Rt=Room temperature, D=Darkness, L=Light, RB=root bark, RW=Root wood, SB- stem bark, SW=Stem wood**

fungi and made SGE samples more vulnerable to spoilage than samples that were exposed to normal light illumination. At varying levels, all SGE samples stored under full light illumination were infected by spoilage fungi notably *Rhizopus* species (35%), *Fusarium moniliforme* (30%), *F. pallidoroseum* (3%), *Cladosporium leguminicola* (5%), *C. sphaerospermum* (2%), *Alternaria alternate* (6%) and *Curvularia lunata* (4%) (Fig. 2). Regarding fungal species relative density, the results show that, of all the isolates recovered from SGE samples, 20% and 19% were *F. moniliforme* in darkness and light stored SGEs respectively. Around 15% and 18% of the isolates were *Rhizopus* sp. in SGEs stored in darkness and light respectively. The rest 38% of the isolates constituted *F. palidoroseum, Cladosporium leguminicola,*

**Table 1: Occurrence of spoilage fungi in SGEs stored under a different temperature conditions**

| | Isolation frequency (Fr) (%) | | Relative density (RD) (%) | |
|---|---|---|---|---|
| | Rt (25$^{o}$C) | Rf (4$^{o}$C) | Rt (25$^{o}$C) | Rf (4$^{o}$C) |
| *Rhizopus* sp. | 58.57 | 0 | 35.19 | 0 |
| *Fusarium moniliforme* | 69.05 | 0 | 39.54 | 0 |
| Fusarium pallidoroseum | 7.62 | 0 | 4.15 | 0 |
| *Cladosporium leguminicola* | 13.81 | 0 | 8.99 | 0 |
| *Cladosporium sphaerospermum* | 4.76 | 0 | 2.77 | 0 |
| *Curvularia lunata* | 6.67 | 0 | 3.66 | 0 |
| *Alternaria alternata* | 9.52 | 0 | 6.34 | 0 |

***Key:*** *Rt = Room temperature storage, Rf = Refrigeration cold storage*

*C. sphaerospermum, Curvalaria lunata* and *Alternaria alternate* (Fig. 2B).

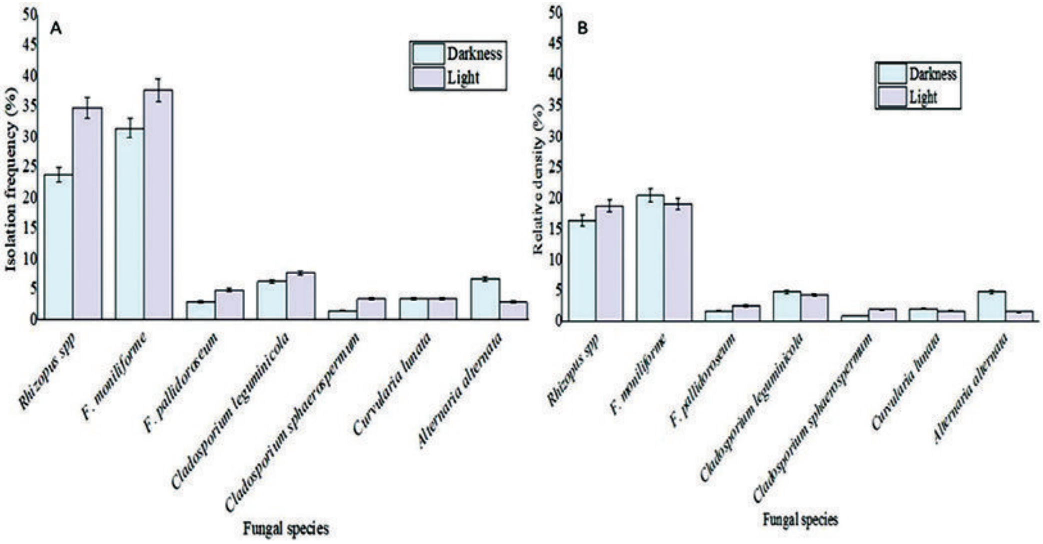


**Figure 2: Isolation frequency and relative density of fungal species in SGEs under different storage light regimes**

**Fungal species in SGEs from different plant parts**

Figure 3 shows that SGEs from all *Synadenium glaucescens* plant parts used in this study contained *Rhizopus* sp., *Fusarium moniliforme, F. palidoroseum*, *Cladosporium leguminicola, C. sphaerospermum*, *Curvalaria lunata* and *Alternaria alternata*. Isolation frequency of these spoilage fungi across SGEs of different plant parts varied significantly (p = 0.002). *Fusarium moniliforme* was the most abundant in all SGEs. The highest isolation frequency of *F. moniliforme* was in SGE from root wood (42%) and stem (42%). This was followed by 36% Fr in stem wood, stem bark and stem wood (Fig. 3A). *Rhozopus* sp. was the

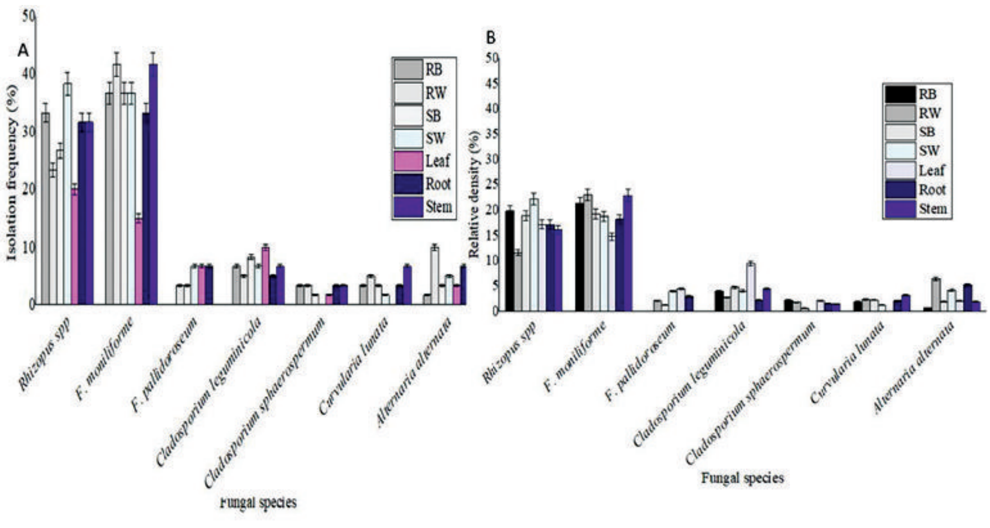


**Figure 3: Isolation frequency (A) (p=0.002) and relative density (B) (p=0.004) of spoilage fungi isolated from different parts of SGEs. SB=stem bark, RB=root bark, SW=stem wood, RW=root wood**

second most abundant fungi in all SGEs. The highest (38%) isolation frequency of *Rhizopus* sp. was in SGEs from stem wood followed by root bark (32%) and 30% in both stem and root. Less than 10% isolation frequency was observed for other fungal species. With reference to the numbers of isolates, species identification showed that relative density varied (p=0.004) with type SGE. For SGEs of RB, SB, and stem, in every 10 isolates, 2 were *F. moniliforme*. Similarly, for SGEs of RB, SB, SB and SW, for every 10 isolates, 2 were *Rhisopus* sp. (Fig. 3B).

**Interaction effects**

Figures 4A and 4B present the findings of the occurrence of spoilage fungi in SGEs that were stored under room temperature conditions. There were no fungal species isolated from SGEs that were stored under cold conditions. The occurrence of spoilage fungi and species relative density in SGEs from different parts of a plant was significantly (p=0.002) dependent on the storage light and storage temperature (Fig. 4A and B).

78%Fm). The *Synadenium glaucescens* extracts treated as RT-L-SW and Rt-L-RB were equally contaminated by *F. moniliforme* at an occurrence of 98% and 96% respectively. This was followed by the occurrence of the *F. moniliforme* in Rt-D-RB, Rt-D-SB and Rt-D-stem at equally 80%. Low occurrence of *F. moniliforme* was observed in Rt-L-leaf (20%) and Rt-D-leaf (40%). Seventy-five percent of each of the *Synadenium glaucescens* extracts were treated with R-D-RB, Rt-D-SW, Rt-L-SW, Rt-L-root and Rt-L-stem contained *Rhizopus* sp. The least (25%) occurrence of *Rhizopus* sp. was recorded in *Synadenium glaucescens* extracts that were treated with Rt-D-leaf (Fig. 4A).

Fungal species relative frequency varied significantly (p=0.002) between treatments. For *F. moniliforme*, the lowest (20%) relative density (RD) was recorded in SGEs treated with Rt-L-leaf while the highest (48%) RD of the same was in Rt-D-RB, Rt-D-SB, Rt-D-stem, Rt-L-RB and Rt-L-SW. *Rhizopus* sp. had the lowest (18%) RD in *Synadenium glaucescens* extracts treated with Rt-D-SW and the highest (50%)

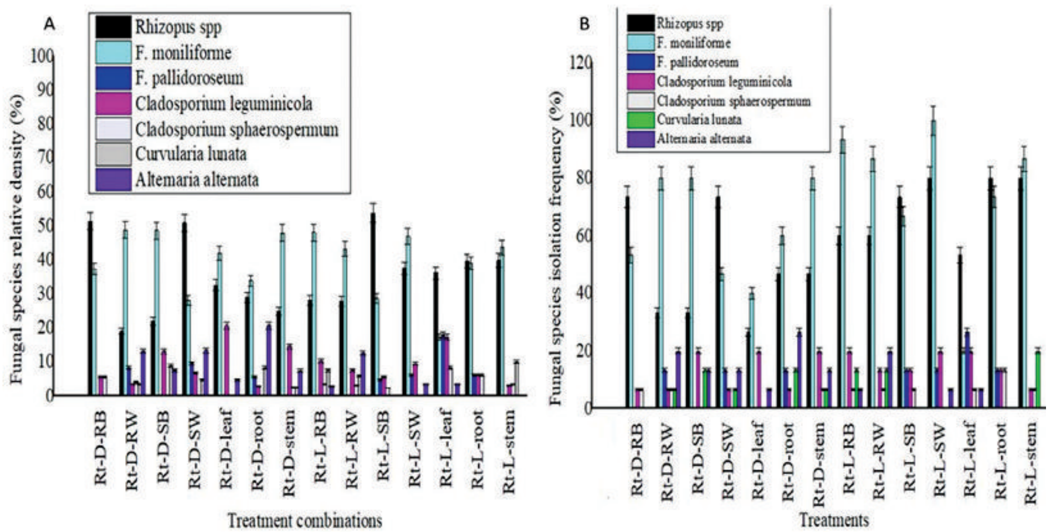


**Figure 4: Isolation frequency and fungal species relative density in SGE samples under different treatment combinations (p=0. 002). SB=stem bark, RB=root bark, SW=stem wood, RW=root wood**

Both *Rhizopus* sp. (Rh) and *F. moniliforme* (Fm) were the most abundantly occurring in almost every sample. The two equally occurred in samples of RT-L-SB (60%Rh, 63%Fm), Rt-L-root (70%Rh, 76%Fm) and Rt-L-stem (76%Rh,

was in each of the Rt-D-RB, Rt-D-SW and Rt-L-SB samples.

**Occurrence of aflatoxins and fumonisins**

Table 2 shows the level of fumonisin

associated with the SGE samples analyzed. In all the samples, aflatoxins were not detected. The results suggest that SGEs that were kept at room temperature were all positive for fumonisins except samples of Rt-D-leaf and Rt-L-leaf. For the positive samples, the toxins were detected during the second week following storage and the mean concentration varied from 0.01µg/Kg to 6.33 µg/Kg. Among the samples contaminated with FB1, SGEs made from roots had consistently the lowest FB1 concentration ranging from 0.03 to 0.04 µg/Kg. The concentration was high in SGEs made from stem bark stored in both light and darkness. In the stem wood, the concentration varied from 1.52 to 6.33 µg/Kg while in the root bark the FB1 concentration varied from 0.01 to 1.83 µg/Kg. Mycotoxigenic fungi were also inoculated in SGE made from stem bark where the FB1 concentration ranged from 1.03 to 4.04 µg/Kg.

## Discussion

### Occurrence of spoilage fungi in SGE

For the first time this study is reporting the occurrence of mycotoxins and mycotoxigenic fungi in herbal syrups. The use of these plant

**Table 2: Occurrence of fumonisins and aflatoxins in SGE samples analyzed (Nd = Not detected)**

| Treatments | Fumonisin B1 (µg/kg) | Aflatoxins B1 (µg/kg) |
|---|---|---|
| R-D-SB | Nd | Nd |
| R-D-SW | Nd | Nd |
| R-D-leaf | Nd | Nd |
| R-D-root | Nd | Nd |
| R-D-stem | Nd | Nd |
| R-L-RB | Nd | Nd |
| R-L-RW | Nd | Nd |
| R-L-SB | Nd | Nd |
| R-L-SW | Nd | Nd |
| R-L-leaf | Nd | Nd |
| R-L-root | Nd | Nd |
| R-L-stem | Nd | Nd |
| Rt-D-RB | 0.01 | Nd |
| Rt-D-RW | 0.60 | Nd |
| Rt-D-SB | 1.03 | Nd |
| Rt-D-SW | 6.33 | Nd |
| Rt-D-leaf | Nd | Nd |
| Rt-D-root | 0.04 | Nd |
| Rt-D-stem | 0.06 | Nd |
| Rt-L-RB | 1.83 | Nd |
| Rt-L-RW | 2.38 | Nd |
| Rt-L-SB | 4.06 | Nd |
| Rt-L-SW | 1.52 | Nd |
| Rt-L-leaf | Nd | Nd |
| Rt-L-root | 0.03 | Nd |
| Rt-L-stem | 4.67 | Nd |
| Control (uninoculated) | Nd | Nd |

products have been useful medicinal herbs for decades in Tanzania and other sub-Saharan African countries (Sánchez-Rangel *et al.,* 2012; Suma *et al.* 2018; Mabiki *et al.* 2013). The identified fungal contaminants of herbal syrups were *Rhizopus* species, *Fusarium moniliforme, F. pallidoroseum, Cladosporium leguminicola, C. sphaerospermum, Alternaria alternata* and *Curvularia lunata*. These fungi occurred as isolates from SGE samples made from the leaves, stems, stem-bark, stem-wood, root-bark and root-wood of *Synadenium glaucescens*. This suggests that no part of *Synadenium glaucescens* can be considered immune from fungal attacks. However, the study elucidates that, SGEs made from leaves were less vulnerable to most of the spoilage fungi than SGE samples made from the rest of plant parts. Previous studies have established that compared to any other part of the plant, leaves, seeds and to lesser extent fruits are commonly preferred herbal extracts. Reasons to why leaves are of choice could not be established in this study. Similar reports have established that such fungi are common fungi that cause spoilage of strawberries, fruits, and vegetables (Gautam and Bhadauria 2009; Ahmad *et al.* 2014; Bankole and Adebanjo 2003).

Levels of spoilage and frequency of fungal occurrence were closely related to storage conditions. The SGE samples stored at room temperature were highly contaminated by almost all the identified fungal species. However, *Fusarium moniliforme* (also known as *Fusarium verticillioides*) attacked the SGEs the highest suggesting they are vulnerable to this fungi. The occurrence of *F. moniliforme* in fruit and other plant products is also reported by Rocha-Miranda and Venancio (2019). Apart from deteriorating the quality of the spoiled product, *Fusarium moniliforme* produces fumonisin, a mycotoxin associated with various illnesses to humans and animals including cancer (Sánchez-Rangel *et al.,* 2012; Madege *et al.* 2018).

*Rhizopus* species which were also isolated in great proportions of SGEs are also known to be spoilage fungi of many foods and feed products. Kumar *et al.* (2015) reported that *Rhizopus* sp. is important spoilage fungi of bread. In this study, the prevalence of *Cladosporium* species in the SGEs was varying with different incubation temperatures and light regimes under invitro conditions. *Cladosporium* sp. are mostly known as potentially pathogenic fungus frequently occurring in outdoor environments (Alwatban *et al.,* 2014). This implies that these fungi possibly were brought in the laboratory as systemic fungi through plant tissues. Since the literature sources do not offer enough to compare these postharvest spoilage fungi, it suggests that possibly this is one of the few studies reporting on the occurrence of *Cladosporium leguminicola, C. sphaerospermum* as spoilage fungi of herbal syrups under storage environment. *Cladosporium* sp. are known mycotoxin secreting fungi which pose a safety concern to the use of SGEs if control measures are not considered throughout the production chain.

*Alternaria alternate* was another fungal species discovered in SGE spoiled samples. These findings are in line with previous studies which report that Alternaria infects fruits and vegetables (Feng and Zheng 2007). The observed infection in SGE confirms the previous reports that *Alternaria alternata* is a common pathogen that infects many plant species under field conditions as well as postharvest plant-based products (Feng and Zheng 2007). The importance of *A. alternata* is not only yielding loss, but also the cause of food and feed safety worries as these fungi produce mycotoxins like alternations, altenuene, tentoxin, and tenuazonic acid (Blandino *et al.* 2017).

Storage practices can also be associated with increased or reduced occurrence of spoilage fungi in stored products. In this study, SGE samples were subjected to different storage temperatures and light regimes. Hence, the study established that *Synadenium glaucescens* extracts were differentially vulnerable to spoilage fungi depending on the part of the plant and storage conditions. It is established that SGEs stored under the cold condition at a temperature of $4^oC$ were completely not attacked by all spoilage fungi. This proves that a cold chain of fresh products is critical because fungi invasion in stored products causes loss, colour change, flavour, and degradation of nutritive value

The occurrence of spoilage was high in samples stored at room temperature. Room temperature (25-27°C) is a suitable condition for the growth of most fungal species (Lahouar *et al.* 2017; Dantigny 2021). The vulnerability of SGEs under different light conditions were also tested. Findings suggest that there was little difference in fungal spoilage between samples kept in darkness and light, an observation which conforms to previous studies (Beyer *et al.* 2004; Mallikarjunan *et al.* 2016). Therefore, it is concluded that whether mould grows faster in a light or dark environment depends on other environmental factors (Dantigny 2021; Liu *et al.* 2016).

### Occurrence of fumonisin B1 and Aflatoxin B1 in SGEs

Fumonisin B1 (FB1) is a mycotoxin produced by the fungus *Fusarium verticillioides* (*F. moniliforme*), which commonly infects maize and other agricultural products. From artificial inoculation of *F. moniliforme* in SGEs, fumonisin B1 was detected in many samples which were stored at room temperature but no FB1 was detected in SGEs that were kept under refrigeration (4°C). The result suggests that on one hand cold storage is not an optimal condition for fungal secondary metabolism, on the other hand, room temperature storage will not only increase product deterioration but also worsen the safety of the stored product through contamination of mycotoxins (Drakulic *et al.,* 2017). Previous studies have established that fumonisin production by *F. verticillioides* starts at a temperature of 15°C and maximum is attained at 25°C (Madege *et al.* 2018)

The study has established that, among the SGE samples that were kept at room temperature, FB1 was not detected in SGEs from leaves of *Synadenium glaucescens*. The reason for this observation could not be established in this study. A similar study involving Chenopodium album plant established that roots and leaves of the plant had numerous chemical compounds (2(3H)-furanone, dihydro-4,4-dimethyl; 9-octadecenoic acid (Z), methyl ester; 9,12-octadecenoic acid (Z), methyl ester; 6-methylene bicyclo (3.2.0) hept-3-en-2-one., 1,2-benzene dicarboxylic acid, mono (2-ethylhexyl) ester and hexadecanoic acid, methyl ester) with possible antifungal effects (Alkooranee *et al.* 2020). Possibly, this is the reason SGEs from roots of *Synadenium glaucescens* stored in darkness had 158 times lower concentrations of FB1 than SGE from stem bark under the same storage conditions. Similarly, FB1 concentration in SGE from roots of *Synadenium glaucescens* stored under darkness was 51 times lower than the concentration in SGE made from stem bark and stored in light. In the different storage conditions, spoilage incidences at room temperature were observed after seven days of incubation suggesting that these fungi likely were a result of postharvest handling and not inherent in plant tissues from the wild.

## Conclusion

It is clear from this study that SGEs made from different parts of *Synadenium glaucescens* have different vulnerabilities to spoilage fungi. The spoilage can be aggravated by storage conditions such as room temperature since it makes the syrups more susceptible to spoilage fungi. The study did not establish clear evidence on whether the storage of syrup in light or darkness changed the spoilage potential. The fact that spoilage and fungal growth happened after twenty-one days of incubation, we can conclude that the fungi did not come with plants from the field but likely were introduced during post-harvest handling in the laboratory. It is recommended that the GMP be emphasized. Furthermore, where efficacy is the same, the leaf of *S. glaucescens* is possibly a better source of SGE formulations.

## Acknowledgement

The authors are grateful to the African Academy of Sciences (AAS) for financing the study through the VASPHARD project at Sokoine University of Agriculture. The efforts of technical staffs and research students from the Department of Chemistry and Physics, Department of Biosciences and Department of Crop Science are well acknowledged. The authors declare no conflict of interest.

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# Farmers' Perspectives on Occurrence and Management of Rust and Groundnut Leaf Spot Diseases in Different Agro-ecological Zones in Mtwara Region

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**Abstract**

*Rust and leaf spot diseases are important constraints of groundnut (Arachis hypogaea L.) production in Mtwara. This study aimed at establishing farmers' viewpoint on occurrence and management measures against foliar fungal diseases in coastal zone (CZ) and eastern plateaux and mountain block zone (EPMBZ) of the Mtwara region. Random and purposive sampling methods were employed and a 200 farmers sample size was used. Semi-structured questionnaire was administered. About 100 farms were selected and, a square quadrat was used whereby in each square, 5 plants were assessed for disease severity and incidence. Early leaf spots (ELS) had the highest incidence (93%) and severity (49%) followed by rust (79% incidence and 35% severity). The lowest incidences and severity were observed for late leaf spot (LLS) as 71% and 30%, respectively. There was a significant difference between the farmers awareness on the fungal diseases in the two zones were significantly varied (df = 198, p = 0.033) Farmers in the CZ were more aware of rust and late leaf spot diseases than those in EPMBZ. The majority of farmers in the CZ adopted appropriate disease management measures especially the removal of volunteer plants (94%) and use of conventional tillage (29%), respectively, to reduce disease inoculum from the soil surface. The study concludes that farmers in Mtwara region differentially understand the fungal foliar diseases. The occurrence and severity of rust, ELS and LLS varied between locations suggesting there is environmental influence. Meanwhile, farmers in CZ and EPMBZ employed different disease management agricultural practices that they did not employ/adopt the use of chemical fungicides. The study recommend intercropping groundnuts with tubers and legumes, usage of certified seeds, management of crop residues, removal of volunteer plants before sowing and conventional tillage as means of rust and leaf spot diseases management options to increase groundnut yield in the Mtwara region.*

***Keywords***: groundnut*, Puccinia arachidis, Cercospora arachidicola, Cercosporidium personatum,* rust, leaf spot

## Introduction

Groundnut (*Arachis hypogaea* L.) is an annual legume crop, which is mainly grown for the oilseed, food, and animal feeds. In Tanzania, the production of groundnuts is mostly done by smallholder farmers. Groundnut productivity in Tanzania is low (909.2 $kgha^{-1}$) compared with global average (1,685.6 $kgha^{-1}$) productivity (Mwatawala and Kyaruzi, 2019). Mtwara region is one of the major groundnut producers in Tanzania (Katundu *et al.,* 2014) but the average productivity (650 $kgha^{-1}$ ) is low (PMO and RALG, 2012). The low yield in Mtwara can partly be due to the occurrence of both early and late leaf spots diseases. The two diseases are common groundnut fields in the Mtwara. The incidence and severity of each disease may vary between localities and seasons depending on prevailing environmental conditions (Waliyar *et al.,* 2000).

The role of environmental conditions on disease occurrence and severity is reported by various authors. Daudi *et al.* (2018) found that rust epidemics are favoured by continuous high temperatures (>22°C), along with wet weather or high humidity (>78%). Also, the development and dispersal of both Cercospora arachidicola and Cercosporidium personatum conidia are most prevalent in temperatures ranging from 16°C - 30°C and relative humidity exceeding 90% (Burns, 2010). However, resistant genotypes lessen the leaf spot diseases by making smaller lesions as a result of host-pathogen incompatible reaction, longer latent periods, and reduced sporulation of fungi (Tshilenge-Lukanda *et al.* 2012). Either, groundnuts varieties with resistance to leaf spot are characterized by relative late maturity (Ibid.). Ramanatha and Mcdonald (1989) reported that the evolution of new and more virulent groundnuts rust and leaf spot races of the pathogen can be counter-balanced by the development of high levels of resistance trait in the host system due to selection pressure during coevolution. Pathogen virulence has been shown to differ between locations (Gremillion, 2007). Pal *et al.* (2014) suggested the management of groundnut foliar diseases by intercropping with cereals like pearl millet or sorghum to reduce the intensity of leaf spot diseases. The same author reported that crop rotation involving cereal–cereal–groundnut helped to manage the late leaf spot diseases. This is because crop rotation provides a time period for the degradation of crop debris, which in turn deprives any surviving inoculum of host tissues. Apart from intercropping and crop rotations, tillage is known to create a soil layer (physical barrier) preventing fungal inoculum from coming into contact with new growing plants (Burns, 2010). Tillage works so because *C. arachidicola* and *C. personatum* are necrophilic and survive from season to season on crop debris.

According to Daudi *et al.* (2018) farmers possess valuable knowledge and can contribute to agricultural research and development. The farmers do acquire information from a member of his or her own group. This farmer to farmer flow of information can increase the adoption of new disease management practices including improved varieties (Banla *et al.,* 2018). According to Mwalongo *et al.* (2020) improved groundnut varieties have higher productivity than non-improved varieties. Farmers' knowledge of groundnut's resistance to rust and leaf spot diseases play a key role in their decision to adopt improved groundnut varieties and other management options (Daudi *et al.,* 2018). The current study determined farmers' awareness on the occurrence of rust and groundnut leaf spot diseases, and establishes the agricultural practices that are commonly used by farmers to manage rust and leaf spot diseases in CZ and EPMBZ.

## Material and Methods

### Description of the study site

The study was conducted in two Agro-ecological Zones (AEZs) of the Mtwara region, which are the Coastal Zone (CZ) and the Eastern plateaux and mountain block zone (EPMBZ). The two zones are defined on the basis of climate, soil type and elevation. The survey was conducted in five wards of each of the two zones; CZ (Nanhyanga, Kitama, Mahuta, Mkwiti and Ngunja) and EPMBZ (Mikangaula, Mangaka, Chipuputa, Likokona and Napacho). The EPMBZ is located between 38o and 39 o while CZ is located between 39 o and 40 o East of Greenwich. The region is located between 10 o and 11 o south of the Equator (U.R.T, 2019). The CZ is characterized by plains with slight hills, sandy and loamy soil, altitude less than 500 m.a.s.l and annual rainfall of 500 -1000mm. The EPMBZ is characterized by plains with medium hills, loamy and clay altitude of 200 - 500 m.a.s.l. and annual rainfall of 800 -1000mm.

### Sampling design

Purposive sampling was applied to select groundnut growers based on criteria of experience of at least five years of growing groundnuts. Simple random sampling was used to obtain a sample of groundnut growers with a balanced representation of gender groups of both Coastal and Eastern plateaux and mountain block zones. Sample size was determined based on Fisher *et al,* (1991).

In each ward semi-structured questionnaires were administered to the selected groundnuts farmers to collect data on the gender, age, farm size, experience in growing groundnuts, usage of certified seeds, groundnut productivity, awareness of rust and leaf spot diseases, groundnut varieties used, fungicide usage, removal of volunteer plants, mixed cropping, management of crop residues and crop rotation (Denscombe, 2014; Manandhar *et al.,* 2016). The number of fields assessed with the rust and leaf spot diseases was recorded to determine the distribution of the diseases in each ward. Respondents were met at their homes and were asked for their consent to participate in the study.

### Occurrence of groundnuts rust and leaf spot diseases

In each of the 10 farms, a quadrat was thrown at starting point for each field and walked in a zig-zag path from one end of the plot to the other covering the whole groundnuts field, crossing different rows and avoiding the edge. From each quadrat throw, 5 plants were assessed for disease severity and incidence. Groundnuts rust and leaf spot diseases severity were determined as per Gaikpa *et al.* (2015) rating scale. Disease severity was rated using modified score scale of 1 to 9 whereby foliar infection area was rated as 1 = 0%; 2 = 1–5%; 3 = 6–10%; 4 = 11–20%, 5 = 21-30%; 6 =31–40%; 7 = 41–60%, 8 = 61–80% and 9 = 81–100% of foliar area infection with plants having almost all leaves defoliated leaving bare stems. For leaf spot disease, the variety with scores 4-6 ware moderately resistant (MR) and 7 was designated as susceptible. For leaf rust diseases, test plants were categorized as resistant (score of <3), moderately resistant (MR) (score of 4 and 5), susceptible, (score of 6 and 7) and highly susceptible (HR) (score of 8 and 9) Sudini *et al.,* 2015).

Farmers awareness level to groundnut rust and leaf spot was examined based on 0 – 100% scores, whereby 20-49% were categorized as low than 50% and above as high (Neindow *et al.,* 2018) whereby seven questions in the questionnaire related with diseases symptoms were used in the evaluation. A questionnaire guided the respondents on to list practices adopted in disease management (choice of variety, management of crop residues, and removal of volunteer plants, rotating crop rotation, usage of fungicides and mixed cropping).

### Data Processing and Analysis

Disease incidences were determined by dividing the number of infected plants over the total number of sampled plants per quadrat times 100%.

$$Disease\ incidence = \frac{Infected\ plants}{Total\ number\ of\ plants} \times 100 \quad (1)$$

$$Disease\ severity = \sum \frac{\sum (n \times V)}{9 \times N} \times 100 \quad (2)$$

where n = number of plants within each infection score, V = numerical values of infection scores, N = total number of plants examined, and 9 is a constant and the highest score value.

The collected and calculated data were subjected to statistical analysis using the Statistical Package for Social Sciences software (IBM SPSS Statistics 25). Both quantitative and qualitative data were coded. Data on disease incidences and severity indices were tested for its dispersion using Coefficient of variation, and then transformed using the Arcsine transformation, in order to ensure homogeneity of the variance and normal distribution of the data. The transformed data were subjected to analysis of variance (ANOVA) and means separated by the least significant difference method at 5% level of probability. A t-test was used to compare results between two locations before they are summarized into figures and graphs. Disease prevalence in the two agro-ecological zones was analyzed using GenStat software 15$^{th}$ edition.

## Results

### Farm size and productivity

Results in Table 1, shows that there were significant differences (t = 7.013, df = 198, p <0.001) in farm size and groundnut productivity between the two agro-ecological zones in EPMBZ, the farmers had relatively large farm size (1.3±0.068ha) compared to those in the CZ (0.67±0.059ha). Also, the groundnut productivity during the 2017/18 cropping season was higher in EPMBZ (0.60±0.51t/ha) compared to the groundnuts productivity in the CZ (0.36±0.036t/ha). This is because in the subsequent season groundnuts productivity in 2018/19 were relatively higher in EPMBZ (0.48 ±0.044t/ha), compared to CZ (0.25±0.028t/ha).

**Table 1 Farmer farm size and productivity in two agro-ecological zones of Mtwara region.**

| Variables | Agro-ecological zone | Means | Standard deviation | t | p |
|---|---|---|---|---|---|
| Farm size(ha) | Eastern plateaux and mountain block zone | 1.30 | 0.07 | 7.013 | <0.001 |
| | Coastal zone | 0.67 | 0.06 | | |
| Groundnut's productivity (t/ha) 2017/18 | Eastern plateaux and mountain block zone | 0.60 | 0.51 | 3.868 | <0.001 |
| | Coastal zone | 0.36 | 0.37 | | |
| Groundnut's productivity (t/ha) 2018/19 | Eastern plateaux and mountain block zone | 0.48 | 0.44 | 4.387 | <0.001 |
| | Coastal zone | 0.25 | 0.29 | | |

Significant differences (t = 4.729, df = 198, p<0.001) were observed in the awareness level (%) of rust disease between the two zones. Eastern plateaux and mountain blocks had lower mean scores (23±2.51%) compared to farmers in the coastal zone (38.5±2.12%). No significant differences in farmer awareness of ELS and LLS were noted between EPMBZ and CZ (Table 2)

**ELS and LLS disease incidence and severity**

The result in Table 3, shows that there were highly significant (df = 90, P<0.001) differences between the two AEZs in incidences and severities of both early leaf spot (ELS), late leaf spot (LLS) and rust diseases. The ELS and rust disease incidence in the EPMBZ exceeded those in the CZ by 10 and 17% respectively. Similarly ELS and rust disease severity in the EPMBZ exceeded those in the CZ by 13 and 11% respectively. On the other hand the LLS disease incidence and severity in the CZ exceeded those in the EPMBZ by 22 and 14% respectively.

**Table 2: Farmer's awareness on foliar fungal diseases affecting groundnut's productivity in two agro-ecological zones of Mtwara region**

| Variable | Agro-ecological zones | Means (%) | Standard deviation | t | p |
|---|---|---|---|---|---|
| **Awareness to:** | | | | | |
| ELS disease | Eastern plateaux and mountain block zone | 28.29 | 23.382 | -0.247 | 0.806 |
| | Coastal zone | 27.67 | 9.262 | | |
| LLS disease | Eastern plateaux and mountain block zone | 24.97 | 23.615 | 0.929 | 0.354 |
| | Coastal zone | 27.34 | 9.650 | | |
| Rust disease | Eastern plateaux and mountain block zone | 23.0 | 21.148 | 4.729 | <0.001 |
| | Coastal zone | 38.5 | 25.045 | | |

**Table 3: Incidence and severity of groundnuts foliar diseases two agro-ecological zones of Mtwara region**

| | Disease incidence (%) | | | Disease severity (%) | | |
|---|---|---|---|---|---|---|
| **Agro-ecological zone** | ELS | LLS | RUST | ELS | LLS | RUST |
| Eastern plateaux and Mountain block | 98 | 60 | 87 | 56 | 23 | 40 |
| Coastal | 88 | 82 | 70 | 43 | 37 | 29 |
| SE± | 0.013 | 0.021 | 0.02 | 0.018 | 0.023 | 0.02 |
| CV% | 9.6 | 17.7 | 16.5 | 18.7 | 31.4 | 25.1 |
| L.s.d | 0.036 | 0.058 | 0.057 | 0.051 | 0.064 | 0.056 |
| p-value | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |

***Key:*** *SE± = Standard error of means, CV% = Coefficient of variation (%), L.s.d = least significance difference, ELS = Early leaf spot and LLS = Late leaf spot.*

In the two agro-ecological zones, the number of groundnut farmers who adopted the different agricultural practices as measures to manage rust, ELS and LLS diseases in groundnut fields varied significantly ($t = 2.485$, $df = 198$, $p<0.01$). The results in Table 4, show that farmers intercropped groundnuts with tubers. Great close to 50% of farmers in EPMBZ intercropped groundnuts with tubers while only one third practiced the same in the Coastal Zone (31±0.046%). The percentage of groundnut's farmers who intercropped groundnuts with legumes exceeded the percentage of farmers doing the same in the Coastal zone by 41%.

**Table 4: Agricultural practices used for management of groundnut rust and leaf spot diseases in Mtwara agro-ecological zones**

| Variables | Agro-ecological zone | Means (%) | Standard deviation | t | p |
|---|---|---|---|---|---|
| Intercropping with Tubers | Eastern plateaux and mountain block zone | 48 | 0.502 | 2.485 | 0.014 |
| | Coastal zone | 31 | 0.465 | | |
| Intercropping with legumes | Eastern plateaux and mountain block zone | 46 | 0.501 | 7.499 | <0.001 |
| | Coastal zone | 5 | 0.2194 | | |
| Removal of Volunteer plants before sowing | Eastern plateaux and mountain block zone | 8 | 0.273 | -3.952 | <0.001 |
| | Coastal zone | 29 | 0.456 | | |
| Conventional tillage system | | | | | |
| | Eastern plateaux and mountain block zone | 78 | 0.416 | -3.334 | 0.001 |
| | Coastal zone | 94 | 0.239 | | |
| Usage of certified seeds | Eastern plateaux and mountain block zone | 95 | 0.219 | 8.963 | <0.001 |
| | Coastal zone | 46 | 0.501 | | |
| Residue control | Eastern plateaux and mountain block zone | 30 | 0.461 | 3.867 | <0.001 |
| | Coastal zone | 9 | 0.288 | | |

The number of farmers practicing removal of volunteer plants in groundnuts fields of EPMBZ was lower than the number of farmers in the Coastal zone by 21%. While eight in ten farmers of EPMBZ practiced conventional tillage, nine in ten farmers of CZ used conventional tillage as one of the disease management measures. Correspondingly higher proportion of farmers reported using farm-saved certified seeds in EPMBZ (95 ±0.022%), compared to those in the CZ (46±0.05%). Higher proportional of farmers in the EPMBZ (30±0.046%) and CZ (9±0.029%) managed the diseases using the management of crop residues through burying or removing off the field.

**Farmer's perceptions on groundnuts varieties' level of resistance to leaf spot and rust diseases**

The study found that there was a significant (df = 99, $p<0.005$) difference between zones in the farmer's perception of the groundnut's resistance to the rust and leaf spot diseases. In the Eastern plateaux and mountain block zone, Naliendele and Johari were perceived by the majority (9 and 36%, respectively) of respondents as resistant to leaf spot; these two varieties were also reported by the majority (10 and 34%) as resistant to rust disease while Pendo, Nyota and Mnanje as susceptible varieties to rust and leaf spot diseases. Similarly there was a significant (df = 99, $p<0.005$) difference between agro-ecological zones in the perception of farmers regarding groundnut's resistance against rust and leaf spot diseases in the Coastal zone using one-sample statistics. Pendo, Mnanje, Serena ndogo and Serena kubwa were perceived by the majority (38, 6, 44 and 15%, respectively) of respondents as resistant to leaf spot disease. Pendo and Mnanje were perceived by the majority (37 and 8%, respectively) as resistant to rust disease while Serena ndogo and Serena kubwa were considered susceptible varieties to the same disease.

**Discussion**

**Farm size and productivity**

Cultivated land size is a good indicator of the importance of the crop in a particular area or community. This study established that area under groundnuts was relatively larger in the EPMBZ. This may be explaining the higher groundnut production (60 tons/year) in EPMBZ than the CZ. Chirwa *et al.* (2015), reported that farm size is among the factors that influence the decisions of smallholder farmers to adopt agricultural innovations for crop protection and choice varieties for high yield. According to Neindow *et al.* (2018), smallholder groundnuts farmers seldom apply crop rotation, burning and burying of crop residues after harvest and removal of volunteer groundnuts. In both two years, 2017/18 and 2018/19, groundnuts productivity was relatively lower in CZ. Lower yield in CZ could be associated with the predominance of late LLS, these results correspond to the study by Banla *et al.* (2018) their study revealed that late leaf spot disease is of economic importance among other groundnuts foliar disease.

**Farmer awareness of diseases affecting groundnuts**

The study has established that the proportion of farmers who were able to identify plants diseases with groundnut rust and LLS was higher in the CZ than in EPMBZ. However, the farmers in CZ had a shortage of knowledge on diseases management strategies. According to Banla *et al.* (2018), farmers' knowledge of the LLS disease helps them to determine the management strategies of late leaf spot.

**Disease incidence and severity**

Groundnuts foliar leaf spots were found in all two agro-ecological zones. However, rust and early leaf spot diseases were predominantly occurring in EPMBZ while late leaf spot disease was mainly in CZ. The high prevalence of rust disease in the EPMBZ could be attributed to the low management of volunteer plants. Volunteer plants become alternative hosts of pathogens especially *Puccinia arachidis* which can only perpetuate on volunteers plants. This is very common in area with mono-modal rain fed cropping (Muimba-Kankolongo, 2018).

In addition, the high incidence and severity of rust in EPMBZ can be ascribed to pathogens' ability to travel long distance across boarders by wind from infected fields (Power, 2014). This becomes a problem especially to crops which are sown later in EPMBZ.

Similarly, higher prevalence of early leaf spot in EPMBZ may be attributed to poor management of volunteer plant and zero tillage practices adopted by majority of farmers. Zero tillage retains residues from previous crop that are hosts of *Cercospora arachidicola* during overwintering as saprophytes to provide initial inoculum for next crop (Burns, 2010)

Occurrence of late leaf spot disease was abundant in coastal zone. The occurrence could be associated with limited adoption of cultural practices that can minimize disease pressure in the coastal zone. For example, according to Boudreau *et al.* (2016) mixed cropping practice would minimize airborne diseases by interrupting the movement of the pathogen from one host plant to another. While this works well with *C. arachidicola*, intercropping efficacy over *C. personatum* is low because the conidia are able to survive and disperse over long distances hence overcome the suppressive effects of intercrops on pathogen. The low adoptability to cultural practices that minimize disease pressure and the nature of *C. personatum* may the reason for the high LLS occurrence in coastal zone. In contrast the lower occurrences of late leaf spot disease in EPMBZ may be associated with high adoption of cultural practices that minimize the disease pressure.

According to Tenga *et al.* (2018) the coastal zone has higher temperature (26°C) compared to EPMBZ (24°C). According to Fulmer (2017), LLS pathogen had higher (60%) germination at 28°C, compared to ELS pathogens which are reduced to 40% germination at 28°C. This may be explaining the high occurrence of LLS in the Coastal zone. According to Panda (2015) groundnut rust and leaf spot disease epidemic is associated with weather condition of cropped area. Alternatively, the virulence potential of the pathogen varies with the races. Damicone, 2014) reported that *Cercospora arachidicola* isolates are less virulent than the *Cercosporidium personatum* which are the most destructive. Groundnut rust and leaf spot diseases severity varied among the agro-ecological zones this may be inherent cultivar's level of resistance. According to Muhammad and Bdliya, (2011) groundnut varieties with inherent susceptibility to leaf spot pathogens attack show severe symptoms. Gaikpa *et al.* (2017) reported that leaf spots disease severity (lesion diameters) was relative higher in the susceptible cultivars. Similarly Chaudhari *et al.* (2019) reported that disease pressure of LLS and rust across individual environments varied with groundnut genotype influence.

**Diseases management practices**

This study has revealed that farmers in the EPMBZ practiced mixed cropping practice which is one of the disease management measures of fungal foliar diseases of groundnuts. This argument is in line with Kumar and Thirumalaisamy (2016) who reported that intercropping groundnuts with sorghum, pigeon pea, and maize are beneficial for the management of groundnut's rust, early and late leaf spots diseases. Intercropping decreases diseases occurrences by making barriers to the pathogens dispersal from infected host to healthy crops. Various authors have associated low ELS and LLS disease incidences and severity with intercropping systems (Neindow *et al.,* 2018; Boudreau *et al.* 2016 and Yussif *et al.,* 2014).

Majority of the farmers in the coastal zone adopted conventional tillage. However, conventional tillage alone wouldn't minimize late leaf spot disease pressure without adoption of other cultural management practices such as burning of crop residues. According to Burns (2010) *C. arachidicola* and *C. personatum* are necrophilic and flourishing on the dead cells and tissues of the host from season to season. Therefore, conventional tillage create a soil layer (physical barrier) that prevent fungal inoculum from coming into contact with newly growing plant. This is possibly the reason that Kumar and Thirumalaisamy (2016) found that rust and leaf spot diseases can be effectively managed by deep burying of crop residues.

Burying, removal or burning crop residues is recommended because these residues favor the overwintering of rust and leaf spot pathogens. After overwintering they become the potential initial source of inoculum in the coming season (Desmae and Sones, 2017). Poor management of groundnuts residues on the field by the majority of the farmers in the coastal zone could be associated with higher foliar disease pressure in this zone. Destruction of crop debris by burning, deep burying and conventional tillage are basis for managing leaf spots and rust disease (Gremillion, 2007). Majority of farmers burn groundnuts residues in Eastern plateaux and mountain block zone, this could be associated with reduced fungal disease occurrence hence high groundnuts productivity in the agro ecological zone.

Choice of variety and planting high quality seed is another disease management option. Majority of groundnuts farmers in both agro ecologies use saved seeds for longer period beyond recommendation. According to Jelliffe (2020), groundnuts are open pollinated (about 99%) and seed saving is effective for up to 10 production cycles. Recycling seeds beyond this recommendation could be attributed to yield losses due to inferior performance of the varieties resulting from increased vulnerability and reduced seedling vigor (Ngwira *et al.,* 2020). The vigor of the initial seeds decline due to inbreeding with time, hence demanding replacement of the genetically pure seed stock (Ntare *et al,* 2008). To counteract these effects, studies have recommended that the variety replacement period of groundnuts is 6–8 years post release. Desmae and Sones (2017) reported that in case the farmers intend to save their own seeds for 2-3 years after receiving initial stock of improved varieties. Field inspection should be conducted to remove any abnormal looking plants while the crop is growing (Desmae and Sones, 2017). This practice helps in maintaining the genetic purity and health of the variety being grown. According to Monyo and Varshney (2016), the low adoption of available new varieties is mainly attributed to the underdeveloped and inadequate seed systems, shortage of quality seed and lack of timely delivery and awareness.

Adoption of groundnuts cultivars that are resistant to rust and leaf spot are effective in decreasing the production costs and improving production quality. Majority of farmers in EPMBZ obtained thorough informal seed supply system. The use of certified seeds in this region can be a reason for the low occurrence of late leaf spot disease in EPMBZ compared to coastal zone where majority cultivate none certified (Serena ndogo and Serena kubwa) varieties. Low adoption of certified verities could be associated with low affordability because they are normally sold high prices (Akpo *et al.,* 2020). Apart from price, the unavailability of the seeds in the production area could be another reason for the observed low utilization of certified seeds (Pande *et al.,* 2001).

Host resistance is an important aspect of managing groundnut fungal foliar diseases. Cultivating disease resistant cultivars would be the most effective, sustainable and cost-effective strategy in groundnut fungal foliar disease management. In this study, farmers demonstrated different perceptions on varietal resistance to rust, ELS and LLS. In the EPMBZ, the Johari variety was perceived as most resistant to rust and leaf spot diseases while Nyota variety as most susceptible. The observation may be ascribed to that the Nyota variety was released earlier in 1983 hence higher possibilities of having lost its purity because farmers used farm saved seeds and Johari released later in 1985. Also such long time recycling could have caused genetic dilution leading to loss of genetic fitness to disease resistance (Sujay *et al.,* 2012). Mwalongo *et al.* (2020) reported that about 81% of the groundnut producers in Tanzania still use old varieties, which are less resistant to foliar diseases though new varieties were available. Only few groundnut growers used Naliendele and Mnanje varieties probably because it is one of the recently (2009) released varieties and many farmers might not be aware of the variety and its potential to increase yield. Another reason could be that the improved varieties are not yet made adequately available within farmsteads. Pendo variety released in 1998 is reported to be the most cultivated variety in this zone. In the EPMBZ majority of farmers perceived Naliendele and Johari as resistant to rust and leaf spot diseases respectively comparable to the coastal zone. Pendo, Mnanje, Serena ndogo and Serena kubwa were perceived by majority as resistant to the leaf spot diseases then Pendo and Mnanje varieties as resistant to rust disease.

## Conclusion

The study revealed that majority of groundnut farmers had inadequate knowledge on the fungal foliar diseases affecting groundnuts fields. Farmers in the Coastal zone had relatively higher awareness to rust disease compared to those in the EPMBZ. Groundnut rust and leaf spot disease occurrences were observed in all agro-ecologies. However rust and ELS were predominant in the EPMBZ while LLS was largely in the Coastal zone. Groundnut farmers in all two zones adopted management options to control diseases. These practices include intercropping groundnuts with tubers and legumes, usage of certified seeds and management of crop residues used by the majority EPMBZ. Removal of volunteer plants before sowing and conventional tillage were adopted by the majority of the farmers in the Coastal zone. Dissemination of knowledge on rust and leaf spot diseases management to the farmers would be the best option toward improved groundnuts productivity in Mtwara region.

## Acknowledgement

The authors extend acknowledgement to the Ministry of Agriculture for funding this study. The authors declare no conflict of interest.

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# Evaluation of Groundwater Recharge Dynamics using the Wetspass Model in the Usangu Plains, Tanzania

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**Abstract**

*A comprehensive understanding of groundwater recharge dynamics is of great importance in enhancing the sustainable management of the groundwater resources and the sound planning of their utilization. This study aimed at evaluating the groundwater recharge dynamics in the Usangu Plains (20,810 km$^2$) by the help of a hydrological GIS-based model named WetSpass. The Water and Energy Transfer between Soil, Plants, and Atmosphere under quasi-Steady State (WetSpass) model used land use/landcover, soil texture, topography, slope, groundwater table and hydrometeorology data to simulate the temporal (yearly and seasonal) averages and spatial differences of groundwater recharge, surface runoff and actual evapotranspiration. The findings of this study showed that 17.8% of the mean annual rainfall contribute to the groundwater storage while 66.1% and 16.1% are lost through evapotranspiration and surface runoff, respectively. The high rates of evapotranspiration occurred in the wet season and in the seasonal/permanent wetlands and water body. Also, the maximum amount of surface runoff took place during the rainy season and in the built-up and in bare land vegetation types given the impervious state of their ground surfaces. About 25% (1.025km$^3$/year) of the annual recharge was found to be the groundwater that can be safely extracted for domestic and economic purposes. Compared to the water lost through evapotranspiration and surface runoff, the simulated portion of groundwater recharge is noticeably low. Consequently, it could be wise to initiate the rainwater harvesting technologies and artificial groundwater recharge strategies particularly in the zones with moderate and low recharge rates to boost the groundwater storage as its users cannot cease to increase.*

***Keywords***: recharge dynamics, groundwater safe yield, WetSpass, Usangu Plains

## Introduction

Groundwater is an important natural resource that forms components of the hydrologic cycle with contribution to the economic development and environmental sustainability (Bhanja *et al.,* 2018). It sustains the ecosystems through maintenance of rivers while stabilizing land in areas with soils that are easily compressed (Foster, 2016). Its quantification is the mainstay of the water resources management and utilization. Though the groundwater is mainly lost through evapotranspiration and surface water bodies, its storage is replenished by the hydrologic process called groundwater recharge (Nyagwambo, 2006). Groundwater can be recharged directly from precipitation, locally from depressions and rivulets, indirectly from rivers, irrigation losses (Vries and Simmers, 2002), urban recharge and intermediate recharge (Scanlon *et al.,* 2006). The indirect and intermediate groundwater recharges imply that some of runoff could end up with groundwater recharge before or after joining in surface water courses (Lei *et al.,* 2010).

For irrigation purpose, groundwater is readily available, more suitable in quantity and naturally sheltered from direct surface contamination by anthropogenic actions (Fenta *et al.,* 2014). However, a great number of farmers rely on surface water resources to meet their crop water requirements. While it is noted that surface water sources are prone to seasonal variations due to climate change and global warming and are disposed to contamination caused by human activities (Meresa and Taye, 2019), still the comparative advantages of groundwater over surface water are not adequately taped. Little understanding of groundwater dynamics may be among the reasons of its limited utilization. Scanlon *et al.* (2006) indicated that there is a gap of knowledge concerning temporal and spatial distribution of groundwater recharge across Africa. In Tanzania, the knowledge gap is partly caused by limited aquifer data as reported for major aquifers (Mahoo *et al.,* 2015). Thus, insufficient data and information for major aquifers in Tanzania has resulted to insufficient groundwater resources management (Mahoo *et al.,* 2015). Consequently, limited information is available on the estimates of recharge flux for diverse aquifers in Tanzania. The available information of estimates for underground water recharge flux are that of the Makutupora groundwater basin which provides ranges between 1 to 2% of annual rainfall (Rwebugisa, 2008). There is a need to conduct studies on groundwater recharge dynamics for different aquifers. The studies are essential for enriching the understanding of recharge dynamics of diverse aquifers for the purpose of enhancing the sustainable management of the groundwater resources.

Groundwater recharge dynamics are very essential for the water resources management strategies. The focus of this study is the Usangu Plains as the areas have great lack of understanding on groundwater recharge dynamics despite the area being rich in research activities (Rwebugisa, 2008). It is well established that, insufficient information of recharge dynamics leads to the unsuitable development of groundwater resource (Shah *et al.,* 2000), which is a key element to expand the water supply to satisfy the domestic use and irrigation requirements. Due to the increasing irrigation water demands in Usangu Plains and the anticipated shifts of water withdrawal towards groundwater, the assessment of groundwater recharge dynamics is recommended with its spatial and temporal distribution for its efficient use.

Diverse methods have been used for the groundwater recharge quantification (Scanlon *et al.,* 2002). They can be generally categorized into numerical modelling, physical techniques, water balance approaches, chemical tracing, streamflow analysis and many more (Huet *et al.,* 2016). For the spatial and temporal evaluation of groundwater recharge, the numerical modelling approaches have been appreciated by many researchers for the accurate, reliable, and rapid estimations (Arshad *et al.,* 2020; Batelaan and De Smedt, 2007; Hailu *et al.,* 2018; Kashaigili *et al.,* 2006; Maréchal et al., 2006; Meresa and Taye, 2019; Wahyuni *et al.,* 2008). Among numerical modeling approaches, the use of GIS (Geographical Information System)-based models is adequate in handling the spatial and temporal variability (Tilahun and Merkel, 2009). In particular, the Water and Energy Transfer between Soil, Plants, and Atmosphere under quasi-Steady State (WetSpass) model has been used to evaluate the temporal averages and spatial differences of groundwater recharge on a seasonal and annual basis. The GIS-based WetSpass model functions depending on groundwater levels, topography, land use, soil texture and hydrometeorological factors (Batelaan and De Smedt, 2007).

This study is designed to analyze the groundwater recharge dynamics for Usangu Plains aquifer using the GIS-based WetSpass model. Specifically, the study intends to (1) determine the water budget components, (2) investigate the groundwater recharge zones and (3) evaluate the quantity of groundwater that can be extracted safely from the Usangu Plains aquifer for economic and domestic use to enhance the sustainable management of the water sources.

## Materials and methods

### Description of the study area

The study was conducted in Usangu plains, Tanzania (Fig. 1). The area is located at an average elevation of 1,100 m above mean sea level (amsl). The area is encircled by the Kipengere, Poroto and Chunya mountains with an elevation reaching 3,000m amsl. Usangu Plains cover an area of approximately 20,810 km$^2$ (Kadigi *et al.,* 2004) and lie between latitudes 7°41' and 9°25' South and longitudes 33°40' and 35°40' East. Its climate is mostly influenced by the air mass movements together with inter-tropical convergence zone (Kashaigili *et al.,* 2009). The Usangu Plains' rainfall regime is unimodal, having one wet season from December to June, with some irregularities, the rainfall distribution varies spatially and is very localized depending on the altitude (Kashaigili *et al.,* 2009). The mean annual rainfall is between 1000 and 1600 mm within the highlands while the central plains, formed of dry fans and wetlands ecosystems, receives 500-700 mm from July to November (Malley *et al.,* 2009). The Usangu Plains' mean annual temperature is between 18°C and 28°C in the highlands and lower parts, respectively and its mean annual potential evapotranspiration goes up to 1,900mm (SMUWC, 2001). The land vegetational cover differs from the high to the low altitudes, where between 2,000m and 1,100m amsl are dominated by the miombo woodland and below 1,100m amsl are the fans, the wetland ecosystems, and agricultural lands (SMUWC, 2001). The high increase of population and the expansion of anthropogenic activities within and in the vicinity of the wetlands have caused the extreme water demand. In both dry and wet seasons, there are water demand for irrigation, domestic use, livestock, brickmaking, and hydropower which is the major water user though taking place a long way downstream (SMUWC, 2001).

**Description of the WetSpass Model**

The WetSpass model is used to evaluate the groundwater recharge dynamics in the Usangu plains. The model is meant to simulate the temporal average and spatial differences of groundwater recharge, surface runoff and actual evapotranspiration. WetSpass stands for Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State (Batelaan and De Smedt, 2001). This model is fully integrated in the GIS ArcView (version 3.2) as raster model, coded in Avenue. WetSpass is a steady state spatially distributed and physically based water balance model. It simulates yearly and seasonal long-term average spatial patterns of the water budget components by employing physical and empirical relationships. Inputs for this model include grids of land use,

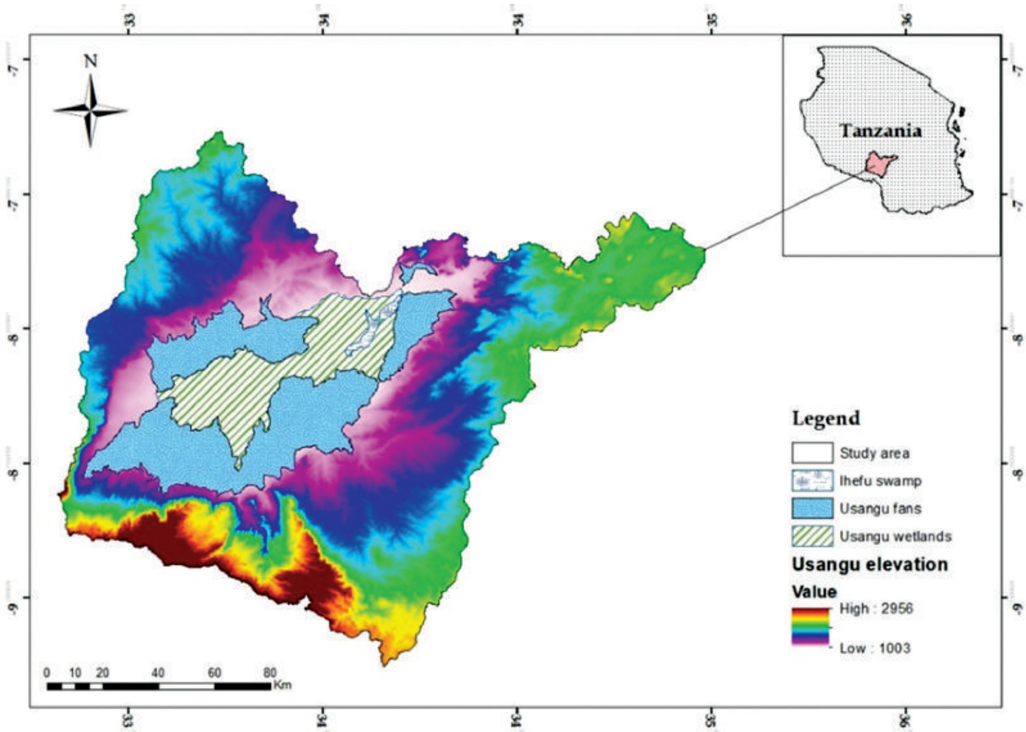


**Figure 1: Map of Usangu Plains showing topography, fans, wetlands, and swamp**

groundwater depth, precipitation, potential evapotranspiration, wind-speed, temperature, soil, and slope whereby parameters such as land-use and soil types are connected to the model as attribute tables of their respective grids.

Given that WetSpass is a distributed model, the water balance calculation is executed at a raster cell level. Individual raster water balance is obtained by summing up independent water balances for the vegetated, bare soil, open water, and impervious fraction of a raster cell (Fig. 2). The total water balance of a given area is thus calculated as the summation of the water balance of each raster cell (Batelaan and De Smedt, 2007).

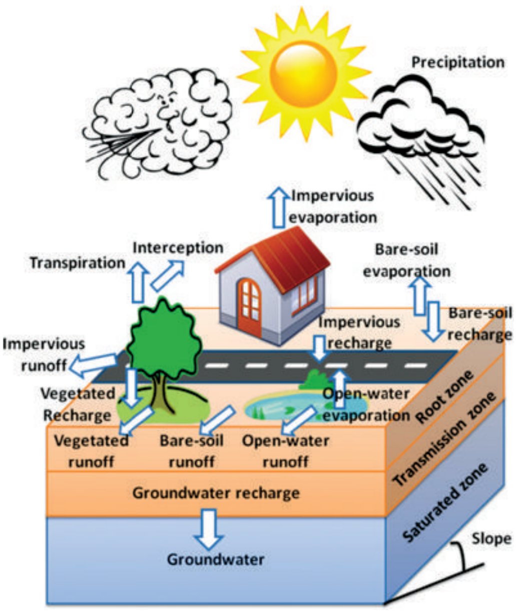


**Figure 2: Schematic representation of water balance for a hypothetical landcover grid cell (Batelaan and De Smedt, 2007)**

Concerning a vegetated area, the water balance depends on the average seasonal precipitation (P), interception fraction (I), surface runoff ($S_v$), actual transpiration ($T_v$), and groundwater recharge ($R_v$) all with the unit of [LT-1], referring to the equation given below:

$$P = I+S_v+T_v+R_v \quad (1)$$

Using the water balance components of vegetated, bare soil, open water, and impervious areas, the total water balance of a raster cell is therefore calculated as illustrated in the following equations:

$$ET = a_v\,ET_v+a_s\,E_s+a_o\,E_o+a_i\,E_i \quad (2)$$

$$S = a_vS_v+a_sS_s+a_oS_o+a_iS_i \quad (3)$$

$$R = a_vR_v+a_sR_s+a_oR_o+a_iR_i \quad (4)$$

Where ET, S and R are the total evapotranspiration, surface runoff, and groundwater recharge of a raster cell respectively, each having a vegetated, bare soil, open water and impervious area component denoted by $a_v$, $a_s$, $a_o$, and $a_i$, respectively.

## Description of input data for WetSpass model

As the WetSpass model necessitates seasonal-based parameters, seven months (December, January, February, March, April, May, and June) are considered as wet (winter) season and the remaining five months (from July to November) as dry (summer) season for the case of Usangu Plains (Kashaigili *et al.,* 2009).The inputs data were prepared in the form of grid maps using ArcGIS software (ArcGIS Desktop version 10.8 Copyright © 1995-2019 Esri Inc., USA) and parameter tables were edited in Microsoft Excel 365 (Microsoft Corporation, Redmond, WA, USA) and converted to dbf format by Advanced XLS Converter. The grid maps were of land-use, soil texture, slope, topography, groundwater levels, precipitation, potential evapotranspiration, temperature, and wind speed. The cell size of grid maps was 30m by 30m and had 7646 columns and 6345 rows. The grid maps were prepared through the ArcGIS environment using universal linear kriging interpolation method. The nearest and bilinear resampling techniques were used to set, respectively, continuous (all weather parameters) and discrete (soil) grid maps to the same resolution (30m). The input files prepared as parameter tables were summer and winter land use, soil texture and runoff coefficient. The runoff parameter table contains runoff coefficients for land use, soil type and slope angles.

## Hydrometeorological inputs

This study used global meteorological data provided by the NASA POWER version 1.0 last modified in 2019/12/19 (https://power.larc.nasa.gov/data-access-viewer/). The collected data from twelve global stations of the NASA

POWER within Usangu were precipitation, dew point, temperature (maximum and minimum), and wind speed at 2m of height from the soil surface. These daily data ranging from 01/01/2000 to 31/12/2017 were validated based on the observed meteorological information from Igawa, Kimani, Msembe and Matamba weather stations of the Usangu Plains. Solar radiation was derived from temperature using the Hargreaves' radiation formula. The daily extraterrestrial radiation values from Allen *et al.* (1998) were averaged to get monthly figures, given that Usangu plains are located in the southern atmosphere between 7 and 10 degrees of latitude. The actual evapotranspiration was computed through the Instat computer package which uses the FAO-Penman Monteith equation, as it is globally recommended for calculating the evapotranspiration (Rwebugisa, 2008). For the WetSpass requires meteorological inputs in the grid format on a seasonal basis, the universal linear Kriging interpolation method in the ArcGIS environment was used to prepare the grid maps of precipitation, temperature, wind speed and evapotranspiration; both for wet and dry seasons.

Groundwater (GW) level fluctuation data were obtained from the Rufiji Basin Water Board (RBWB). Six years, ranging from 2015-2020, daily groundwater level data of six boreholes were availed. The universal linear Kriging interpolation technique of the ArcGIS Desktop10.8 environment was used to generate the grid maps of the wet and dry seasons of GW depths. The adoption of mean GW depths does not influence the WetSpass simulation results if the GW depths in the study area are more than the root depths (Tilahun and Merkel, 2009). Since the water balance is regulated by some factors like precipitation, soil texture and land cover types (Nyagwambo, 2006), the combined method in ArcGIS environment was used to detect the influence of biophysical features on the water budget components.

**Table 1: The summary of meteorological data used**

| Parameter | Season | Minimum | Average | Maximum |
|---|---|---|---|---|
| Precipitation | | | | |
| (mm) | Wet | 800 | 1001 | 1229 |
| | Dry | 80 | 105 | 132 |
| | Annual | 893 | 1106 | 1361 |
| Temperature (C) | Wet | 17.99 | 20 | 21.66 |
| | Dry | 18.04 | 20 | 23.09 |
| | Annual | 18.01 | 19.90 | 22.37 |
| Wind speed (m/s) | Wet | 0.70 | 1.00 | 1.88 |
| | Dry | 1.18 | 2.00 | 3.00 |
| | Annual | 0.94 | 1.69 | 2.44 |
| Evapotranspiration (mm) | Wet | 651.7 | 728 | 808.9 |
| | Dry | 582.7 | 710 | 850.6 |
| | Annual | 1234.4 | 1438.2 | 1659.5 |

**Areal-based biophysical inputs**

**Topography and slope**

For slope and topography data, digital elevation model (DEM) of the study area was extracted from the Shuttle Radar Topography Mission (SRTM) available on the United States geological survey (USGS) earth explorer website (https://earthexplorer.usgs.gov/) at a spatial resolution of 30m. The raster images were imported into ArcGIS 10.8 and merged to cover the whole study area. With the Usangu basin boundary, its raster was clipped from the combined satellite images. The clipped raster of Usangu was used to create elevation and slope grid maps of the Usangu Plains using spatial analyst tools of ArcGIS 10.8, considering the year 2017 for spatial data. The elevation ranges from 1003m to 2956m (Fig. 3(b)) above mean sea level with an average of 1429m and the slope varies from 0% to 74% (Fig. 3(a)).

**Soil texture**

Soil textural information is an important input of the WetSpass model for the recharge quantification. As far as this study is concerned, the soil data were obtained from the FAO-UNESCO (http://www.fao.org/geonetwork/srv/en/metadata.show%3Fid=14116) digitized (vector dataset) soil map of the world at a scale of 1:5,000,000. ArcGIS software was used to clip the soil textural map of the Usangu Plains from the digital soil map of the world. The attribute table of soil textures of Usangu was adjusted using the Soil Water Characteristics program developed by United States Department of Agriculture (USDA) Agricultural Research Service (http://hydrolab.arsusda.gov/soilwater/Index.htm). The textural classes were found to be clay (24%), clay loam (32%), sandy clay loam (13%), loamy sandy (3%) and sandy loam (28%) (Fig. 3(c)). The soil classes outputs of this program were validated based on the soil textural triangle.

**LULC classification**

Land use/land cover data were processed based on Landsat 8 images of the year 2017 extracted from the United States geological survey (USGS) earth explorer website at a spatial resolution of 30m. Usangu catchment covers three different paths and rows, the periods of the Landsat images used in the area of interest and their respective rows and paths are given in Table 2. Land use classification was made using Random Forest classifier in the R-Studio software after performing a supervised classification in ArcGIS environment to generate the spectral classes (regions of interest, ROI). The classification accuracy assessment was executed based on the Google Earth pro truths of

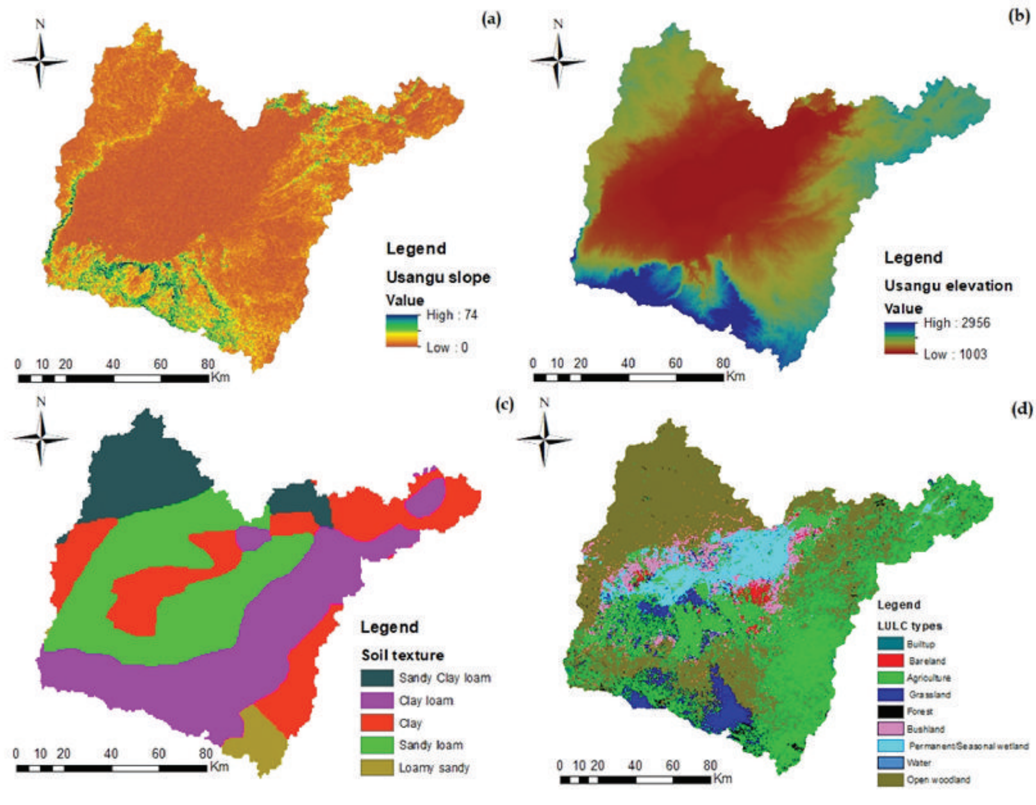


**Figure 3: Slope map (a), topographic map (b), Soil textural map (c) and LULC map (d) of the Usangu Plains**

the Usangu catchment boundaries. The overall classification accuracy was 82.5% while the overall Kappa statistics was 83.2%. Normally, the land use/ land cover classification accuracy assessment results (Fig. 3(d)) in this study are satisfactory, for the kappa statistics greater than 80% represent strong accuracy between the performed classification and ground truth information (Manandhar *et al.,* 2009).

**Table 2: characteristics of the Landsat 8 images of the Usangu Plains**

| Period | Path | Row |
|---|---|---|
| 2017-05-02 / 2017-05-15 | 168 | 066 |
| 2017-11-17 / 2017-11-22 | 169 | 066 |
| 2017-11-17 / 2017-11-22 | 169 | 065 |

## Results

### The water budget components of the Usangu plains

#### *Surface runoff*

The spatial mean annual surface runoff estimated by the model is presented in Figure 4(a). Seasonal and annual average values of surface runoff are illustrated Table 3 in comparison with the annual average rainfall and other features. The annual surface runoff simulated by the model varies from 1 to 1,005 mm with an average of 178mm which represents 16.1% of the annual mean rainfall (1106 mm). About 85.4% of the surface runoff occurred in the wet season while the remaining 14.6% happened during the dry season. The maximum amount of annual average surface runoff (813-1005mm) takes place in the built-up and in bare land vegetation types given the impervious state of their ground surfaces. On the other hand, the minimum runoff (1-95mm) occurred in sandy loam and loamy sandy soil types (Fig. 4(a) and 5(a)).

#### *Evapotranspiration*

The WetSpass model computed the total actual evapotranspiration (AET) as a sum of evaporation from the bare soil within land cover types, evaporation from rainwater intercepted by vegetation, evaporation from open water bodies, and transpiration from the vegetation canopy. The simulated spatial mean annual AET is presented in Figure 4(b) and compared to the mean annual precipitation in Table 3. The annual average AET is 731mm which represents 66.1% of the annual rainfall (table 3). 80.4% (588m) of the mean annual evapotranspiration occurred in the wet season whereas 19.6% (143mm) happened in the dry season. The maximum evapotranspiration took place in the seasonal/ permanent wetlands and water body (Fig. 5(b)). The next highest values of evapotranspiration occurred in the forest, this is because of the high transpiration and evaporation from the intercepted water. The lowest values are from built-up and bare land due to the impermeable surfaces which allow more surface runoff than transpiration and interception.

#### *Groundwater recharge*

The average long-term annual groundwater recharge in the Usangu plains simulated by the WetSpass model is presented in Figure 4(c) with comparison to the annual average precipitation in Table 3. The simulation results proved the spatial and temporal variations of the groundwater recharge process within the area. The recharge dynamics depend much on the hydrometeorological conditions, land use/ landcover composition and soil textures. The model results for the winter, summer and annual average recharge are 254mm, -29mm and 226mm, respectively. This temporal variation of recharge is caused by the reason that during dry season there is high evapotranspiration compared to the precipitation. The fact that the mean dry season recharge reached a negative value of -29mm indicated the absence of groundwater recharge and led to a decrease of 2.6% of annual average recharge.

Therefore, about 17.8% (197mm) of the annual average recharge represents the contribution of the rainfall to the groundwater storage. The highest annual values of recharge occurred in all soil classes covered by open woodland but specifically in loamy sandy and sandy loam soil types. The lowest recharge values appeared in clay soils covered by wetlands, bare land, and water body; and sandy clay loam soils covered by water body (Fig. 5(c)).

**Table 3: Water budget components of Usangu Plains simulated by the WetSpass model**

| Parameter | Summer (mm) | Winter (mm) | Annual (mm) | Percentage (%) |
|---|---|---|---|---|
| Precipitation | 105 | 1001 | 1106 | 100 |
| AET | 143 | 588 | 731 | 66.1 |
| Surface runoff | 26 | 152 | 178 | 16.1 |
| Recharge | -29 | 254 | 226 | 17.8 |

## Groundwater recharge zones of the Usangu Plains

Ensuing the total annual groundwater recharge, the potential recharge zones in the Usangu Plains are illustrated in Figure 4(d). The natural break slice method in the ArcGIS environment was used to investigate the recharge zones. There were three zones of recharge with different rates (0-138mm/year, 139-337mm/year and 338-767mm/year). The groundwater recharge zone with the highest recharge rates occupied 47% of the total Usangu area, the zone receiving the moderate recharge rates has 30% while the zone with the lowest rates occupied 23%.

On Figure 4(d), groundwater recharge is mostly happening in the southern part and in some zones of the north-eastern and north-western places. The moderate recharge rates occurred in the northern and some central zones of the area. The lowest rates are located majorly in the central and southwestern zones of the Usangu catchment.

## Groundwater safe yield of Usangu Plains

The term safe yield of groundwater in a catchment is used when determining the amount of water that can be extracted from the catchment without depleting the storage (Meyland, 2011). Safe yield is considered as percentage of

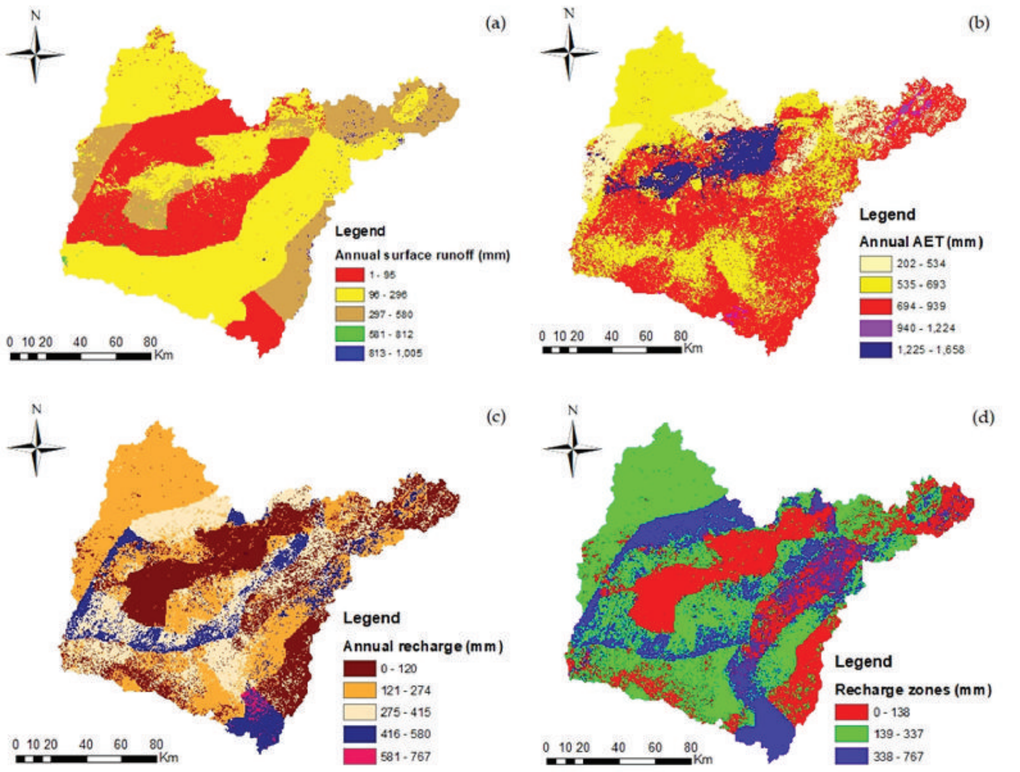


**Figure 4: Map of annual average of surface runoff (a), annual average of AET (b), annual average of recharge (c) and recharge zones (d) of the Usangu Plains**

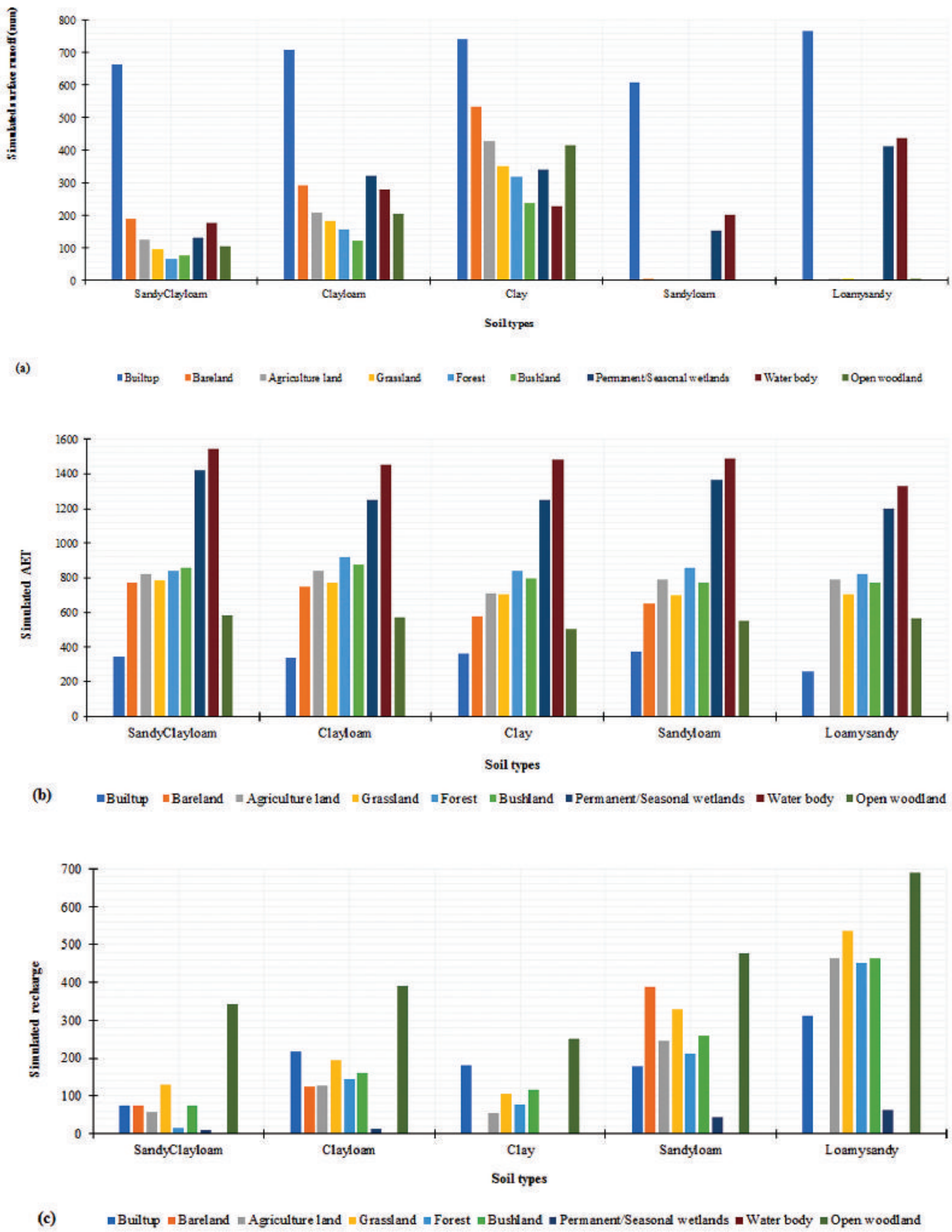


**Figure 5: Simulated mean annual surface runoff for combinations of LULC and soil texture (a), simulated mean annual AET for combinations of LULC and soil texture (b), simulated mean annual recharge for combinations of LULC and soil texture (c).**

groundwater recharge; moreover, a number of authors suggest different percentages of safe yield, from the least conservative (100%) to the reasonably conservative (10%) (Gebreyohannes *et al.,* 2013). This concept implies the sustainable groundwater management to the extent of not exceeding the annual recharge and remain within the safe level of groundwater

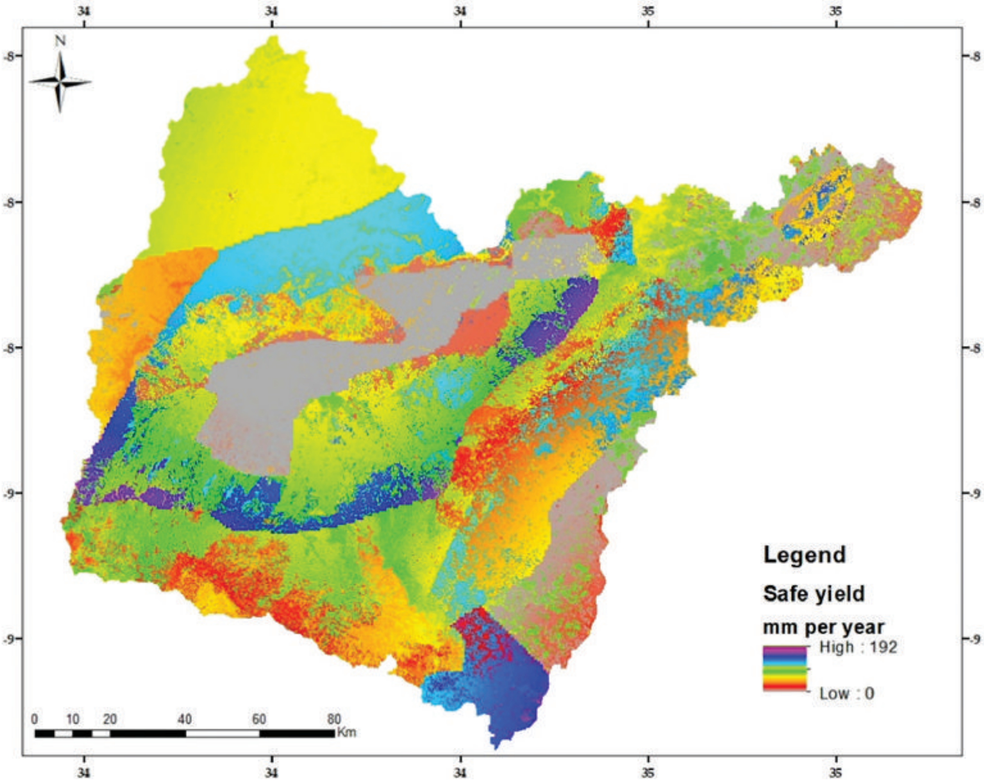


**Figure 6: groundwater safe yield of the Usangu Plains**

utilization (Russo *et al.,* 2014). Practically, the sustainable yield of groundwater of more than 10% of annual recharge requires to account for the groundwater-dependent ecosystems (Zeabraha *et al.,* 2020). Three studies done in Ethiopia (Gebreyohannes *et al.,* 2013; Meresa and Taye, 2019; Zeabraha *et al.,* 2020) adopted the safe yield of 25% of recharge. Consequently, the reasonably conservative estimate of safe yield of 25% of the mean annual recharge was adopted for the Usangu plains from the formula below:

$$SY = 0.25*R \qquad (5)$$

where SY is safe yield (mm/year) and R the total mean annual groundwater recharge (mm/year). According to equation 12 and Figure 6, the groundwater safe yield ranges from 0 to 192mm/year with an average of 49.25 mm/year. Considering the area of Usangu (20810km$^2$), 1.025km$^3$/year of groundwater can be safely withdrawn for irrigation, domestic use and many more purposes. 3.996 km$^3$ being the maximum of groundwater to be extracted annually.

**Discussion**

The aim of this study was to evaluate the spatial and temporal (seasonal and annual) distribution of the groundwater recharge in Usangu Plains using the WetSpass model. The model simulated the water budget components (surface runoff, actual evapotranspiration, and groundwater recharge) of the Usangu Plains.

Surface runoff depends mainly on the availability of land use/landcover types, soil type, rainfall, topography and slope of the area (Batelaan and De Smedt, 2007). As Figure 5(a) illustrates, surface runoff was very high in the clay, clay loam and sandy clay loam soils covered with built-up and bare land because of the less infiltration capacities of the soil types similar to the findings of the study done by Zeabraha *et al.* (2020). Likewise, the highest values of surface runoff occurred in sandy loam and loamy sandy soils covered by built-up areas due to the imperviousness of this surface cover type. On the other hand, the minimum surface runoff happened in loamy sand and sandy loam soils covered by forest, open woodland, bushland, agricultural land, grassland, and uncovered soils as a result of the highest permeability of the soils and the high evapotranspiration rate of the land cover types. As SMUWC (2001) reported, a high proportion of vegetation in Usangu reduces the rate of runoff. There was less runoff amount in the lowland compared to the highland of Usangu (Fig. 3). Similar to the study done by Tilahun and Merkel (2009), this study showed that elevation and slope are major factors causing the high surface runoff rate.

The study of Helena (2016) showed a great increase of evapotranspiration in the Usangu catchment in both dry and wet seasons. This is proved by the fact that the evapotranspiration losses passed from about 700mm/year (SMUWC, 2001) to 731mm/year as per the findings of this study. The high rate of AET occurred in sandy clay loam soil covered by open water sources, then followed clay loam covered by forest. Uncovered loamy sandy soils present low rates (Fig. 5(b)). AET decreased in the highlands compared to the lowlands of the Usangu Plains because of the high altitudes and low temperature. This decrease of AET in highland can be a factor to enhance agricultural activities during dry season. In agreement with other studies conducted in Usangu catchment and worldwide (Kashaigili *et al.,* 2009; Rwebugisa, 2008; SMUWC, 2001; Helena, 2016 and Zeabraha *et al.*, 2020), the major factors influencing the actual evapotranspiration are soil texture, land use/landcover types and climate parameters.

SMUWC (2001) defined the lowlands in Usangu catchment as areas below about 1100m of elevation and the remaining areas above 1100m to be the highlands. The same report (SMUWC, 2001) considers the whole zone of highlands as groundwater recharge area. Similarly, this study found that the highest recharge rate occurred in the south-western highland and slightly above the lowland zones (Fig. 4(d)). The minimum recharge happened in the lowlands particularly the zones covered by the permanent and seasonal wetlands for they act as discharge zones of the catchment. Figure 5(c) shows the maximum occurrence of recharge in loamy sandy and sandy loam soils covered by open woodland, grassland, bushland, and agricultural land due to the fact that the soil types have good infiltration capacity and the land use/landcover types which reduce surface runoff rate. It is also due to the low rate of evapotranspiration caused by less temperature and high elevation (SMUWC, 2001). A study done in Ethiopia (Meresa and Taye, 2019) indicated that clay soils covered with wetlands, water bodies and clay-based bare lands had low recharge values similar to the findings of this study (Figure 4(d)). The comprehensive understanding of potential recharge zones in the Usangu Plains is of paramount benefit for locating areas of conservation.

The study conducted in Dodoma, Makutupora basin, indicated that recharge represents 1-2% of annual rainfall (Rwebugisa, 2008), this is because the area is arid and receives less amount of annual rainfall compared to Usangu Plains. In contrast, 17.8% of annual rainfall in Usangu Plains go to the groundwater reserve. The sustainable groundwater yield was adopted to be 25% of the annual groundwater recharge (Fig. 6) to account for other groundwater-dependent users as it has been stated by the study conducted in Ethiopia (Zeabraha *et al.,* 2020). The information on the safe yield plays a tremendous role in conserving the groundwater storage. This study agreed that topographic, soil types, land use and land management are driving factors of spatial and temporal recharge dynamics.

## Conclusions and Recommendations

Groundwater usage covers many sectors such as irrigated agriculture, domestic use, industrialization, livestock, and many more. Sustainable management of the groundwater storage is vital; however, it requires a clear understanding of the groundwater recharge distribution whether spatially and/or temporally. This study aimed at evaluating the groundwater recharge dynamics in the Usangu plains using the hydrological WetSpass model to help water users and decision makers have a comprehensive understanding of the quantity of recharge that replenishes the groundwater storage. The model showed that 17.8% of the annual rainfall goes to groundwater storage while 16.1% and 66.1% go to surface runoff and actual evapotranspiration, respectively. Low slopes and a high proportion of vegetation were found to reduce the surface runoff, hence increase the groundwater recharge contribution. Open water sources and vegetated soils have high rates of actual evapotranspiration. The model reported the absence of groundwater recharge in the dry season; however, 47% of the total Usangu area receives the high rates (338-767mm/year) of groundwater recharge in southern zone and some zones of the north-eastern and north-western area. The northern and some central zones of the Usangu Plains are moderately recharged while the lowest recharge rates occurred mainly in the central and southwestern zones. The groundwater safe yield was 25% of the total annual recharge allowing 1.025km$^3$/year to be sustainably abstracted to mainly support all the water requirements in the Usangu plains without depleting the groundwater storage. The findings of this study are useful as a base for future groundwater recharge-oriented considerations. Further studies are needed to understand the interactions between groundwater recharge dynamics and groundwater withdrawal (pumping) actions in the Usangu Plains for the sound and efficient management. Moreover, there must be rigorous regulations for groundwater drilling/extracting entities to not deplete the water storing capacity which may lead to the water usage conflicts. Compared to the water lost through evapotranspiration, the simulated portion of groundwater recharge is obviously low. Consequently, it could be wise to initiate the rainwater harvesting technologies and artificial groundwater recharge strategies particularly in the zones with moderate and low recharge rates to boost the groundwater storage as its users cannot cease to increase.

**Acknowledgements**

The first author is an MSc student under the East African Community Scholarship Program through the Inter-University Council for East Africa; therefore, the Scholarship Program is greatly acknowledged for financially enabling this study. The Authors are grateful to the Rufiji Basin Water Board for availing groundwater levels data.

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# Relationship between Plant Parasitic Nematodes, Arbuscular Mycorrhizal Fungi and Soil Characteristics on Clove (*Syzygium aromaticum* (l.) Merr and Perr) Agroecosystem in East Usambara Mountains-Tanzania

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**Abstract**

*Native communities of arbuscular mycorrhizal fungi (AMF) and plant parasitic nematodes (PPN) were examined in fields previously under climate-smart agriculture (CSA) and non-climate smart (NCSA) of the East Usambara Mountains. The field were differing in soil properties and agricultural practices. Soil samples were taken from 10 sites in each of the 30 fields. AMF spores and PPN were isolated using wet- sieving method and the Baermann tray method, respectively. The isolated fungal spores and PPN were morphologically identified, classified and quantified. A total of 10 AMF and 27 PPN genus were recorded. The CSA and NCSA fields had 51% and 56% of genus Glomus, respectively. About 73.2% and 72% of genus Rotylenchulus were recovered in CSA and NCSA, respectively. No association was found between AMF and PPN, a significant correlation between PPN and AMF abundance with agricultural practices was observed (p=0.001). No significant difference was found between AMF (p=0.8) and PPN communities (p=0.6) with agriculture practices. Correlating AMF and PPN with soil properties showed no association and no significant difference except for PPN with total nitrogen (p=0.03). Whatever the causes of no significant difference between the treatments,the results suort that CSA practices can facilitate mycorrhizal colonization.. Our results showed that both agriculture practices didnot influence AMF and PPN abundance in the soil.*

***Keywords***: Arbuscular mycorrhizal fungi, climate-smart agriculture, cloves, plant parasitic nematodes

## Introduction

The clove tree, (*Syzygium aromaticum* (L.) Merr and Perr), originating from Indonesia has been used globally for its spice and aromatic properties. In Tanzania, cloves trees are grown in East Usambara Mountain characterized by a warm and humid climate (Baietto, 2014). It is cultivated for its unopened flower buds (Laban *et al.,* 2020; Suprihanti, 2020). The flower buds are used as spices and provide the raw material for cigarette production. It is also used in the production of essential oils which is needed by a variety of industries such as pharmaceuticals, food and drinks. Also, it serves as a source of income to smallholder farmers and a source of foreign exchange money for the country. Despite its economic importance, clove production is still very low with only 360 kg/ha of clove buds produced compared to its potential production of 600 kg/ha (Mardiningsih *et al.,* 2020).

Clove production tends to decline due to poor agronomic practices, climate change and susceptibility to pests and diseases (Maerere, 2014; Suprihanti, 2020). Among these constraints, plant parasitic nematodes (PPN) have been reported to be one of the main factors limiting clove production (Seguna, 2017). These parasites are capable of damaging roots and tubers (Schouteden *et al.,* 2015; Myint *et al.,* 2017; Vieira and Gleason, 2019). Nematode attack can lead to plants infection by other pathogens (Ye *et al.,* 2015; Gnamkoulamba *et al.,* 2018) such as plant viruses (Schouteden *et* *al.,* 2015) and fungi (Upadhaya *et al.,* 2018) which later lead to delayed crop maturity and yield reduction (Onkendi *et al.,* 2014; Gnamkoulamba *et al.,* 2018) and eventually death of the plant (Mwesige *et al.,* 2016).

Estimated crop yield loss due to PPN annually is US$100 billion worldwide because these soil-borne pathogens are very difficult to control (Benjlil *et al.,* 2019; Mateille *et al.,* 2020). Several strategies have been developed to control phytonematodes. These include the use of nematicides, crop rotation and the use of resistant varieties (Mwesige *et al.,* 2016; Chitambo *et al.,* 2019; Mateille *et al.,* 2020; Nzogela *et al.,* 2020). However, these practices have not been effective enough because some resistant crop varieties are reported to increase PPN (Chitambo *et al.,* 2019). Some component crops in crop rotation are known to hosts a wide range of PPN (Nzogela *et al.,* 2020). The use of synthetic pesticides has a detrimental effect on public and environmental health (Olaifa and Adenkule, 2016) but is also too expensive for farmers to afford. In the eye of integrated Pest Management (IPM), the use of biocontrol agents like arbuscular mycorrhizal fungi (AMF) is proposed. The use of AMF is known to be much safer, sustainable and eco-friendly solution for the management of PPN. AMF form an obligate mutualistic symbiotic association with various plant species, which often improve uptake of plant nutrients, improve plant growth and protect the plant from pathogens (Singh *et al.,* 2019; Wolfe *et al.,* 2020; Zhu *et al.,* 2020). Application of AMF to a large number of crop species has proved to lower the number of PPN (Pinochet *et al.,* 1996; Hol and Cook, 2005; Elsen *et al.,* 2008). Sayed and Kesba (2005) reported that AMF suppressed PPN in grapes. Affokpon *et al.* (2011) reported that native AMF suppressed nematode populations in the vegetable crops.

In general, the PPN are detrimental to plant health while AMF is beneficial, however, they both share plant roots as a source of space and food (Majic *et al.,* 2008; Hol and Cook, 2015). But their populations and interaction vary among plant species and sites, this variation is attributed to differences in soil fertility and management practices (Jefwa *et al.,* 2009; Dobo *et al.,* 2016; Fleming *et al.,* 2016; Herrejon *et al.,* 2019; Modal *et al.,* 2018; Upadhaya *et al.,* 2018; Adeyemi *et al.,* 2019; Hontoria *et al.,* 2019; Summuna *et al.,* 2019). The abundance of these microbial communities are influenced by soil characteristics like soil pH, soil type and organic matter (Upadhaya *et al.,* 2018; Mokrini *et al.,* 2019). Other studies indicate that farming practices can influence mycorrhizal association with plants (Herrejon *et al.,* 2019). The practices influence the mutualistic association between AMF and PPN because they can as well affect the populations of PPN and AMFs (Upadhaya *et al.,* 2018).

Many research works on AMF - nematode interaction has focused on specific groups of nematodes. Only limited information is available on the main drivers of AMF population dynamics as influenced by different agriculture practices (Herrejon et al., 2019). Few studies have examined the AMF-PPN interactions ( Pinochet *et al.,* 1996; Elsen *et al.,* 2008; Herrejon *et al.,* 2019; Hontoria *et al.,* 2019). A review by Pinochet *et al.,* (1996) indicates that numerous articles have addressed the interaction of AMF and PPN in diverse crops, but only a few studies have been reported such interactions with perennial crops including clove. The objectives of this study were to firstly establish the association between the population of native PPN and AMFs and secondly establish the influence of climate-smart, non-climate smart agricultural practices and soil properties with AMF and PPN soil communities

## Material and methods

### Location of the study area

The study was conducted in Zirai and Misalai wards within the East Usambara Mountains (EUM) in the Muheza district, Tanga region. Both wards are located at longitude 38°32′ and 38°48E, latitude 4°4′and 5°13′S and 600m-1, 300m above sea level. The study area is characterized by soft and steep slopes, humid tropical zone, with an average annual rainfall of 1 918 mm which is bimodal and a mean annual temperature of 20.6°C. The fields in the study area were comprised of perennial spice crop plantations grown as mixed cropping systems with cloves as the main crop. Cloves were intercropped with other spices such as cardamom, cinnamon and black pepper, and cloves intercropped with food crops such as root crops e.g. yams and cassava; cereals e.g. maize; and legumes e.g. beans.

**Soil Sampling**

The wards were selected purposively based on long term cloves growing and had previously practiced CSA practices. In each ward, 15 clove fields were purposively sampled. Soil sampling was done during the wet season on August 2019. Samples were collected during the clove reproductive phase (bud formation). The total sample size was thirty fields sampled purposively based on used climate-smart agricultural practices such as soil conversation methods including terraces, agroforestry and mulching, characteristics symptoms of plant parasitic nematode attack such as dwarf and drying of clove trees. At each field, one composite sample was made from 10 sub-samples that were randomly collected within a distance of 3m apart in a zigzag pattern. Two kilograms of rhizosphere soil and 500gram of roots were collected at a depth of 40cm using a soil auger. Plant roots were carefully collected in order to access the fine active roots where mycorrhizal colonization occurred. The samples were packed in plastic zip-lock plastic bag, transported to the laboratory, and kept at 40C before direct evaluation of plant parasitic nematodes, arbuscular mycorrhizal fungi and soil analysis.

**Extraction and identification of plant parasitic nematode**

The PPN in the soil and roots were extracted by using the Baermann funnel as described by Coyne *et al.* (2007). Before extraction, the roots were washed in running water, cut into small pieces and blended. Nematodes were killed and fixed in 1ml of glycerol, 10ml of formalin (40% formaldehyde) and 89 ml of distilled and permanent slides were mounted in glycerol. The PPN of each sample were identified to genus level based on morphological characteristics including body shape, stylet type, stylet length, mouth type, lip region, pharyngeal overlap, vulva position and tail shape (Mekete *et al.,* 2012). Nematodes were categorized by genera and enumerated under a stereomicroscope at 100× magnification.

**Isolation and identification of Arbuscular mycorrhizal fungi**

Soil samples were air-dried before AMF spores were isolated and enumerated. AMF spore isolation was performed using a method in Song *et al.,* (2019). To disperse the soil aggregates and release AMF spores, a 50g sample of air-dried soil was placed in a 2-L glass beaker filled with tap water to form a suspension. The suspension was agitated with a glass rod. The soil mixture was left for one hour and poured onto nested sieves with 500, 300, 180 and 53 μm openings. The residue collected in the smallest sieve were washed, transferred into a petri plate and placed under the dissecting microscope. Spores were picked via a micropipette glass and transferred to a microscopic slide. The spores were counted on a plate after 40X magnification using the stereomicroscope. The spore samples were later mounted on slides with PVLG (polyvinyl alcohol in lacto glycerol) and PVLG + Melzer's reagent (1:1 v/v). The AMF spore samples were identified by a microscope up to the genus level. The identification of AMF genera was made through morphological structures of spores, such as colour, size, characteristics of the spore wall (thickness and adornments), reaction to Melzer and spore-bearing hyphae and compared with descriptions of fungal genus according to the taxonomic key (Perez and Shenck, 1990). Also, the spores were identified by comparison with the aid of the site content of the international culture collection of arbuscular mycorrhizal fungi (INVAM) guideline http://invam.wvu.edu/the-fungi/classification.

**Isolation of AMF from clove roots**

Clove roots were separated, rinsed in tap water and cut into 1 cm pieces. Three grams of fine roots were cut into 0.5–1.0 cm pieces immersed in 10% KOH at 100°C for 1hour. Later the roots were washed in distilled water and stained using 0.05% trypan blue, 8% acetic acid and 92% distilled water for 30minutes. Mycorrhizal colonization was assessed using the root intersection method by Trouvetal *et* *al.,* (1986). The estimate of the proportion of infected roots was measured after 40X magnification using a dissecting microscope (40X) according to Trouvetal *et al.* (1986). Five replicates of 10 roots per slide were assessed for the presence or absence of AMF structures (arbuscules, vesicles, and hyphae) using a light microscope. The percentage of root colonization was performed by the observation of fifty root fragments of 1 cm, randomly selected to quantify mycorrhizal in each sample. These fragments were arranged in parallel groups of 10 to 15 in a drop of glycerinated water between slide and coverslip. Each fragment was carefully checked throughout its length, at magnifications of 100X and 400X. The presence of colonization in a root segment was recorded if only hyphae, arbuscule or vesicles were found. Total root colonization was calculated using the following formula: % Colonization = Total number of positive segments / Total number of segments studied x 100.

**Soil laboratory analysis**

Soil physiochemical analyses were carried out in the Soil Analysis laboratory of the Sokoine University of Agriculture in Morogoro. The soil samples were air-dried and sieved through a 2-mm sieve. The following soil characteristics were determined: Soil pH, total nitrogen (N), organic carbon (OC) and available phosphorus (P). Total N, organic carbon, available P and soil pH were analyzed following standard methods for tropical soils (Anderson and Ingram, 1993). Phosphorus was extracted using 0.5M $NaHCO_3$+0.01M ethylenediaminetetraacetic acid (EDTA) (pH 8.5, modified Olsen) using a 1:10 soil/solution ratio and considered to indicate "available" phosphorus (Olsen *et al.,* 1954). Organic carbon content was determined with the oxidation method of Walkley and Black (Nelson and Sommers, 1996). The total nitrogen was measured using the Kjeldahl nitrogen method (Kjeldahl, 1883). Soil pH was measured in an a queous suspension (1:2.5 w: v). The physical properties regarding the proportions of sand, silt and clay were determined by the pipette method (Claessen *et al.,* 1997).

**Statistical analysis**

The frequency of occurrence (FO), relative abundance (RA) and spore density (SD) equations (1, 2 and 3) were used to estimate the structure of the AMF community. These parameters were calculated by using the following formula: SD = number of spores in 300g air-dried soil, RA = (spore number of genus/ total spore number) x 100%, FO = (number of samples in which the genus was observed / total samples) x 100%. Where we determined the dominant AMF genus according to relative abundance (RA>3%) and frequency of occurrence (FO > 40%).

$$Spore\ density = \frac{Number\ of\ spores\ of\ genus}{Weight\ of\ air\ driedsoil} \quad (1)$$

$$Relative\ abundance = \frac{Number\ of\ spores\ of\ genus}{Total\ number\ of\ spores} \times 100 \quad (2)$$

$$Frequency\ of\ occurrence = \frac{Number\ of\ samples\ per\ genus\ observed}{Total\ number\ of\ samples} \times 100 \quad (3)$$

Following the formula in equations 4, 5 and 6, the population density, abundance, frequency of plant parasitic nematode genera were also assessed. The frequency and abundance of each nematode genus were assessed based on the limits established by (Fortuner and Merny, 1973). The frequency was calculated by dividing the number of positive samples in which the nematode was observed by a total number of nematodes and expressed as a percentage. Abundance indices were calculated as the logarithm of the average observed on nematode population density in the farms in which the genus was found (log 10 x +1) and a nematode was regarded as abundant if abundance value ≥ 2.3 (=200 individuals/L soil). A nematode was regarded as frequent in soil or roots when it was observed in at least 30% of the samples.

Population density (PD)

$$PD = \frac{Number\ of\ nematodes\ genus\ per\ sample}{300g\ of\ soil\ sample} \times 100 \quad (4)$$

Frequency of occurrence (FO)

$$FO = \frac{Number\ of\ fields\ positive\ for\ genus}{Total\ number\ of\ sampled\ fields} \times 100 \quad (5)$$

Abundance index (AI)

$$AI = \frac{Number\ of\ nematodes\ per\ gram\ of\ soil}{number\ of\ samples\ in\ which\ the\ nematodes\ was\ found} \quad (6)$$

Data were log transformed to meet normality, then t-test was used to compare significant effect of PPN and AMF abundance on CSA and NCSA practices. Pearson correlation analysis was used to examine the relationship between agricultural practices, soil parameters, PPN and AMF abundance.

## Results

### Occurrence of PPN in clove fields of EUM

Twenty-seven genera of PPN were identified in all the sampled fields of EUM (Table 1, Fig. 1). In CSA cloves fields, the prevalent nematodes were *Rotylenchulus* (100%), *Helicotylenchus* (93%) and *Meloidogyne* (83%) while NCSA fields, *Helicotylenchus* (100%), *Rotylenchulus* (93.3%) and *Meloidogyne* (86%). In CSA fields, *Rotylenchulus* (1029/300 g soil) had the highest

**Table 1: Population density, prevalence and average abundance of plant parasitic nematode from soil (300g) sampled from clove fields in East Usambara Mountain**

| | CSA | | | NCSA | | |
|---|---|---|---|---|---|---|
| **Nematode genera** | **PD** | **FO%** | **AI** | **PD** | **AI** | **FO%** |
| *Rotylenchulus* | 1029 | 100.0 | 1.84 | 1022.0 | 1.87 | 93.3 |
| *Radopholus* | 11 | 40.0 | 0.45 | 11.0 | 0.57 | 26.7 |
| *Helicotylenchus* | 147 | 93.3 | 1.06 | 145.0 | 1.03 | 100.0 |
| *Tylenchus* | 18 | 60.0 | 0.48 | 16.0 | 0.80 | 20.0 |
| *Tetylenchus* | 4 | 13.3 | 0.48 | 3.0 | 0.60 | 6.7 |
| *Tyleptus* | 0 | 0.0 | 0.00 | 1.0 | 0.30 | 6.7 |
| *Hoplolaimus* | 8 | 26.7 | 0.48 | 44.0 | 1.08 | 26.7 |
| *Scutellenoma* | 17 | 20.0 | 0.82 | 10.0 | 0.54 | 26.7 |
| *Pratylenchus* | 49 | 53.3 | 0.85 | 15.0 | 0.50 | 46.7 |
| *Ditylenchus* | 27 | 53.3 | 0.64 | 34.0 | 0.77 | 46.7 |
| *Seinura* | 6 | 26.7 | 0.40 | 23.0 | 1.10 | 13.3 |
| *Xiphinema* | 15 | 26.7 | 0.68 | 3.0 | 0.30 | 20.0 |
| *Merlinius* | 1 | 6.7 | 0.30 | 4.0 | 0.48 | 13.3 |
| *Melodoigyne* | 51 | 80.0 | 0.72 | 3.0 | 0.09 | 86.7 |
| *Oionchus* | 1 | 6.7 | 0.30 | 42.0 | 1.63 | 6.7 |
| *Tylenchorhynchus* | 8 | 26.7 | 0.48 | 1.0 | 0.07 | 40.0 |
| *Aphelenchoides* | 0 | 0.0 | 0.00 | 7.0 | 0.90 | 6.7 |
| *Actinolamiane* | 1 | 6.7 | 0.30 | 1.0 | 0.30 | 6.7 |
| *Criconema* | 1 | 6.7 | 0.1 | 1.0 | 0.30 | 6.7 |
| *Dolichodorous* | 3 | 6.7 | 0.60 | 1.0 | 0.30 | 6.7 |
| *Psilenchus* | 1 | 6.7 | 0.30 | 1.0 | 0.30 | 6.7 |
| *Hirshmaniella* | 1 | 6.7 | 0.30 | 0.0 | 0.00 | 0.0 |
| *Caloosia* | 1 | 6.7 | 0.30 | 1.0 | 0.30 | 6.7 |
| *Criconemella* | 1 | 6.7 | 0.30 | 0.0 | 0.00 | 0.0 |
| *Paratylenchus* | 1 | 6.7 | 0.30 | 1.0 | 0.30 | 6.7 |
| *Trichodorous* | 1 | 6.7 | 0.30 | 0.0 | 0.00 | 0.0 |
| *Tyencholaimalles* | 2 | 6.7 | 0.30 | 2.0 | 0.30 | 6.7 |

**Key:** *PD-population density. AI-abundance index. FO-frequency of occurrence. CSA = Climate smart agricuture, NCSA = Non climate smart agriculture*

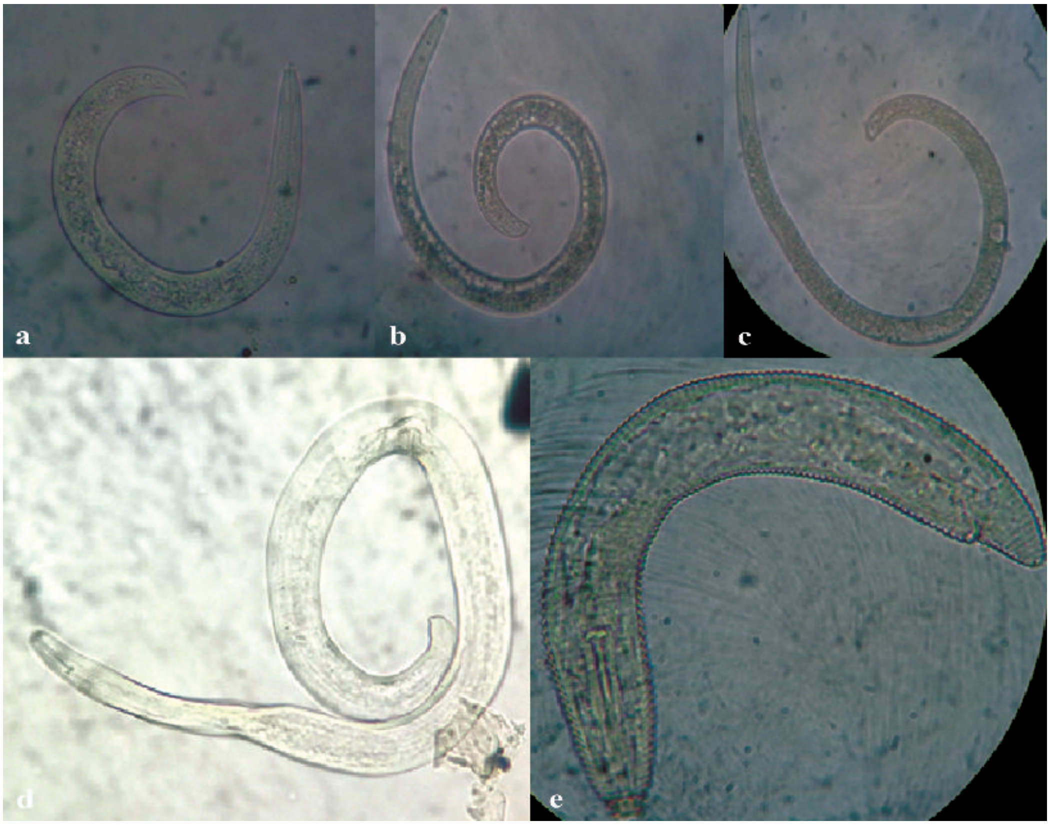


**Figure 1: Shows some of the morphology identification of plant parasitic nematode genera recorved from the survey from clove growing agroecosystem in East Usambara Mountains (x40) a. *Xiphinema* spp, b. *Helicotylenchus* spp, c. *Scutellonema* spp d. *Rotylenchulus* spp and e. *Criconema* spp**

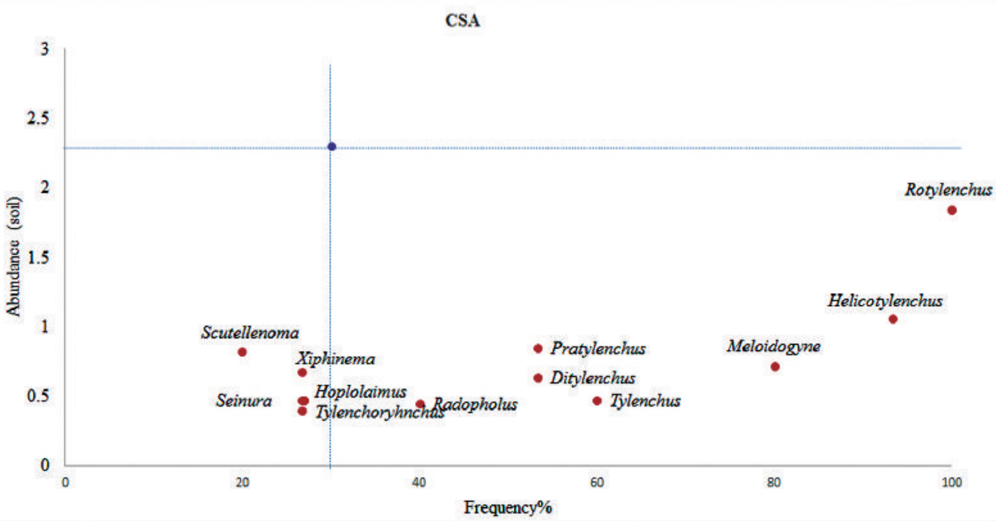


**Figure 2: Frequency and abundance of plant-parasitic nematode genera associated with climate-smart fields. Dotted vertical lines represent nematode frequency limit (F, 30%) and dotted horizontal lines represent the abundance threshold in soil (AI, 2.3) according to Fortuner and Merny (1973)**

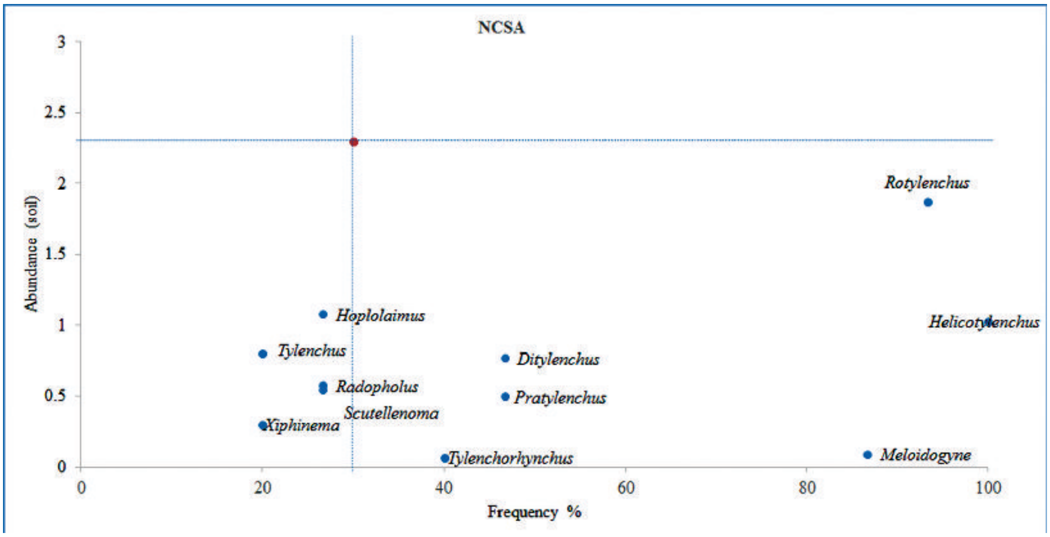


**Figure 3: Frequency and abundance of plant-parasitic nematode genera associated with non-climate smart fields (NCSA). Dotted vertical lines represent nematode frequency limit (F, 30%) and dotted horizontal lines represent the abundance threshold in soil (AI, 2.3) according to Fortuner and Merny (1973)**

population density followed by *Helicotylenchus* (147/300 g soil), while the rest of the genera had lower population densities ranging from 1 to 48/300 g soil (Table 1). In NCSA fields *Rotylenchus* had the highest population density (1022 /300 g soil), followed by *Helicotylenchus* (145/300 g soil). The population density of *Meloidogyne* was lower in NCSA (30/300 g soil) than in CSA fields (51/300 g soil). The genera with the highest mean abundance in both CSA (73.2%) and NCSA (72.7%) was *Rotylenchulus* (Table 1). However, there was no significance difference between abundance of PPN and agricultural practices (t=0.0012, p=0.8).

The frequency and abundance of plant parasitic nematodes in climate-smart fields (CSA) and non-climate smart fields (NCSA) with a population density above 5/300g soil are presented in dominance diagram in Figures 2 and 3. All nematode genera identified had low abundance indices (<2.3) and 40% of the genera were widely spread (F>30%).

## Occurrence of AMF in the clove fields in EUM

A total of 11600 fungal spores in CSA and 9747 fungal spores in NCSA were isolated from the soil rhizosphere. Out of these spore specimens, 10 genera were identified (Table 2, Fig. 3). Expressing relative abundance and isolation frequency in brackets. In CSA, *Glomus* (51.6, 100%), *Acaulospora* (24.38, 100%) *Gigaspora* (10.29, 100%), *Scutellospora* (8.53, 53%) and in NCSA Glomus (56.1, 100%), *Gigaspora* (12.22, 100%) and *Acaulospora* (22.93, 100%), *Scutellospora* (5.85, 53%) were the dominant genera (Table 2). However, there was no significant differenct between AMF abundance and agricultural practices (t=0.528, p=0.6)

## Mycorrhizal colonization

Generally, there was no significant difference between mycorhhizal colonization in both CSA and NCSA (p=0.0914).The mean mycorrhizal colonization in clove roots was 98.1% in CSA and 97.3% in NCSA (Fig 4, Fig 5).

## Soil properties of cloves in CSA and NCSA fields in East Usambara Mountain

Three classes of soil were identified in assayed clove fields, this includes clay, sandy clay and sandy clay loam. Soil collected from all 15 sites had moderately high pH values in NCSA field, ranging from 4.97 (field 2) to 6.41 (field 4) compared to CSA field where pH was generally low with the majority field having

**Table 2: Spore density (SD), relative abundance (RA) and isolation frequency (IF) of AMF from soil (300g) sampled from clove fields in East Usambara Mountains**

| Genera | CSA | | | NCSA | | |
|---|---|---|---|---|---|---|
| | SD | RA (%) | IF (%) | SD | RA (%) | IF (%) |
| Glomus | 5988 | 51.62 | 100 | 5469 | 56.11 | 100 |
| Gigaspora | 1194 | 10.29 | 100 | 1191 | 12.22 | 100 |
| Acualospora | 2828 | 24.38 | 100 | 2235 | 22.93 | 100 |
| Scutellospora | 990 | 8.53 | 53 | 570 | 5.85 | 53 |
| Racocetra | 120 | 1.03 | 20 | 54 | 0.55 | 20 |
| Redeckra | 42 | 0.36 | 20 | 36 | 0.37 | 13 |
| Sclerocytis | 192 | 1.66 | 33 | 108 | 1.11 | 33 |
| Dentiscuta | 54 | 0.47 | 27 | 24 | 0.25 | 7 |
| Claroideoglomus | 138 | 1.19 | 53 | 30 | 0.31 | 13 |
| Cetraspora | 54 | 0.47 | 40 | 30 | 0.31 | 13 |
| **TOTAL** | **11600** | **100.00** | | **9747** | **100.00** | |

*Dominant AMF genus was determined according to relative abundance (RA>3%) and isolation frequency (IF>40%) according to Dandan and Zhiwei (2007). CSA = Climate smart agricuture, NCSA = Non climate smart agriculture*

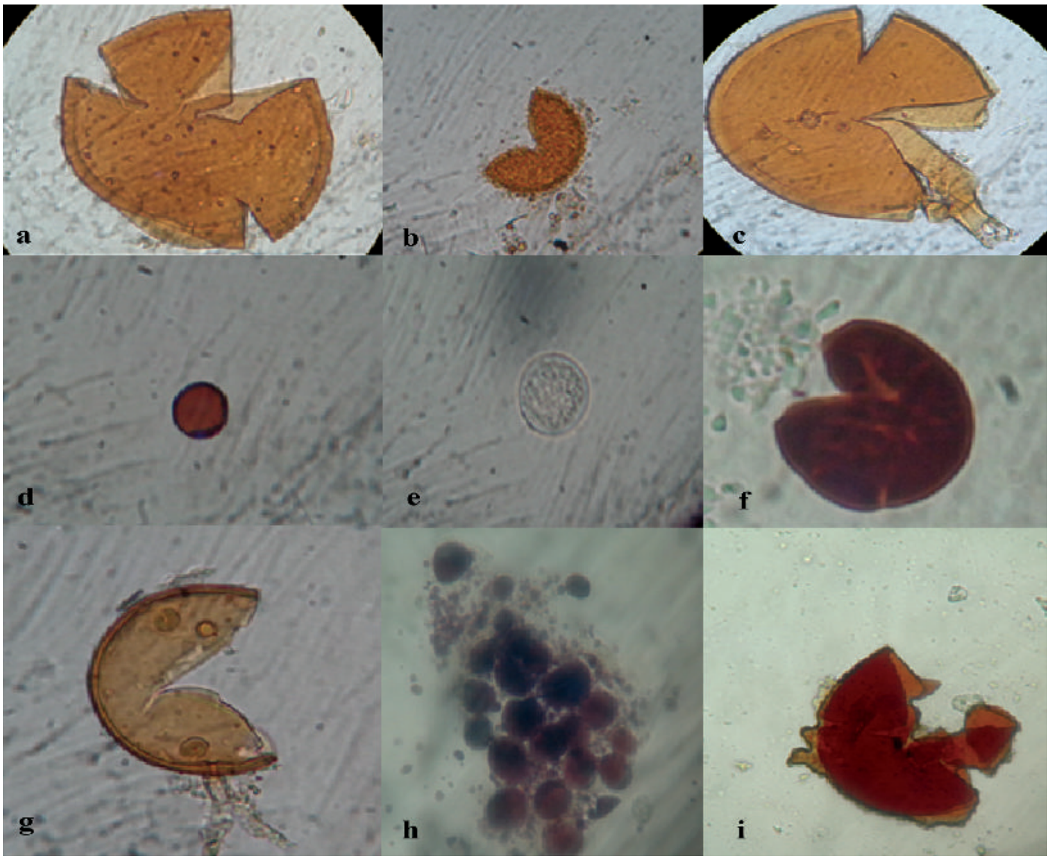


**Figure 4: Shows AMF spores isolated from rhizosphere soil of clove fields in East Usambara Mountain a-c. *Acualospora* spp, d-g. *Glomus* spp h. *Gigaspora* spp**

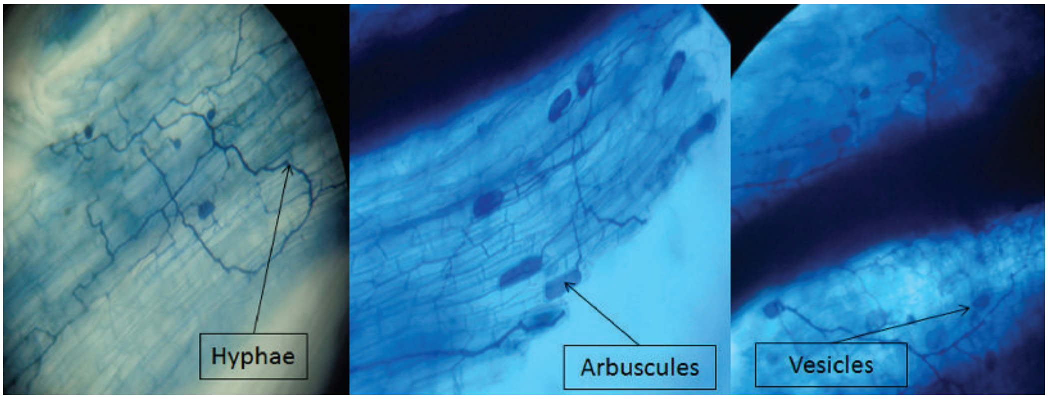


**Figure 5: Show clove root segment exhibited mycorrhizal colonization identified by the presence of hyphal structures such as arbuscules, vesicles and hyphae**

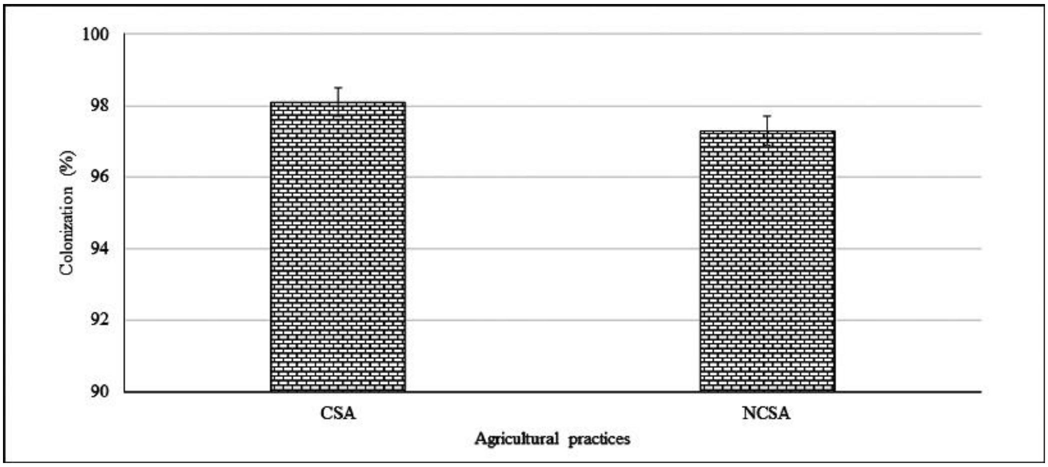


**Figure 6: Graph showing percentage of mycorrhizal colonization (presence of hyphae, vesicles and arbuscules) in CSA and NCSA fields. CSA = Climate smart agricuture, NCSA = Non climate smart agriculture**

pH lower than 6. The available P levels in CSA and NCSA fields were low and generally not different. Total nitrogen levels were low between the field that previously has CSA practices and those which has no CSA being practiced. Similar trends were observed for the potassium element. Organic carbon content was higher in CSA than in NCSA fields however it was very low in both fields.

**Relationship between agricultural practices, soil properties with PPN and AMF abundance**

Correlation analysis was performed among different fields in order to determine if there was a relationship between the abundance of AMF, PPN and the use of agricultural practices. There was significant ($p=0.001$) positive correlation ($r^2=0.999$) between PPN abundance and AMF abundance ($r^2=0.843$, $p=0.001$) on different agricultural practices (CSA and NCSA). In general, there was no relationship between the abundance of AMF and PPN in the soil ($r^2=0.128$, $p=0.498$). There was no significant correlation between PPN abundance and AMF abundance with soil properties. PPN vs soil pH ($r^2=0.208$, $p=0.268$), ,organic carbon ($r^2=0.09$, $p=0.601$), phosphorous ($r^2=-0.02$, $p=0.902$) and potassium ($r^2=-0.03$, $p=0.85$). AMF abundance verses soil pH (-0.08, $r=0.641$), nitrogen ( ($r^2=-0.11$, $p=0.538$) pottassium ($r^2=0.134$, $p=0.478$) and organic carbon ($r^2=0.12$, $p=0.495$). However, significant associations were found only between nematode abundance and total nitrogen ($r^2=0.393$, $p=0.032$) only.

**Table 3: Soil properties from different fields in EUM**

| | CSA | | | | | | | NCSA | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field No. | Ph | Ec | TN | OC | P | K | Field No. | pH | Ec | TN | OC | P | K |
| 1 | 6.06 | 208 | 0.31 | 2.41 | 2.42 | 0.43 | 16 | 6.15 | 337 | 0.37 | 1.22 | 5.42 | 0.23 |
| 2 | 5.93 | 210 | 0.36 | 2.49 | 0.42 | 0.48 | 17 | 4.97 | 139.9 | 0.24 | 2.60 | 1.07 | 0.25 |
| 3 | 4.48 | 120.7 | 0.21 | 1.56 | 0.99 | 0.21 | 18 | 5.52 | 115.8 | 0.25 | 1.71 | 1.49 | 0.25 |
| 4 | 5.96 | 124.4 | 0.28 | 1.03 | 0.92 | 0.38 | 19 | 6.41 | 167.8 | 0.47 | 2.24 | 0.82 | 0.51 |
| 5 | 6.15 | 106.2 | 0.23 | 1.82 | 0.42 | 0.24 | 20 | 6.22 | 127.7 | 0.10 | 1.67 | 0.06 | 0.22 |
| 6 | 5.49 | 126.2 | 0.20 | 1.18 | 1.78 | 0.26 | 21 | 5.97 | 202 | 0.34 | 2.38 | 0.64 | 0.21 |
| 7 | 5.24 | 83.2 | 0.24 | 1.48 | 0.24 | 0.18 | 22 | 6.04 | 138 | 0.32 | 2.24 | 0.63 | 0.21 |
| 8 | 5.74 | 150.3 | 0.29 | 2.03 | 0.06 | 0.37 | 23 | 6.34 | 204 | 0.30 | 2.20 | 1.13 | 0.45 |
| 9 | 6.03 | 142.3 | 0.25 | 2.38 | 0.99 | 0.22 | 24 | 6.02 | 200 | 0.36 | 2.24 | 2.35 | 0.21 |
| 10 | 5.8 | 129.2 | 0.38 | 2.28 | 1.10 | 0.18 | 25 | 6.0 | 134 | 0.30 | 1.86 | 0.42 | 0.32 |
| 11 | 6.02 | 200 | 0.36 | 2.24 | 2.35 | 0.21 | 26 | 6.03 | 142.6 | 0.25 | 2.38 | 0.99 | 0.22 |
| 12 | 5.34 | 119.2 | 0.24 | 1.92 | 0.95 | 0.24 | 27 | 5.87 | 198.2 | 0.29 | 2.01 | 0.56 | 0.22 |
| 13 | 6.05 | 108.2 | 0.27 | 2.40 | 2.54 | 0.36 | 28 | 6.15 | 129.3 | 0.39 | 2.28 | 2.20 | 0.19 |
| 14 | 5.3 | 122.2 | 0.19 | 1.45 | 0.47 | 0.35 | 29 | 5.36 | 124.9 | 0.26 | 1.76 | 0.33 | 0.28 |
| 15 | 6.01 | 204 | 0.34 | 2.26 | 2.39 | 0.39 | 30 | 6.26 | 129.3 | 0.28 | 1.98 | 0.85 | 0.27 |

## Discussion

Twenty seven plant parasitic nematodes were identified in this study, however *Rotylenchus*, *Helicotylenchus*, *Meloidogyne*, *Pratylenchus Radopholus* and *Ditylenchus* were most frequent encountered and dominant. This contradicts with the work done by Bridge (1978), who found association of up to 12 plant parasitic nematodes of cloves such as *Caloosia paradoxa*, *Meloidogyne incognita* and *Macroposthonia onoesis* being the most abundant .This maybe due to seasonal variation, geographical location or agricultural practices. On the basis of potential pathogenic ability,despite of there abundance they are considered omnipresent pathogens (Fortuner and Merny,1973).

The findings also revealed that Rotylenchus spp is the most abundant genera in cloves in EUM. And these is in agreement with other studies which reported a great abundance of *Rotylenchus* in spice crops such as turmeric, ginger (Rama and Dasgupta, 2010; Nguyen *et al.,* 2020). The *Rotylenchus* spp have the ability to feed inside the root and form association with fungal and bacteria pathogens producing disease complexes (Mondal *et al.,* 2019; Nguyen *et al.,* 2020). In addition cloves roots in the field were not found affected by *Meloidogyne* spp this may be due to the fact *Meloidogyne* spp are not the main pathogen of cloves (Lau *et al.,* 2018).

Among the arbuscular mycorrhiza fungi identified in cloves, Glomus was the most dominant genera followed by *Acualospora*, *Gigaspora* and *Scutellospora*. This finding is in agreement with the work by Choudhary *et al.* (2010) who reported the same genera was the most dominant in their study. However similar observation of Glomus being dominant followed by Acualospora was reported in different crops such as banana (Jefwa *et al.,* 2012), tomato (Songachon *et al.,* 2012) and apple (Summuna *et al.,* 2019). The point that an equal number of spores of genus Glomus were present in both the CSA and non-CSA agricultural practices, was in agreement with the work by Dandan and Zhiwei, (2007) who reported that Glomus is highly dominated by small spores and widely distributed in a wide range of ecological conditions. The AMF is adapted to live in a wide range of environmental conditions and different agricultural practices, can survive in alkaline and acidic soils and also produce a quite high number of spores within a very short period of time (Oehl *et al.,* 2009, Soka *et al.,* 2018; Summuna *et al.,* 2019; Adeyemi *et al.,* 2019).

Agricultural practices are important indicators of the abundance of PPN and AMF in soil (Depontes *et al.,* 2017; Adeyemi *et al.,* 2019). However, in this study both CSA and NCSA practices showed positive association but there were no significant effects of PPN and AMF abundance. This could be attributed of the fact that nematode and AMF communities take along time to respond to changes in agriculture practices (Herrejon *et al.,* 2019). In addition, the measured soil properties showed no association with AMF abundance. Similar observations were reported by Manoharan *et al.* (2017) where no association was observed between soil properties and AMF abundance.

AMF have been shown to reduce development of root diseases caused by pathogens include plant parasitic nematodes (Hill *et al.,* 2018; Wolfe *et al.,* 2020). However, in this study no association was established between AMF spore abundance and nematode abundance in the soil. Similar results were also obtained by Ferreira *et al.* (2018) who reported no association was found between AMF and nematode abundance. Also the insignificant AMF-nematode interaction observed in this study is in agreement with Herrejon *et al.* (2019) and Hol and Cook (2005) who reported the interaction between AMF and plant parasitic nematodes can be positive, negative or neutral and also depends on several factors such as host plant, agricultural practices ,AMF and plant parasitic nematode species.

## Conclusion and recommendation

This study indicated that Rotylenchulus and Glomus were the dominant genera recorded in clove fields in East Usambara Mountain. Moreover, no association was found between PPN abundance and AMF abundance. CSA and NCSA agriculture practices had association on AMF abundance and plant parasitic nematodes, despite a lack of clear difference in AMF and PPN community. This could be influenced by other factors such as environmental factors, geographical location, host plant, soil microbial community. Soil properties did not influence nematode and AMF composition in the soil although there was a significant relationship between total nitrogen and plant parasitic nematodes abundance. More study is needed to generate more information on what drives these communities in clove fields and how these drivers can be influenced by climate change.

## Acknowledgments

Funding for this project was funded by Biotechnology and Biological Sciences Research Council through UK research and Innovation, as part of the Global Challenges Research. AFRICAP programme, grant number BB/P027784/1. We are grateful to the community members and village leaders who allowed us to collect soil sample in their fields.

## Conflict of Interest

The author declare no conflict of interest. The funders had no role in the design of the study;in the collection, analysis or interpretation of data;in the writing of the manuscript, or in the decision to publish the results.

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# Innovative "Swahili based Agricultural Apps" Underutilized new Way of Reaching Farmers and Disseminating Information in Tanzania

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**Abstract**

*Agricultural professionals are constantly in the search of innovative ways to engage farmers and timely dissemination of information. Smartphone application is one of the popular avenues used in some countries, to engage farmers and disseminate information. This study was conducted to assess the use of Swahili based agricultural apps in Tanzania. Virtual product snowball sampling was used to identify Swahili based agricultural apps in android Google Play Store for sixty days i.e. November to December 2020. The findings show that at least 23 Swahili based agricultural apps were available in android Google Play. The oldest of identified apps was released on 2017, which suggest that the use of customised apps to reach farmers is a new phenomenon in Tanzania. Content of the identified apps show that three apps (13%) provide exclusively information on poultry farming; others have general information on crops and livestock. The content on fisheries and aquaculture is notably meagre in the existing livestock apps. Most (83.2%) of the apps had less than 10,000 downloads and only one app has reached 100,000. The users' opinions are skewed to positive. Taking into account the number of farmers and adoption rate of internet based smart phones in Tanzania, downloads figures suggest that existing apps are under-utilised. The study concludes that the use of Swahili based agricultural apps is a new practice at the early stage of adoption, which should be harnessed for timely and fruitful engagement with farmers and transformation of extension services in Tanzania.*

***Keywords***: Apps, Smartphone apps, Agriculture, Agricultural technologies

## Introduction

Agricultural professionals are constantly in the search of innovative ways to engage farmers and timely disseminate information on weather forecasting, crop production, disease and pest management, postharvest storage and marketing (Barh and Balakrishnan, 2018a). Advancement of Information and Communication Technologies (ICTs) has transformed farmers engagement system and how extension and advisory services are delivered (Khan *et al.,* 2019). Smartphone is one of ICT tools promoted to tackle the drawbacks of traditional agricultural extension and advisory services (Emeana, Trenchard and Dehnen-schmutz, 2020). The use of smartphone applications in agriculture is becoming popular among farmers in the developing countries as in developed ones (Sharma and Kiranmayi, 2019). Smartphone applications, usually referred as apps have made it possible for farmers to access various agricultural information and advisory services in some countries (Mahapatra, 2020; Naika *et al.,* 2021). Smartphone apps are moving agriculture to the next level by facilitating the availability and accessibility of vital information in a real time (Saiz-Rubio and Rovira-Más, 2020). According to Kusyama *et al.,* (2020) apps are cost-effective and provide real time information to farmers. The apps are reported to be the best means of engaging and disseminating agricultural information to farmers' because of its interactive nature, easiness to user and acceptance among lay public (Kandagor, Githeko and Opiyo, 2018).

Studies on the use of apps to disseminate agricultural information show countries with high adoption rate to be United States of America (USA), Brazil, and India (Barbosa *et al.,* 2020). Apps are customized to disseminate specific and/or general agricultural information (Barh and Balakrishnan, 2018b). The diversity and availability of apps helped Bangladesh farmers to access all kind of information on their fingertips (Sadekur-Rahman *et al.,* 2020). Mandi and Patnaik (2019) found out that Indian farmers use smart phone apps to get most up-to-date agricultural information. The use of apps is promoted in Africa to stabilise irregularities of delivering agricultural information to the farmers in need (Samuel, 2018).

In Tanzania farmers call for friendly communication systems to help them access agricultural information in real time (Misaki *et al.,* 2019). Nyamba (2017) publicized early use of mobile phones apps among farmers in Tanzania. The accounts which was affirmed by (Karimuribo *et al.,* 2017). Previously, Karimuribo *et al.* (2016) documented the use of smartphone apps and encourged application of digital technologies to improve animals health service deliverly through inclusive disease survellance. Tumbo *et al.* (2018) unveil the use apps among Tanzania farmers seeking agricultural information related to climate change adaptation. Studies on Tanzania have not identified suitable and easily reached apps for Tanzania farmers. Therefore, the study on which the paper is based was conducted to establish the existing and use of "Swahili based agricultural apps" in Tanzania.

## Methods

Useful Keywords Research and Analysis Approaches as described by Joshi and Motwani (2006) were adopted in this study to search for Swahili based agricultural apps in Android Google Play Store. Virtual Product Snowball Sampling is a non-probabilistic sampling method that was used to increase the sample size in this study. The method permits the search of Apps in Android Google Play Store and websites of respective products (Baltar and Brunet, 2012). It allowed one app to lead to the other. Only apps that have agricultural content in Swahili were recorded. Initially, the two researchers worked independently to review the identified apps and later worked together to compare notes and validate the list of apps. It was noted that google provide information on approximation basis and not exact number of app downloads.

The study focused on Android operating because of its dominance in Tanzania mobile phone market and among users across the globe (Chmielarz, 2020). The used keywords were Kiswahili terms, the language used by majority of Tanzanian farmers besides their tribal languages. Consequently, the suitable apps are expected to have its content in Kiswahili. The searched short-tail keywords are: *Kilimo* (agriculture), *Ufugaji* (livestock keeping), *Kilimo cha Kisasa* (modern farming), *mkulima* (a farmer), *wakulima* (farmers), *bustani* (garden), mboga mboga (vegetables), *kilimo biashara* (commercial agriculture).

The data was collected for sixty days period, November to December 2020. The study investigated only free version apps (apps which allow free to download and use) because the free version apps have high rate of adaptability and download also, apps users prefer free version app over paid version app (Arora *et al.,* 2017).

## Results

The study identified twenty three (23) Swahili based agricultural apps in Play Store for android operating Smartphone. All identified apps were freely available for download and use. Twenty (87%) apps have general information in farming and animal husbandry, 3(13%) are specific for poultry farming. The status of the identified apps in terms of content/information, date of release and number of downloads is detailed beneath each app.

### *i. Kilimo na Ufugaji Bora*

This app provides information and manuals to guide farmers on crop and animal husbandry. The manuals aims at helping farmers effectively manage pest and diseases and learn modern farming practices. It was released on 05/02/2017 by Technology Tza. This was the most downloaded Swahili based agricultural app with over 100,000 downloads. One of the reviewers commented that "This app is very important to farmers as it gives detailed information about farming, we are grateful".

***ii. Kilimo Biashara***

The app provides information in agricultural business. It intends to equip farmers with skills on food processing, animal keeping and horticulture crop farming. It was released on 13/09/2019 by Mshindo Media. Ten thousands (10,000) users have downloaded the app for the period of one year. Based on users' feedbacks, the app is considered to be "excellent" and "easy to access"

***iii. Kilimo Taarifa***

This app provides platform for farmers, extension staff, researchers, retailers, advisors, aggregators, processors and distributors to interact. The information is categorised as business crops, food crops and wild crops, and oil crops. The app was released on 19/06/2018 by Fahamu Tech. In the period of two years, about 1,000 users have downloaded the app. The app reviewers' commented that *"inanisaidia kuamua jinsi ya kulima"* and "a very useful app for Tanzanian farmers".

***iv. Kilimo* Smart**

The app covers information on pest and diseases management, agrochemicals, farming and animal husbandry, market and agricultural news, with the aim of improving farmers' productivity through good agricultural practices and encourages the adoption of conventional agriculture. Kilimo Smart incorporated company released the app on 23/08/2018. It has attracted over 1,000 downloads in two year time. One of the reviewers commented that "Very special app. I like it. I get to learn much of agriculture" as the other collaborated with a five star rating "this app is helpful to me love it, my five star are fairly given to you"

***v. Kilimo* Tanzania**

This app offers information on farming, animal husbandry, agricultural technologies, and entrepreneurship. It was the first app released on 13/07/2018 by Mshindo Media, it has 5,000+ downloads. The users' feedback signifies the app is of good quality. One user applauded the app saying "Good app ever seen before, thanks so much".

***vi. Kangeta Kilimo***

The app has information on agricultural technology, inputs, market, pest and weeds management, and provides guidance to the farmers from planting to harvest. Kangeta Kilimo released the app on 27/05/2019. One thousand (1,000+) users have downloads the app in a period of over one year. The reviewers viewed the app very useful and helping farmers to solve their information problems. One of the users endorsed this app as the most useful to farmers *"Wakulima kweli tumepata mkombozi kupitia hii app nimeipenda sana ni utatuzi wa changamoto zetu vitu kama mbolea mbegu bora dawa na utaalam wakilimo mbalimbali pia miche. Nimevutiwa na app hii kuwa inaweza kukumbusha kupiga dawa na kuweka mbolea hongera sana kageta kilimo kwa kazi nzuri. kwel kilimo na utandawazi"*.

***vii. Kilimo cha Kisasa (Jifunze kilimo Kwa Kiswahili)***

*Jifunze Kilimo Kwa Kiswahili* literally means learn agriculture in Swahili is the main goal of *Kilimo cha Kisasa* app. App users obtain information on conventional agriculture. Farmers can get free guide on proper use of fertilizer, greenhouse technology and horticulture cropping. Mzansi incorporated company released this app on 06/06/2018 and has attracted 5,000+ downloads. Users commend this app.

***viii. Kilimo Bora***

The app aims at helping farmers to improve their living standard through agriculture. It provides information on agricultural technologies, production, processing and entrepreneurship. This was the latest app Mshindo Media series released on 11/11/2020. One hundred (100+) users have downloaded *Kilimo Bora* app in a month time. Users have not reviewed this app.

***ix. Kilimo na Ufugaji***

DAC Tech developed this app to provide

agricultural education on breeding, employment opportunities and economic growth. Users have a platform to discuss different issues on agriculture. The app has attracted 1,000+ downloads since its release on 08/02/2019. The feedbacks from app users give credit to the developer. For example, one user commented that "this app can help you to grow in self-employment, it is like home banking, thank you "as the other collaborated that "this good for me".

***x. Kilimo na Mifugo***

The app was released on 03/10/2018 by Chegula to providing farmers with information and knowledge on poultry farming, livestock diseases detection and management and general information on crop production. The app has attracted 500+downloads and no review for the period of two years. No user has reviewed the app.

***xi. Kilimo Bora na Ufugaji-Jifunze Kilimo cha Kisasa***

The app provides information and guiding manuals on crop and animal farming. The manuals on sun flowers, sugarcane, hot pepper, bee and fish farming are available. This app was released on 26/06/2018 by H.b.r Inc., and has 5,000+ downloads. Users have commended the app for farmers.

***xii. Mkulima Mbunifu***

Mshindo Media released this app on 21/08/2020, which had 100+ in December 2020. The app has information packed in text and video clips to train farmers on entrepreneurship, proper use of fertilizer, and processing. No review was recorded for the period of three months.

***xiii. Ongeza Mkulima***

Ongeza Tanzania released an app for their registered farmers on 10/15/2020. Ten (10+) users had downloaded the app by the end of December 2020. No review was recorded for the period of two months.

**xiv. Ufugaji Bora-Mafunzo ya Ufugaji na Matibabu**

The app was released on 09/06/2020 by Mshindo Media to provide animal and veterinary advisory services to farmers. The app focuses on animal husbandry and management of pests and diseases. It has 1,000+ downloads, and reviewers consider the app to be useful.

***xv. Ufugaji Bora***

The app promotes the farming of indigenous chicken; and provides general information on animal husbandry. It was released on 14/05/2017 by Technology Tza and has 10,000+ downloads. The app users commented that "this app is real important for our country "and "it is good, I like it".

***xvi. Ufugaji Bora-Fuga kitaalamu***

The app focuses on animal keeping. It provides information on poultry production, breeding and rearing of dairy goat and cattle sheep; pigs and fish farming. The app contains information on production and diseases management. It was released on 11/09/2020 by Chegula and has 1,000+ downloads in December 2020. Users' comments were positive, for example one user commented that "great app for agriculture. I like it" and other said "it is a good app for modern agriculture".

***xvii. Ufugaji Bora-Mafunzo ya Ufugaji na Matibabu***

The app developed to provide training for farmers on animal production and disease prevention and management. It was released on 10/05/2019 by Afrotech Studios and has 10,000+ downloads. The app is applauded by users, as one wrote that "the app is much educative I like to learn how to keep chicken "and the other said "very nice app".

***xviii. Ufugaji***

Ufugaji app promotes commercial animal farming. Similar to Ufugaji bora- Fuga kitaamu app, it provides information on poultry production, breeding and rearing of dairy goat and cattle sheep; pigs and fish farming. The app was released on 26/03/2018 by Chegula and has 1,000+ downloads. Users have commended the app.

***xix. Ufugaji na Matibabu and Veterinary Care***

Mshindo Media released this app on 23/05/2020 and 10,000+ users downloaded it in a period of seven months. The app is exceptional for providing information on animal production and veterinary services.

***xx. Fuga Kibiashara-Mafunzo ya Ufugaji na Matibabu***

Mshindo Media released this app on 26/08/2019, 1,000+ users have downloaded it. The app offer training on commercial animal farming.

***xxi. Ufugaji wa Kuku Kitaalamu***

This app provides information on poultry farming. People interested in poultry farming are guided on how to start and manage the farm, also, it offer market information to farmers. The app was released on 22/07/2020 by Mshindo Media and has 1,000+ downloads. Users have not provided feedback on this app.

***xxii. Kuku Kalenda-Aquinus***

This app is optionally good as it provides platform for farmers and veterinary officers to directly interact virtually. A farmer can contact a veterinarian with this app and get advice. The app also provides information on different chickens breed, market and packages. NdomskKey Technologies released this app on 13/08/2019 and has 1,000+ downloads. Users have commended this app.

***xxiii. Kuku ni Biashara***

The app provides information on commercial production of chicken. The user can pose a question through the app and receive veterinarian advice from the app or social media such as Facebook, YouTube, Instagram, and WhatsApp group. Mshindo Media released this app on 27/07/2020 and has 500+ downloads. No review was recorded on this app.

**Discussion**

The first Swahili based app was released on 05/02/2017, but only 100,000+ people have downloaded it. This hints early initiatives of exploring the use of customized apps to serve Tanzania farmers. The findings from Kusyama *et al.* (2020) reaveled that main sources of agricultural information to Tanzania farmers are radio, television and extention officers, which enlight why small number downloads over five years. Studies elsewhere suggest farmers are not aware of agricultural apps (Sadekur-Rahman *et al.,* 2020), and so low download and usage. Most (87%) Swahili based agriculture apps disseminate crop and animal farming information, which reflects the nature of farming system in Tanzania. The provision of general information could be contributing factors for unpopularity of the apps. However, few (13%) agricultural Swahili based apps disseminate specific information, which was one poultry farming. Elsewhere, Mandi and Patnaik (2019) identified various apps disseminating information about specific crops such as rice, groundnut and pomegranate, the specificity of the app increases its adoptability and attracts more users suggesting future apps developers may need to focus in specific crop or animal (Tamil and Balasubramaniam, 2019). Also, Kumar and Karthikeyan (2019) argues that the farmers need information that is accurate, brief, timely and trustworthy. The app with specific information and advisory services would interest farmers (National Institute of Agricultural Extension Management, 2017). However, the scope of specificity is questionable as other studies suggest that agricultural apps should help farmer get solution to all of information needs in a single platform (Mahapatra, 2020).

The use of smartphone apps to disseminate agricultural information was projected to help farmers improve production in 2017 (Nicholas-Ere, 2017). Tanzania was not left behind; Swahili based agricultural apps were developed from 2017 at increased release rate, as only two apps were developed and released in 2017 compared to five apps in 2020. However, the practice of customising apps in Swahili language is still an immature stage. According to Barh and Balakrishnan (2018b) the mature stage will be attained when the use of apps will boost agricultural sector in term of information availability. Gao *et al.* (2020) collaborated that this innovative agricultural technology has the significant impact on dissemination of agricultural information to farmers.

Swahili based agriculture apps are still lacking in key sub-sectors. For example, this study did not find an app specific for fish farming. Elsewhere, Sharma identified 124 apps related to fishing sector. Similar to other sub-sector, underutilization of this technology has negative impact because of the potential to address many of the shortcoming in dissemination of information (Bradley *et al.,* 2019; Kusyama *et al.,* 2020).

## Conclusion

The paper concludes that the use of Swahili based agricultural apps is a new practice, which should be harnessed for timely and fruitful engagement with farmers and transformation of extension services in Tanzania. Evidence proves that suitable smartphone apps are cost efficient and can provide real time information and advisory services to farmers. Therefore, there is need to develop more specialized Swahili based agricultural apps for the purpose of addressing shortcoming in dissemination of agricultural information and reaching out farmers.

## Acknowledgments

Authors are grateful to app developers who have invested their resources to help farmers to access agricultural information.

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# Suitability of Pigeon Pea and Soybean Flours as Extenders and Binders in Restructured Meat Product (Sausage)

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**Abstract**

*The suitability of pigeon pea and soybean flours as an alternative to chemical binders and extenders in meat restructuring technology was investigated in this study. Pigeon pea flour (PPF) and soybean flour (SBF) were separately developed, assessed for their protein contents and each was used for sausage preparation at 2, 4, and 6% with plain (CB) and chemical phosphate binder (PhB) sausages serving as control samples. The processed sausages were then subjected to texture profile, water solubility index (WSI), sensory profile, and consumer acceptability analyses to assess the flours' performance. Soybean flour had a significantly ($p<0.05$) higher protein content (31% DM) than pigeon pea flour (22-24% DM). Texture profile parameters differed significantly($p<0.05$) between samples with the highest hardness value observed inCB(424.0±1.53g) and lowest values in SBFs (277±1.11-332±1.5 g). The PhB and 4 and 6% SBFs samples had higher cohesiveness (0.46±0.02-0.54±0.03g), adhesiveness (9.0±0.10-10.9±0.25g) and WSI (2.8-3.0%) than respective lower values of 0.29± 0.04-0.42±0.04, 2.5±0.10-6.0±0.66and 1-2.4% in plain control and PPFs samples. The sensory analysis results revealed that PhB samples had significantly ($p<0.05$) higher colour (8.2±1.30), saltiness (5.8±1.56), and mouthfeel (6.9±1.20) intensities than other samples. Furthermore, the PhB, and 4 and 6% SBFssamples had significantly ($p<0.05$) higher moistness (0.46±0.02-0.54±0.03g), consumer acceptability (7.1±1.67-7.3±1.88) and preference (125-177)as well as lower hardness intensity (5.9±2.54-6.0±2.82) than other samples. In conclusion, soybean is richer in protein than pigeon pea and its incorporation of up to 6% in sausage produces a more acceptable product than plain control samples but with WSI, texture, and sensory profiles comparable to chemical binder samples. However, further studies to establish appropriate pigeon pea flour levels that will produce acceptable products with similar physical and sensory properties to chemical binder is recommended.*

***Keywords***: Pigeon pea, soybean, sausages; Binder, sensory profiles; water solubility index

## Introduction

Legume seeds are important staple foods and are one of the richest and cheapest sources of proteins for the majority of people living in developing countries (Maphosa and Jideani, 2017). The most commonly consumed are pigeon pea, common beans, kidney beans, black gram, chickpeas, green gram, and lentils (Singhali *et al.,* 2014). Pigeon pea (*Cajanu scajan*), is an erect perennial legume shrub belonging to Family Fabaceae originated in the Indian subcontinent and is currently grown in subtropical and tropical regions of several countries (Odeny, 2017). Tanzania is the 4thworld producer of pigeon pea with an annual production of 271 210 tons (FAOSTAT, 2017) after India (4 870000 tons), Burma (798 689 tons), and Malawi (470 630 tons). The key production regions in Tanzania are Arusha, Dodoma, Manyara, Lindi, and Mtwara (Mponda *et al.,* 2014).

Pigeon pea is a good source of crude protein (22 - 27%), fiber, vitamins especially riboflavin, thiamine, choline and niacin, and antioxidants

(Olagunju *et al.,* 2018; Talari and Shakappa, 2018). The health benefits due to the presence of these components have widely been reported and they include regulation of blood pressure, growth, and development, prevention of anemia as well as boosting the immune system (Olagunju *et al.,* 2018). Talari and Shakappa (2018) further associated bioactive compounds present in pigeon pea with modulation of natural microbiota present in the gut hence reduce inflammation.

However, despite its nutritional and health benefits, pigeon pea is still an underutilized crop and its utilization is lowered to low-income families (Fasoyiro *et al.,* 2010).The long cooking time and the presence of antinutrients are among the factors that limit its utilization (Ahmed and El-Tabey, 1992). Furthermore, the crop has received little attention from research and development to unlock its potential contribution as an important food ingredient in industrial applications in the country. Due to its high protein content, pigeon pea can be processed into flour and be used in the food industry as an ingredient for various food products like biscuits, noodles, and pasta (Keshav, 2015). Besides, the flour can be processed into an extender or binders in meat restructuring technology the same way as soybean protein is used (Mora and Andres, 2015). The technology enables the production of value-added meat products from low-quality cuts and trimmings by improving water holding capacity, tenderness, fat content, binding strength, and shape of meat products (Xue *et al.,* 2016). Protein in the meat facilitates water molecules to be bound by polar groups of proteins which is necessary for them to retain their spatial structure and remain intact (Pospiech and Montowska, 2011). Salt and phosphates are among the traditional binders that are in use in the food industry facilitating the extraction of myofibrillar proteins and enhance cohesion and binding of meat particles (Teye and Teye, 2011). They also increase the protein solubility as well as expose hydrophobic groups leading to a better product. However, their applications have been impeded by causing discoloration, rancidity, and harmful residues (toxins) (Teye and Teye, 2011) with consequent health problems (Inetianbor *et al,* 2015).

Soybean protein has widely been used in the food industry as an alternative to chemical extenders and binders in restructured meat products (Badpa and Saghir, 2014). Nevertheless, soy is among the eight (8) most significant food allergens (Solomon *et al.,* 2017) and hence suggesting another protein source such as pigeon pea. Gomezulu (2020) developed pigeon pea binder for sausage which produced a good quality product at 6%, however, its production costs and the overall final sausage cost seemed to be high and probably unaffordable by the majority of people especially low-income earners. Thus, the development and application of the protein-rich pigeon pea flour seem to be a very suggestive and good alternative. The aim is not only to reduce high dependency on chemical binders in the food industry, some of which are linked to health issues but also to produce relatively cheaper restructured meat products. These products will increase overall consumption, marketability, farmer's income as well as positive nutrition and health outcomes of consumers in the country. Despite adequate literature review information on the application of pigeon pea flour alone or its comparison with soybean flour as an extender or binders in the restructuring technology is limited. This study was conducted to assess protein contents of the flours, texture and sensory profiles and consumer acceptability of the sausages prepared by chemical and flour binders.

## Materials and Methods

### Study area

The study was conducted at Sokoine University of Agriculture (SUA) and the Nelson Mandela African Institute of Science and Technology (NM-AIST).Sausage preparation, sensory evaluation, and texture profile analyses were done at the Department of Food Technology, Nutrition and Consumer Sciences (DFTNCS), SUA while protein analysis and water solubility index analyses were conducted at the NM-AIST laboratory.

### Materials and their sources

Two varieties of pigeon pea (improved and local varieties) were purchased from farmers in Lindi region. Ultrafiltration tubes for protein extraction were purchased from Dableen General Suppliers Company - Arusha, Tanzania. Fresh meat, sausage spices, phosphate binder, and sausage lamb casing were purchased from a local market and butcher in Morogoro Municipality.

**Chemicals and reagents**

Analytical grade chemicals and reagents for protein profile analysis were obtained from NM-AIST and SUA laboratories. These included hydrochloric acid (HCl), potassium iodide (KI) solution, ethanol, sodium hydroxide (NaOH), distilled water ($H_2O$), concentrated sulphuric acid ($H_2SO_4$), acetic acid, sodium carbonate ($Na_2CO_3$) solution, tannic acid solution, Folin-Dennis reagent and concentratedammonium hydroxide ($NH_4OH$).

**Methods**

**Research designs**

A completely randomized design (CRD) was used in this study. The principal factors were binder types (chemical and flours). The effect of this factor on flour protein content, product texture profile, and water holding capacities were determined and compared. The designed mathematical model is depicted in Equation 1.

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij} \quad (1)$$

Where μ is the overall (grand) mean, αi is the effect due to the ith treatmenteffect (variety and binder type) and εij is the error term.

Balanced incomplete block design (BIB) was used in sensory analysis. The BIB design (ISO 29842, 2011) is applied to sensory tests in which the total number of samples is greater than the number that can be evaluated, before sensory and psychological fatigue set in. Hence, each assessor evaluates only a subset of the total number of samples in a single session randomly. The principal factors were assessors and sausage formulated from different binders. The effects of these factors on sensory profile of sausages and consumer acceptability and preferences were determined and compared. The mathematical expression is depicted in Equation 2.

$$Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij} \quad (2)$$

Where μ is the overall mean, τi is the ith treatment effect (binder type), $\beta_j$ is the jth block effect (assessors) and εij is the random effect.

**Flour preparation**

Flour preparation was done based on the method described by Adenekan *et al.* (2017) with slight modifications. Soybean and pigeon pea were washed and soaked in water (1 kg pigeon pea: 3 liters of water) for 24 hours at room temperature (22°C). It was then dehulled and oven-dried at 60°C for 24 hours followed by milling (Bunn G2 Black Model 875 miller, USA) into a fine powder then stored in a desiccator (Desiccator; Stainless steel, Tempered Glass Windows, Series 100, USA).

**Sausage formulation**

Sausage samples were formulated using methods described by Dzudie *et al.* (2002) and Teye and Teye, (2011) with slight modifications. Three formulations consisted of soybean flour (SBF) and pigeon pea flour (PPF) each at 2, 4, and 6% were prepared as depicted in Table 1. The sausage with no flour and/or chemical phosphate binder (0.5% per kg of meat) served as control samples.

**Sausage preparation**

Sausage samples were prepared using methods as described by Dzudie *et al.* (2002) and Teye and Teye, (2011). Meat muscles were removed from the meat carcass after 24 hours chilling at 4°C, trimmed of visible fat and connective tissues, and ground through a 3 mm plate using a meat grinder. The ground meat was sealed in 8×12 cm polyethylene zipper bags (500g package) and stored at -18°C for 24 hours. Before processing, thestored meat was thawed at 4°C for 16 hours.To each formulation (presented in Table 2.1), a constant amount of 20g salt, 300g water, 1 g ground black pepper, 1 g ground white pepper, and 4g of ground coriander (basic ingredients) were added. The sausage batters were processed by replacing beef with binders at levels of 2, 4, and 6% (Dzudie *et al.,* 2002; Teye and Teye, 2011) of the weight of the meat. The whole mixture (a batter)and 1/3 of the total water (10°C) were chopped in a Stephan UMC 5-12 Electronic cutter (Marne-la-Vallee, UK) for 3 minutes. Binders and the remaining water

**Table 1: Beef sausage formulations with chemical binders and different proportions of flours**

| Sample | Proportions (%)/kg of meat | | |
|---|---|---|---|
| | Phosphate | Soybean flour | Pigeon pea flour |
| Control (CB) | 0 | 0 | 0 |
| Phosphate binder (PhB) | 0.5 | 0 | 0 |
| SBF1 | 0 | 2 | 0 |
| SBF2 | 0 | 4 | 0 |
| SBF3 | 0 | 6 | 0 |
| PPF1 | 0 | 0 | 2 |
| PPF2 | 0 | 0 | 4 |
| PPF3 | 0 | 0 | 6 |

(2/3) were added and the mix was chopped for 10 minutes and the final chopping temperature did not exceed 15°C. The sausage batters were stuffed into 22 mm lamb casings using a hand-operated stuffer (VLA 13 - France) and formed into links of 15 cm in length.

The sausages were cooked at 85-90°C in a water bath (PURATM Series 30, UK) for about 45 minutes to an internal temperature of 72°C. They were then rapidly chilled to 15-20°C with cold water for 10 minutes and stored in polyethylene bags in a refrigerator at 4°C for 48 hours before sensory analysis.

**Determination of protein content**

The protein content of the samples was determined by the CHNS/O analyzer method as described in method 44.4.04 by AOAC (2005). The samples were combusted and the produced gases were carried by Helium flow to a second reactor filled with Copper.The gases were then swept through $CO_2$ and $H_2O$ traps through a gas chromatography(GC) column (Series 4060, UK) and finally detected by a thermal conductivity detector (TCD Detector, Teledyne Series 100, Model 2020, USA). A complete report was automatically generated by software that automatically converts the nitrogen content into protein content. For this case, a specific protein factor of 6.25 was used.

**Texture profile analysis**

The textural properties (hardness, cohesiveness, adhesiveness, and springiness) were determined using a texture analyzer (Genway Universal Testing Machine, Japan). After peeling off the casing, a texture profile was performed using the central cores from three slices of each cooked sausage (Jung *et al.,* 2012). All measurements were performed in triplicate.

**Determination of Water solubility index (WSI)**

The WSI of sausages was measured as expressible moisture (EM%) by centrifugation, according to the modified method of Menegassi *et al.* (2011). Approximately 1.5 g of each cooked sausage was wrapped with dried filter paper (Whatman no. 3) and weighed. After centrifugation (in an 800-1 Centrifuge, China) at 3000 rotations per minute (rpm) for 15 minutes, the expressible moisture (EM %) was calculated as the weight difference between the sample weight before centrifugation and sample weight after centrifugation.

**Sensory analysis**

**Quantitative descriptive analysis (QDA)**

A quantitative descriptive analysis test was conducted at the DFTNCS laboratory at SUA involving a trained panel of 9 assessors comprising of 7 male and 2 females with age ranging from 22 to 28 years according to the method described by Lawless and Heyman (2010). The assessors were selected and trained for three (3) days according to ISO 8586 (2012). During training, panelists developed descriptors describing differences between samples and they agreed on the following attributes; color, saltiness, mouthfeel, moistness, compactness, and hardness (Table 2). They also developed and agreed on an unstructured 9-line scale for rating the intensity of an attribute. The left side of the scale corresponded to the lowest intensity of each attribute (value 1) and the right side corresponding to the highest intensity (value 9). The samples were coded with 3-digit random numbers and were served to each panelist in a randomized order using BIB design. The obtained average responses were used in the univariate and multivariate analyses. Both pre-trial test and panel performance assessment was done to ascertain the agreement of panelist in discriminating samples and their reproducibility.

**Table 2: Definitions of sensory attributes used in descriptive sensory analyses**

| Attribute | Description | Reference | Scale ranges(1-9) |
|---|---|---|---|
| Color | Characteristic of visual perception described through color categories | Himalaya color | 1- Pale Himalaya<br>9- Himalaya |
| Saltiness | The quality of being salty | Table salt (NaCl) | 1- Less salty<br>2- Very salty |
| Mouthfeel | The spread of particles while chewing | Beef Vienna Sausage | 1- Loose particles<br>2- Dense particles |
| Moistness | Moisture experienced by the finger feel | Beef Vienna Sausage | 1- Not moist<br>2- Very moist |
| Compactness | The denseness of meat particles in the sausage as perceived by the eye | Beef Vienna Sausage | 1- Not compact<br>2- Very compact |
| Hardness | Characteristic of the product as perceived for the first teeth bite | Beef Vienna Sausage | 1- Not hard<br>2- Very hard |

***Source:*** Study QDA Panel (2020)

## Consumer Test

### Hedonic test

The hedonic test was conducted at the Department of Food Technology Nutrition and Consumer Sciences (DFTNCS) by 59 untrained consumers of both sexes aged between 20 - 45 years using a 9-point hedonic scale as described by Lawless and Heyman (2010). The sausages were thawed and warmed in an oven (Turbofan 3000, Blue seal, UK), sliced into uniform sizes (about 2 cm in length) then served on white disposable plates which were randomly coded with 3-digit numbers. Then the plates were served to the panelists in a randomized order on the day of evaluation using BIB design. They were then asked to evaluate and express their degree of liking for sausage product attributes on appearance, color, aroma, taste, softness, moistness and finally expressing judgment on overall acceptability using a 9-point hedonic scale (where 1 = dislike extremely and 9 = like extremely). Good sensory practices such as blind labeling and mouth rinsing between tastes were observed.

### Preference test

The preference test was conducted at the DFTNCS by 59 untrained consumers of both sexes between 20 - 45 years using a 5-point ranking scale described by Lawless and Heyman (2010). The sausages were thawed and warmed in an oven (Turbofan, Blue seal, UK), sliced into uniform sizes (about 2 cm in length) then served on white disposable plates which were randomly coded with 3-digit numbers. The samples were then served to the panelists in a randomized order on the day of evaluation using a BIB design and panelists were asked to test and rank the sample according to their preference using a scale provided (where 1 = most preferred and 5 = least preferred).

## Statistical Data analysis

Data were analyzed by using the R statistical package (R Development Core Team, Version 3.0.0 Vienna, Austria) for analysis of variance (ANOVA). Mean were separated using

Tukey's honest significant differencetest (HSD) at $p<0.05$. Also, principal component analysis (PCA) was used to determine the systematic variations between a sensory profile and texture characteristics in sausage formulations. Results were presented as an arithmetic mean and standard deviation in tables and PCA biplot.

## Results and Discussion

### Protein contents of flours

The protein contents of soybean and the two pigeon pea varieties (local and improved) are shown in Table 3.The contents differed significantly between soybean with 38.7 g/ 100 g DM and pigeon pea flour with 22.1-24.9 g/ 100g DM. The variation among varieties was also significant with an improved variety having higher values than the local variety.

**Table 3: Protein contents of soybean flour and pigeon pea varieties flours**

| Flour | Protein (% DM) |
|---|---|
| Soybean | 38.7 ± 0.2a |
| Local Variety | 22.1 ± 0.1c |
| Improved Variety | 24.9 ± 0.4b |

*Values are expressed as Mean ±SD (n=3). Mean values with different superscript letters are significantly different at p<0.05*

serve as a good dietary source of protein and an important ingredient in meat restructuring technology. Protein in restructured meat facilitates water molecules to be bound by polar groups of proteins which is necessary for them to retain their spatial structure and remain intact (Pospiech and Montowska, 2011). This enhances bind strength, physical and sensory properties necessary for consumer acceptability. Similar protein contents in local and improved varieties ranging from 21.1 to 28.1%, were also reported by Aruna and Devindra (2016). The relatively high protein content in the improved pigeon pea varieties suggests its superiority to local ones and its suitability for industrial application to enhance physical, chemical, and sensory qualities of restructured meat products such as sausages (Pazmiño *et al.,* 2018).

### Texture profile of the sausage samples

Table 4 shows the results of texture profile parameters which varied significantly between and among sausage formulations. Application of binder and flour reduced hardness but increased other parameters in both crops flour except springinesswith soybean flour higher effects than its pigeon pea counterpart. Similar effects were observed within each crop as the level of its flour in the formulation increased.

**Table 4: Texture profile parameters of sausage samples**

| Formulation | Hardness (g) | Cohesiveness (g) | Adhesiveness (mm) | Springiness (mj) |
|---|---|---|---|---|
| CB | $424.0 \pm 1.53^{a}$ | $0.29 \pm 0.04^{d}$ | $2.5 \pm 0.10^{e}$ | $14.0 \pm 0.35^{b}$ |
| PhB | $361.3 \pm 4.35^{ab}$ | $0.54 \pm 0.03^{a}$ | $10.6 \pm 0.57^{a}$ | $14.3 \pm 0.11^{ab}$ |
| PPF1(2%) | $359.0 \pm 8.19^{ab}$ | $0.33 \pm 0.01^{c}$ | $4.1 \pm 0.56^{d}$ | $14.5 \pm 0.17^{ab}$ |
| PPF2 (4%) | $348.0 \pm 1.67^{b}$ | $0.37 \pm 0.07^{c}$ | $5.9 \pm 0.31^{c}$ | $14.5 \pm 0.29^{ab}$ |
| PPF3 (6%) | $344.7 \pm 2.88^{bc}$ | $0.42 \pm 0.04^{bc}$ | $6.0 \pm 0.66^{bc}$ | $14.6 \pm 0.17^{ab}$ |
| SBF1 (2%) | $332 \pm 1.50^{c}$ | $0.46 \pm 0.02^{b}$ | $7.3 \pm 0.25^{b}$ | $14.7 \pm 0.17^{a}$ |
| SBF2 (4%) | $300e \pm 1.09^{d}$ | $0.48 \pm 0.03^{ab}$ | $9.0 \pm 0.10^{ab}$ | $14.8 \pm 0.11^{a}$ |
| SBF3 (6%) | $277 \pm 1.11^{e}$ | $0.49 \pm 0.04^{ab}$ | $10.9 \pm 0.25^{a}$ | $14.8 \pm 0.10^{a}$ |

*Values are expressed as mean ± SD (n = 3). Mean values with different superscript letters are significantly different at p<0.05. Key: CB - Control sausage, PhB is the phosphate binder, PPF is the pigeon pea flour, SBF is the Soybean flour*

The findings revealed that both crop flours are rich in protein contents but soybean contains a substantial amount compared to pigeon pea as previously reported (Adeola *et al.,* 2011). This suggests that both crops may

Systematic variation of sausage samples and their associated texture parameters are further shown in the principal component analysis bi-plot of multivariate analysis (Fig 1). PC 1 accounts for 82.9% of the total variability and it is a contrast between phosphate binder, soybean flour, and 6% pigeon pea flour associated with all texture parameters on one side and control and remaining 2 and 4% pigeon pea flours associated with high hardness intensity on the other side. PC2 accounts for 10% of the variability and it's a contrast between flours on one side and control and binder on the other side.

ions in phosphate binder tend to increase sausage hardness in non-fat meat.

Increase protein contents in the formulation also tends to increase cohesiveness, which is the degree of difficulty in breaking down the internal structure of the sausage (Abdolghafour and Saghir, 2014). Previously, Syuhairah *et al.* (2016) reported similar observation that an

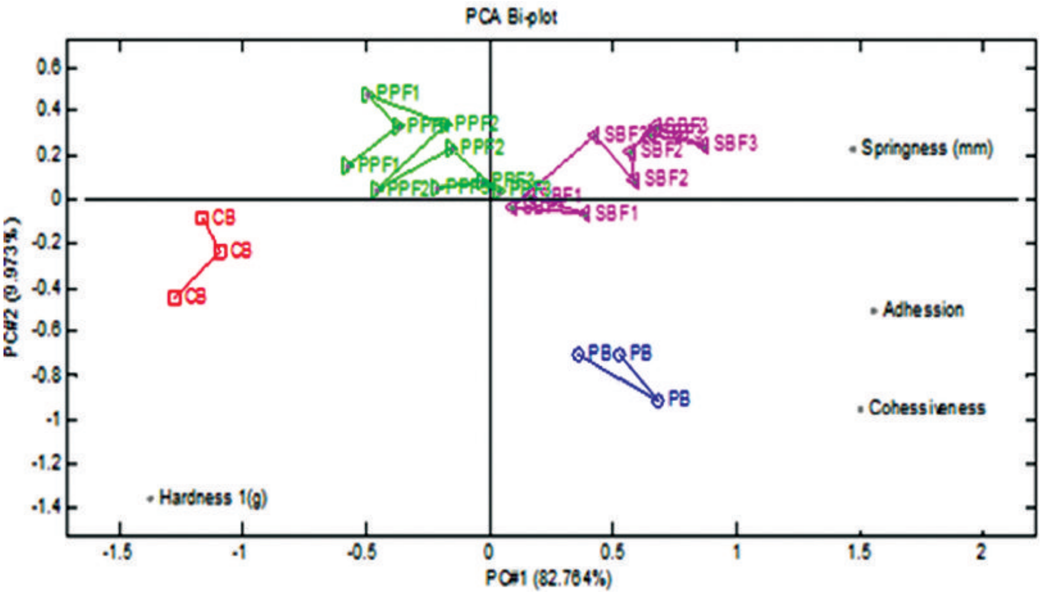


**Figure 1: PCA bi-plot showing systemic variations between sausage samples and their associated sensory profiles**

A decrease in sausage hardness with increasing levels of flours in the formulation could be associated withthe increase in protein in the flours. According to Abdolghafour and Saghir (2014) protein improves water holding capacity and binding strength of the meat particles leading to a tender final product. The absence of protein in the control sample results in water separation from the protein matrix caused by destabilization of meat structure (Hidayat *et al.,* 2018.) thus increasing meat hardness. A similar high hardness value in the control sample was also observed by Syuhairah *et al.* (2016). Low hardness values in phosphate samples may be explained by the fact that phosphates facilitate extraction of myofibrillar proteins and enhanced binding of meat particles resulting in a decrease in meat hardness (Wang *et al.,* 2009). Contrarily, Hemung and Chin (2015) observed that the presence of phosphate

increase in non-meat ingredients resulted in a slightly higher degree of cohesiveness while Shand (2000) reported low cohesiveness in control samples compared to meat products treated with potato starch, waxy barley, and wheat flour meal. Adhesiveness is the necessary work required to overcome the forces of attraction between the food surface and the surface of other materials in contact with the food (Wambui *et al.,* 2017). This too could be linked to the presence and level of protein in the formulation and explains why the control samples with no protein had significantly low adhesion values compared to other samples (Syuhairah *et al.,* 2016). Springiness is the sample's ability to recover its original form after the force of deformation is removed. In our study, springiness mostly increased with the addition of flours (especially SBFs). This could be associated with increased protein contents similar to the observation in beef sausage by Wambui *et al.* (2017. However, these results contradict those of Syuhairah *et al.* (2016) who reported that the control chicken meat sample (with no binder) had the highest springiness score compared to formulations with binders.

**Water solubility index (WSI)**

The 6% soybean flour, phosphate binder, and 4% soybean flour samples had the significantly highest water-binding index (2.7-3.0%) while CB and PPF1 had the lowest values of 1 % (Fig. 2). In each flour type, there was a significant and progressive increase in WSI as the proportion of flour increased.

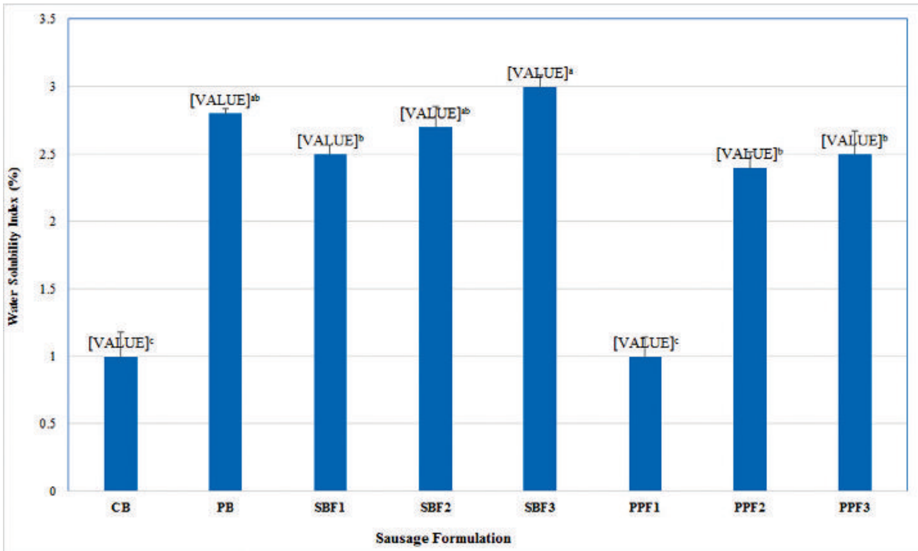


**Figure 2: Water solubility index of sausage samples**

Water solubility index (WSI) is the ability of meat to retain and hold moisture including any fluids added during the processing of the meat and moisture initially present in the meat muscle (Abdolghafour and Saghir, 2014). The highest water holding capacity in 4 and 6% soybean samples (Fig. 2) compared to all other samples could be ascribed to the presence of a high level of soluble protein which influences water holding capacity (Reddy *et al.,* 2015). Protein facilitates water molecules to be bound by polar groups of proteins and retain their spatial structure and remain intact (Pospiech and Montowska, 2011).Similar WSI between 4 and 6% pigeon pea flours and phosphate binder shows pigeon pea flour, at increased levels, may be used in the food industry for the preparation of restructured meat products like sausage. The observed results in this research are similar to the results of several studies where the addition of protein-rich materials like bean flour and gelatin increased WSI in sausages (Dzudie *et al.,* 2002; Lee and Chin, 2016; Souissi *et al.,* 2016)

**Sensory analysis**

**Quantitative descriptive analysis**

Table 5 shows the mean intensity scores of sensory attributes of sausage samples. Phosphate binder samples differed significantly in all sensory attributes intensities with control and phosphate binder samples having the highest colour score followed by soybean flour and lowest intensity in pigeon pea flour. Furthermore, chemical phosphate binder samples had the highest saltiness, mouth feel and compactness intensities compared to all other samples. On the other hand, 4 and 6% soybean flour had the lowest hardness intensity and highest similar moistness intensity to phosphate binder samples

Furthermore, the principal component analysis bi-plot (Fig. 3) of multivariate analysis shows that principal component 1 (PC 1) accounts for 44.3% and it shows clearly sample treatment separation. It groups and separates control and pigeon pea flour samples and their associated high hardness intensity on one side and soybean flour and phosphate binder samples associated high intensities of the remaining sensory attributes on the other side. PC 2 accounts for 26.9% of the variability and it is a contrast between both control and low levels (2%) samples and high level (4 - 6%) samples. The findings further support the Table 3 results that hardness, aroma, and colour decreased while moistness increasing within each flour with their increasing levels of flour in the formulations The observed high color intensity score in phosphate binder samples (Fig. 3) could be due to the impact of phosphate addition which increases buffering capacity of meat with resulting pH change and stable colour (Long *et al.,* 2011). Stable colour is among the main physical characteristics that determine the acceptability of sausage by consumers and is a parameter that can easily be altered by the proportion of non-meat ingredients in the formulation (Syuhairah *et al.,* 2016) as observed in flour samples. However, nevertheless, the addition of soybean resulted in less colour

**Table 5. Mean intensity scores of sausage samples with different binders**

| Sample | Color | Saltiness | Aroma | Mouthfeel | Moistness | Compactness | Hardness |
|---|---|---|---|---|---|---|---|
| CB | $8.2 \pm 1.09^{a}$ | $5.0 \pm 1.87^{b}$ | $7.7 \pm 1.11^{ab}$ | $4.7 \pm 1.40^{c}$ | $5.1 \pm 1.96^{e}$ | $4.3 \pm 2.40^{c}$ | $6.8 \pm 2.71^{a}$ |
| PhB | $8.2 \pm 1.30^{a}$ | $5.8 \pm 1.56^{a}$ | $7.8 \pm 1.09^{ab}$ | $6.9 \pm 1.20^{a}$ | $7.6 \pm 1.23^{a}$ | $6.4 \pm 1.81^{a}$ | $6.0 \pm 2.82^{c}$ |
| PPF1 | $7.1 \pm 1.56^{c}$ | $5.1 \pm 1.67^{a}$ | $7.4 \pm 1.59^{b}$ | $5.4 \pm 1.54^{b}$ | $6.0 \pm 2.34^{d}$ | $4.2 \pm 2.11^{c}$ | $6.4 \pm 2.51^{b}$ |
| PPF2 | $7.1 \pm 2.15^{c}$ | $5.0 \pm 1.73^{b}$ | $7.9 \pm 1.54^{a}$ | $5.9 \pm 2.14^{b}$ | $6.3 \pm 1.92^{c}$ | $4.2 \pm 2.22^{c}$ | $6.1 \pm 3.00^{c}$ |
| PPF3 | $7.0 \pm 2.40^{c}$ | $5.1 \pm 1.83^{b}$ | $7.8 \pm 1.30^{a}$ | $5.7 \pm 2.22^{b}$ | $6.9 \pm 3.21^{b}$ | $4.2 \pm 1.88^{c}$ | $6.0 \pm 2.54^{c}$ |
| SBF1 | $8.1 \pm 1.51^{a}$ | $5.2 \pm 1.62^{b}$ | $8.0 \pm 1.42^{a}$ | $4.0 \pm 2.09^{d}$ | $7.3 \pm 1.11^{ab}$ | $4.6 \pm 2.33^{b}$ | $6.3 \pm 2.06^{a}$ |
| SBF2 | $7.5 \pm 1.79^{b}$ | $5.2 \pm 1.83^{b}$ | $7.9 \pm 1.41^{a}$ | $4.1 \pm 2.09^{d}$ | $7.5 \pm 2.00^{a}$ | $4.6 \pm 2.28^{b}$ | $6.0 \pm 2.83^{ab}$ |
| SBF33 | $7.6 \pm 1.00^{b}$ | $5.1 \pm 1.66^{b}$ | $7.6 \pm 1.88^{ab}$ | $4.6 \pm 1.94^{c}$ | $7.7 \pm 3.00^{a}$ | $4.7 \pm 2.22^{b}$ | $5.9 \pm 2.54^{b}$ |

*Values are expressed as mean ± SD(n = 3). Mean values with different superscript letters along the columns are significantly different at p<0.05. Key: CB is the Control sample, PhB is the phosphate binder, PPF is the pigeon pea flour and SB is the soybean*

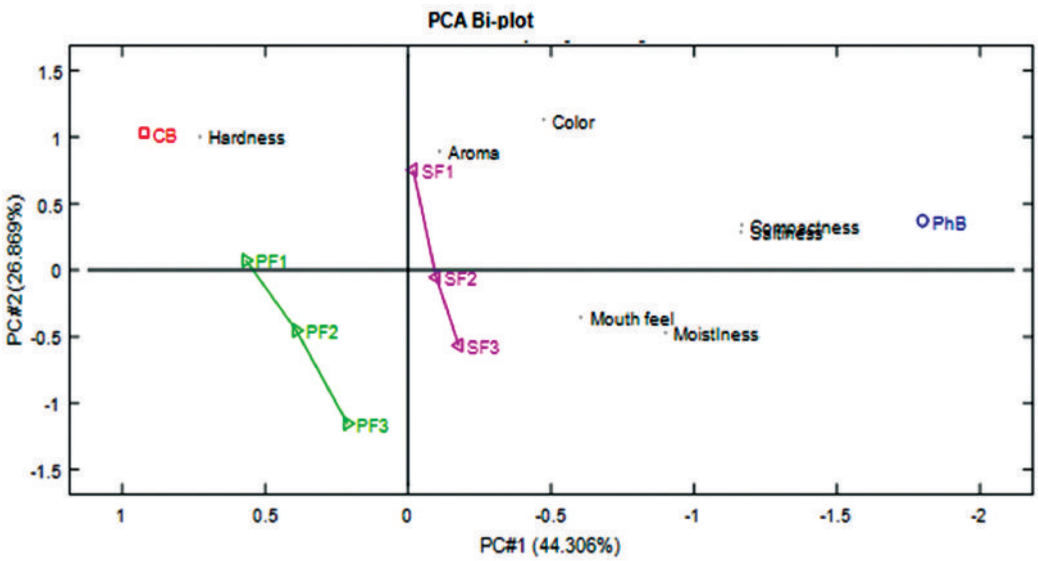


**Figure 3: PCA biplot showing systematic variation in sausage samples with their associated sensory attribute intensities**

reduction compared to pigeon pea flour. Similar colour increased in the sausage due to legume proteins were reported by Hidayat *et al.* (2018) and Babatunde *et al.* (2013). The high saltiness intensity in phosphates binder samples could be due to the salt nature of the binder (Glorieux *et al.,* 2017). Furthermore, the addition of phosphate improves the compactness and mouth feel of the sausage by holding the water molecules together (Long *et al.,* 2017; Peng *et al.,* 2009;). High moistness and lower harness in 4 and 6% soybean flour samples could be due to increased protein contents in the formulations. The protein interacts with water and myofibrillar protein in meat forming a stable hydrophobic interaction and increasing water holding capacity, resulting in a compact, moist and tender sausage (Wi *et al.,* 2020). The lower intensities for color, mouthfeel, moistness, compactness, and high hardness in control and pigeon pea flour samplesthan phosphate and soybean flour could be to an inadequate amount of protein present in the flours. Lack of binder in the control samples could be responsible for their high hardinessintensity and other low sensory attributes as similarly reported by Teye and Teye (2011) and Babatunde *et al.* (2013)

**Consumer test**

Table 6 shows the acceptability and preference of different sausage samples by consumers. The phosphate binder was the most acceptable sample (7.3) followed by 6 % soybean flour samples (7.1) and the lowest values in control samples (5.7). It was further observed that acceptability within the flours increased significantly with their increased level in the formulations. Moreover, consumer preference among samples varied significantly ($p<0.05$) with 4 and 6 % soybean flour samples ranked the most preferred samples with a rank-sum score of 125 on a five-point scale (1 being the most preferred and 5 being the least proffered) followed by phosphate binder samples with a rank sum of 177. The pigeon pea flour samples were the least preferred with a rank sum of 194-228.

By producing sausage samples with high consumer acceptability and preference, it suggests the suitability of using soybean flour up to 6% and greater in sausage and other restructured meat preparation as previously reported by Odiase *et al.* (2013). Protein in the flour could have enhanced physical and sensory properties resulting in an increased influence on consumer overall acceptability and preference of the sausage samples. Oluwaseun (2019) and Syuhairah *et al.* (2016) observed similar findings. In product development, consumer testing is considered to be one of the most important tests and its primary purpose is to assess the personal response by current and potential customers of a product or specific product characteristics (Soma, 2013). The observed low performance

**Table 6: Hedonic scores and Friedman rank sum test of the sausage samples of sausage samples**

| | Acceptability[1] | Preference[2] | |
|---|---|---|---|
| **Sample** | **Mean hedonic** | **Median** | **Rank Sum** |
| CB | $5.7 \pm 2.12^{ef}$ | 3 | $181^{ab}$ |
| PhB | $7.3 \pm 1.88a$ | 3 | $177^{ab}$ |
| PPF1 | $5.1 \pm 2.03^{g}$ | 5 | $228^{b}$ |
| PPF2 | $5.5 \pm 3.11^{f}$ | 4 | $212^{b}$ |
| PPF3 | $5.9 \pm 1.11^{e}$ | 3 | $194^{ab}$ |
| SBF1 | $6.2 \pm 2.11^{d}$ | 3 | $193^{a}$ |
| SBF2 | $6.4 \pm 1.84^{c}$ | 2 | $153^{a}$ |
| SBF3 | $7.1 \pm 1.67^{b}$ | 2 | $125^{a}$ |

*1Values are expressed as mean ± SD (n = 3)1 and Rank sum (n=70)2. 1Mean and 2Rank sum values with different superscript letters along the columns are significantly different at p<0.05.2Friedman chi-squared = 29.683, p-value = 0.0001085, and least significant rank difference (LSRD) is 43.3. Key: CB - Control sausage, PPF - Pigeon pea flour, and SBF is the soybean flour.*

of pigeon pea flour as an extender compared to chemical phosphate binder and soybean flour suggests for a study to determine appropriate flour portion with adequate protein content to enhance the binding effect in restructuring meat technology without affecting physicochemical and sensory properties of the final products.

## Conclusion and recommendation

In conclusion, soybean has higher protein contents than pigeon pea and its incorporation of up to 6% in sausage produces a more acceptable product than plain control samples but with WSI and texture and sensory profiles comparable to chemical binder samples.

The study has failed to show clearly the suitability of pigeon pea flour upto 6% in restructured sausages, further studies to establish appropriate pigeon pea flour levels that will produce acceptable products with similar physical and sensory properties to chemical binder is highly recommended.

## Acknowledgement

The authors acknowledge the Veg – Leg (Vegetable and Legumes) project for their financial support in the accomplishment of this study.

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# Gas Extraction Operations and changes in Livelihood Activities: Experience from Mtwara Rural District in Tanzania

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**Abstract**

*The effects of gas extraction operations on livelihood activities among communities remained unknown albeit the extractions pursued in Mtwara District of Tanzania. This paper analyses the changes in local livelihood activities due to gas extraction operations in the district. The paper uses the Sustainable Livelihood Framework (SLF). Data were collected through a household survey (n=260,) focus group discussions (n=8) and key informant interviews (n=15). Quantitative data were analysed using IBM SPSS Statistics whereby descriptive and multiple response analyses were performed. Qualitative data were analysed using content analysis method to supplement the quantitative information. Results show a decline in; fishing activities from 58.5% to 17.65%; decline in crop business from 36.9% to 8.92%; decline in petty business from 12.3% to 9.2%; boat driving and repair 10.0% to 3.05% during gas extraction respectively. Also, the paper reveals an increase in; sea-shells collection from 1.75% to 39.2%; farm labour in neighbouring villages from 1.65% to 5.4% and an increase in other non-farm activities like carpentry, brick making and motor circle and bicycle repair to closer villages. The study concludes that after introduction of gas extraction operations local community's livelihood activities have changed. We recommend more investment in education and vocational training to equip local communities with skills to engage in gas extraction industries and diversified income activities. Building rural infrastructure will improve transportability and will create job opportunities for poor households.*

***Keywords***: Gas extraction operations, extractive investments, livelihood and livelihood activities

## Introduction

The progressive record of resource-rich countries has acknowledged much attention on extractive investments since the oil boom of the 1970s. Russia, India, China and South Africa have run extraordinary stages of global investment in the extractive industries (Robbins, 2013). While such investments had significant social, political and economic implications for actors at all scales from the global to the local level, the livelihood impacts of intensified resource extraction at the community level have been particularly diverse and thoughtful. Managing natural resources continues to challenge resource rich countries (Besada, *et al.,* 2015; Elbra, 2017). This is more pronounced in Africa where resource rich countries are characterised by widespread poverty and material deprivation to the extent that their natural endowments might be described as a curse (Elbra, 2017). Some studies on the management of natural resources point to poor governance arrangements and mechanisms as a primary cause of the challenges associated with extractive resources development (Diamond and Mosbacher 2013; Besada, *et al.,* 2015).

In theory, mineral extraction, including oil and gas, should contribute to development by increasing employment, economic growth and public services, and thus improve wellbeing of nearby local communities (Budiono *et al.,* 2018). Since the 2008-2009 recession, the growth of natural gas extraction has been regarded by some as a highly positive investment for development as it increases employment and economic diversification while bringing lower energy prices to consumers. The major concern is the extent to which production operations in natural gas extraction pose environmental risks, while others are concerned about the impacts that sudden economic expansion can have on communities' livelihood strategies (Shannon and Larry, 2012). The impact of large gas extractive investments on local communities is complex and extensive. As noted by Hilson (2012), few extractive investment operations have as large an environmental mark and are gifted of exercising as much influence on the livelihoods of a community. This process is of significant global concern due to dramatic regional-scale economic and environmental changes that can result from these activities, along with the perceived vulnerability of indigenous people, their livelihoods and lands (O'Faircheallaigh, 2013).

In response to criticism of past practices and the growing influence on environmental and indigenous movements, corporate and government policies on resource extraction have become more promising to local communities over time (Khosla and Jena, 2019). Nevertheless, the social and environmental history of the extractive industries in Mtwara is unpleasant (Mwesiga and Mikova, 2017; Kabendera, 2016), and local communities remain at an enormous disadvantage when interacting with gas extraction investments (Bozigara *et al.,* 2016). These worries lead to this empirical research to investigate on the changes in the livelihood activities among local communities due to gas extraction operations.

This study used the sustainable livelihood framework (DID, 2000) to explain the influence of gas extraction operations on changes in livelihood strategies among local communities. The livelihood ambiguity was a consequence of variations in social, economic, and government policies (Budiono *et al.,* 2018). A livelihood strategy is often a combination of different activities performed by different household members, and it varies by season and context (Amevenku *et al.,* 2019). The livelihood strategy is related to the management or combination of various livelihood assets to uphold or improve livelihoods (Peng *et al.,* 2016). Yizengaw *et al.* (2015) reported that local communities' households in Northern-west, Tanzania, had practised diverse livelihood strategies by combining activities inside and outside the extractive sector for household wellbeing. Meanwhile, in Southern-east, Tanzania where Mtwara is located, local communities located in the countryside have diversified their livelihoods by involving all family members. This diversification had a significant contribution to the increase in household income (Saha and Bahal, 2016).

Other studies in rural Mozambique and Nepal found that agricultural land owned by rural farmers was a major determinant of household access to livelihood strategies when shocks occurred (Walelign, 2016; Khatiwada *et al.,* 2017). It is therefore clear that, the livelihood strategies in rural local communities are conceived differently depending on the available livelihood resources or assets, and vulnerability circumstances (Wulandari, 2017).

Household livelihood strategies are embedded in the natural and socio-economic contexts in which people live (Buur *et al.,* 2013). The gas extraction and production may create changes in the predominant livelihood systems either to the benefit or damage of local communities living near extraction investments (Dowokpor, 2015). The extraction of gas resources in rural areas is often considered an important source of income and a means of livelihoods for low-income rural households (Roe *et al.,* 2015 and Schaafsma *et al.,* 2015). Normally, the nature of livelihood capital held by a household is considered in deciding on the available livelihood strategies, and the risk associated with such decision. Meanwhile, local communities in the south-eastern region of Tanzania majorly depends on natural resources for their survival and they employ the use of family labour and other strategies to achieve their objectives on these natural resources (MDC, 2016). To attain a positive livelihood result, local communities need to have different livelihood strategies at hand. The livelihood strategies possessed by households are a strong determinant of the strategies for achieving livelihood objectives, such as income, shelter, security, and general welfare (Fang *et al.,* 2014). Furthermore, selections become abundant with increased livelihood strategies, in addition to the ability to substitute among livelihood strategies which are products of interaction between gas extraction operations and local communities. Thus, studies on the relationship between extractive investments operations and livelihood activities of the household in local communities received much attention in recent years (Xueyan, *et al.,* 2018 and Walelign *et al.,* (2016).

Many studies, for example, Yin and Xiao (2020); Xuxi *et al.,* (2019); Xiaolan *et al.,* (2019); Jing *et al.,* (2019) and Wenqiang, *et al.,* (2018) have focused on the impact of farmers' livelihood capital differences on their livelihood strategies in Three Gorges Reservoir Area in China. Studies by Islam and Alam (2021); Sharaunga and Mudhara (2021); Sarker, *et al.,* (2020) have focused only on household livelihood strategies and resource dependence. Among the notable findings are reported by Shuxin *et al.,* (2020) and Delgadillo et al., (2020). who reported that the position of different livelihood capitals determines the choice of farmers' livelihood strategies, and the ability to achieve diversified strategies of living depends on the livelihood of farmer-owned capital items of main ethnic minorities in Chongqing, China. Yizengaw *et al.,* (2015) reported that the households in local communities in Northern-west Mongolia had practised diverse livelihood strategies by combining activities inside and outside the extractive sector for household wellbeing. Hence scanty information on the changes in local community's livelihood activities as a result of gas extraction investment operations among households residing closer to gas processing plant.

Furthermore, other empirical studies have reported the dynamics of livelihood strategies in relation to income, asset ownership and income composition (Anggriawati, *et al.,* 2021; Beyan, *et al.,* 2018; Yili *et al.,* 2017; Paudel *et al.,* 2017). However, these studies could not address the impact of gas extraction operations on changes in livelihood activities among local communities. Understanding rural livelihoods activities and the gas extraction operations dependence can reduce and prevent livelihood stress induced by gas extraction operations during gas exploration and extraction processes, especially for low-income households (Nguyen *et al.,* 2018; Babigumira *et al.,* 2014). Therefore, this paper analyses the influence of gas extraction operations on changes of livelihood activities in Mtwara Rural District of Tanzania. Specifically, the paper examines the livelihood activities before and after the introduction of gas extraction operations to capture changing livelihood patterns. The results of the influence of gas extraction operations on changes in livelihood activities is imperative for policy makers and will sustainably benefit local communities to avoid the common resource curse scenario.

**Theoretical Perspective**

The core function of the sustainable livelihood framework (SLF) is the assessment of different capitals that are deemed to underpin livelihood at the individual, household, village or group levels (Ahmed *et al.,* 2011). The only natural and human capitals were included in the study. These capitals are then assessed in terms of soil potential, landholding size, water potential, and the surrounding environment. On human capital is assessed in terms of skills and knowledge; family labour; health status; leadership potential; household size; home possession; previous personal experience; expertise/skill; exposure to social and cultural norms; their vulnerability to shocks and the institutional context within which they exist. Once this is understood, interventions can be put in place to enhance livelihoods and their sustainability, perhaps by increasing the capital available or by reducing vulnerability. Thus, the process is about understanding the existing situation and developing suggestions for improvement based upon that understanding. The SLA is meant to avoid a situation where intervention is unguided giving little positive impact or is at worst detrimental. In this study, the livelihood activities are affected by gas extraction operations, and this could be attributed to a high degree of heterogeneity of extractive investment operations in the local communities of Mtwara Rural District, Tanzania.

In this study, the dependent variables are livelihood activities linked with gas extraction operations. There are also intervening variables which are age, sex, marital status, education level, main occupation, household size, distance from households to gas processing plant, geographical location and resource endowment. Besides these variables, contextual factors are considered to influence household decisions to engage in various livelihood activities (e.g. farming, local off-farm or casual labour work) (Wang *et al.,* 2012; Huber *et al.,* 2015).

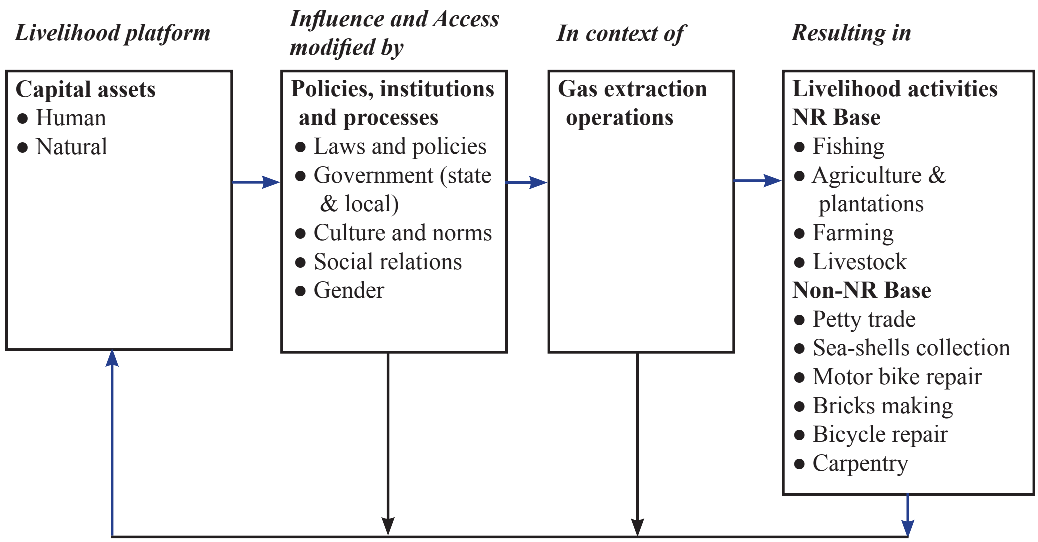


**Figure 1: Sustainable livelihoods framework DFID (2000) modified by a researcher**

## Methodology

### The Study Area

The study was conducted in Mtwara District, which is one of 7 districts of Mtwara Region located in South-Eastern Tanzania. The district lies between longitudes 39°0" and 40°27" East of the Greenwich and between latitudes 10°0" and 10°07" South of the Equator. It is bordered by the Indian Ocean to the East, and Lindi Region to the North and Ruvuma region to the West. Mtwara District has an area of 3,597 square kilometres including the Nanyamba Town Council (Mtwara District Council, 2015). Mtwara Region and Mtwara Rural District were purposively selected due to high gas reserves in the country and the existence of gas extraction operations in the areas where marginalized people are living. Msimbati and Madimba wards were selected for the study due to the existence of gas processing plant and extraction activities. The villages included in the study were Msimbati, Mtandi, Namindondi and Mngoji respectively.

### Research Design and Sampling Procedure

A cross-sectional research design was used. The design was suitable because it is cost-effective (Chaudhuri *et al.,* 2002) and allows the inclusion of participants or groups of people among whom comparison can be made (Matthew and Ross, 2010). The unit of analysis was a household of local communities where the heads of households were involved in the survey. The households in the named villages of Msimbati, Mtandi, Namindondi and Mngoji respectively were categorized as close to or away from the gas extraction processing plant and were purposely selected based on their distance to the gas processing plant. The number of households heads selected for the study was 260; they were randomly sampled based on a proportionate formula computed at 5% for equal chances of being represented in the survey (Bailey, 1994). The total number of households in each village are as indicated in Table 1. Krejcie and Morgan (1970) sample size formula (Equation 1) was used in estimating the sample size for the study.

$$S = \frac{X^2NP(1-P)}{d^2(N-1)+X^2P(1-P)} \qquad (1)$$

Where S is the required sample size, $X^2$ is the Z value (for instance, 1.96 corresponding to 95% confidence level). N is the population size, P is the population proportion (assumed to be 0.5 or 50%), and d is the accuracy level (5%) expressed as a proportion (0.05) signifying the margin of error. In addition, 15 key informants were purposely selected based on their positions and more knowledgeable and experienced in gas extraction operations and changes in livelihood strategies in the study area.

**Data Collection**

A household survey was conducted between July and October 2020 whereby a questionnaire was administered to the household heads that were sampled for the study. The questions were on socio-economic and socio-demographic situations (including household size, income sources and age, education, and occupation of

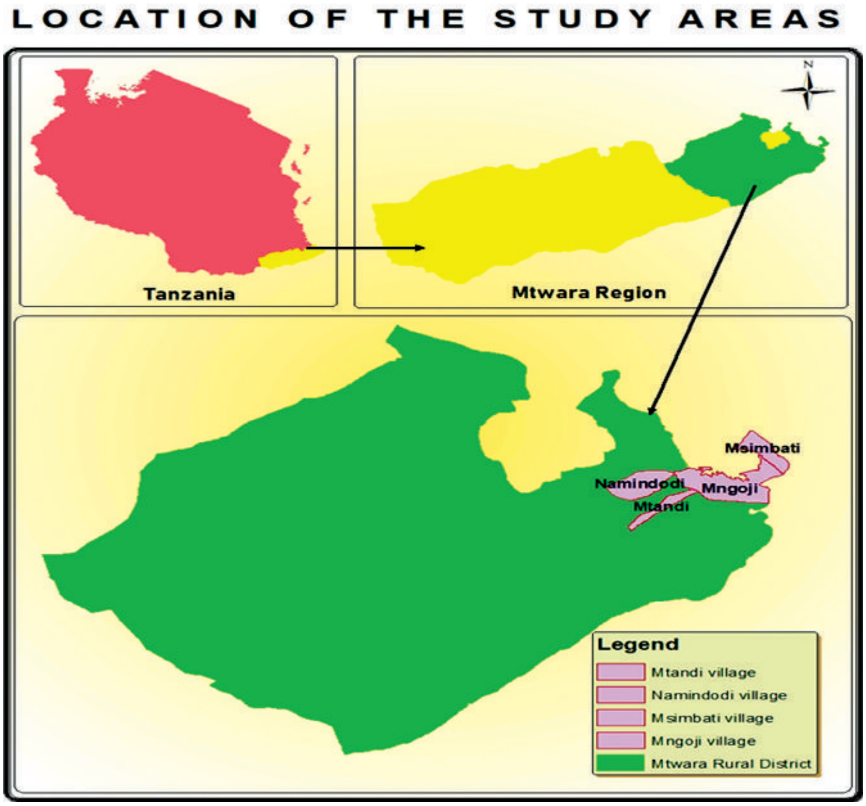


**Figure 2: A Map to show study area location and its village**

**Table 1: Sample distribution for the study among villages in the study area**

| Ward | Villages away | Total Households | Sampled households | Percent (%) |
|---|---|---|---|---|
| Msimbati | Msimbati | 755 | 74 | 28.4 |
| | Mtandi | 690 | 67 | 25.8 |
| | **Villages closer** | | | |
| Madimba | Namindondi | 656 | 63 | 24.2 |
| | Mngoji | 580 | 56 | 21.5 |
| **Total** | **4 villages** | **2681** | **260** | **100** |

***Note:*** **The number of household heads in the surveyed villages was based on discussions with local people in the field* all household members), and gas extraction operation activities and livelihood strategies before the gas extraction activities and at the time of the survey. Semi-structured interviews with local village leaders and officials supplemented the data that were collected using the questionnaire. For the semi-structured interviews, 15 key informant interviews (KIIs) were conducted using a checklist of items for discussion, and 8 Focus Group Discussions (2 FGDs per village) with 6-8 participants were held using an FGD guide.

**Data Analysis**

To describe local communities' livelihood strategies and gas extraction operations in the study area, we first use quantitative data to conduct descriptive analyses of community-level interaction with gas extraction investment (Table 3) and of various dimensions of household livelihood strategies (Table 4). The quantitative data that were collected were analysed using the IBM Statistics Version 20 (SPSS) programme and frequencies were calculated. Key informant interviews (KIIs) and Focus Group Discussions (FGDs) were recorded, transcribed, and analysed together with field observations. Coding comparison queries allowed similar comments and suggestions to be synthesized under common themes. These procedures were intended to relate and analyse key themes that arose from the study as suggested by Patton 2005. In what follows, the research results are presented in the form of a synthesis of the field observations, questionnaire, and interview results.

**Results and Discussions**

This paper classified villages into two groups (closer and away) based on the distance from households to gas processing plant. The away villages being the control group and closer villages being the experimental group. This study targeted the households closer (0.2-5) km to gas processing plant and the households away (8-20 km) from gas processing plant but closer (0.2-5) km to gas extraction wells. The purpose of the present paper was to examine the changes in livelihood activities as a result of gas extraction operations among local communities' households in Mtwara rural district.

**Socio-Demographic Characteristics of the respondents**

The demographic information about the questionnaire participants in the study area is summarized in Table 2 below. The number of male respondents 56.9% was slightly higher than female participants 43.1%. The average household size was (4.8). The majority of respondents were aged between 25 and 54 years old, which indicates that they may fall into the working age with family group. This is the age which is more energetic and productive but more affected by the challenges of unemployment and poverty which all together made them more active in economic activities. About one-fourth of the survey participants were crop sellers and about two-fifth of participants were farmers; 10.4% were sea-shells collectors; 5.8% of the participants reported that they had casual jobs and were under employed; and approximately seven-eighth of the surveyed population were unemployed to gas extraction investment at the time the questionnaire was undertaken.

**Livelihood Activities before and during Gas Extraction in Mtwara rural district**

Though fieldwork for this study was in 2020, the year 2012 was useful in providing a reference point because extraction of gas commenced in the Mtwara Field area in 2012. As part of our survey, we undertook a comparison regarding the occupation of people in the year of the field work (2020) and the year extraction commenced (2012). We believe this assessment is useful for obtaining a standpoint of whether the extraction of gas had made a change on local communities' livelihood activities. The comparison indicates that economic activity within this period (that is between 2012 and 2020) was relatively stable with the population remaining in traditional local roles as farmers, fishers and so on. The local community is a subsistence fishing and farming community where fishing and farming play a vital role in the lives of populaces. The assorted collection of livelihood activities suggest that rural households are frequently engaged in multiple activities and livelihood divergence, which are

**Table 2: Socio-demographic characteristics of the respondents**

| Household characteristics | Total | Percent (%) |
|---|---|---|
| Average household size | | 4.8 |
| Sex | | |
| Male | 148 | 56.9 |
| Female | 112 | 43.1 |
| Education level of household head | | |
| None | 60 | 23.1 |
| Primary | 174 | 66.9 |
| Secondary | 20 | 7.7 |
| Vocational | 4 | 1.5 |
| University degree | 2 | 0.8 |
| Average age of household heads | | 44.4 |
| Marital status | | |
| Single | 22 | 8.5 |
| Married | 175 | 67.3 |
| Divorce | 19 | 7.3 |
| Separated | 14 | 5.4 |
| Widow/Widower | 30 | 11.5 |
| Years of schooling | | 5.6 |
| Main occupation | | |
| Farming | 110 | 42.3 |
| Crop sales | 67 | 25.8 |
| Self-employee off fishing | 15 | 5.8 |
| Off fishing | 5 | 1.9 |
| House keeping | 3 | 1.2 |
| Sea-shells collection | 27 | 10.4 |
| Petty business | 17 | 6.5 |
| Motor circle | 9 | 3.5 |

vital for persistence and for reducing dangers in a rural economy location (Liu and Lan, 2015).

Table 3 informs that, majority 92.3% of households from closer villages and away villages to gas processing plant use farming as a prominent livelihood activity before and during gas extraction operations followed by fishing (fishing gear, boat repair, sale of fish and its products respectively). The results show that the most crops business done in the study areas were cashew-nuts, cassava, paddy and coconuts. These findings are is in line with the findings from a study by Rigg *et al.,* (2016) who suggested that farming as the livelihood strategy for the rural economy remains the largest contributor to household's total income and income from farming is still by far the main source of farm income (especially for subsistence). The results in Table 3 show that livelihoods in closer (Namindondi and Mngoji) and away (Msimbati and Mtandi) villages were mainly based on farming and fishing, boat driving, crop sales and fishing gear repair and petty business. The crops grown for business

**Table 3: Livelihood activities before and during gas extraction in Mtwara Rural District**

| Livelihood Activities | Closer villages (Namindondi and Mngoji) | | Away villages (Msimbati and Mtandi) | |
|---|---|---|---|---|
| | Proportions (%) of cases before gas extraction | Proportions (%) of cases during gas extraction (%) | Proportions (%) of cases before gas extraction | Proportions (%) of cases during gas extraction (%) |
| Farming | 92.3 | 100 | 93.85 | 97.5 |
| Fishing | 53.85 | 17.65 | 13.8 | 5.9 |
| Petty trade (Food vendors) | 12.3 | 9.2 | 17.7 | 7.6 |
| Boat driving | 10.0 | 3.05 | 3.05 | 2 |
| Crop business | 36.9 | 8.92 | 24.6 | 12.15 |
| Seashell collection along shores of Msimbati | 1.75 | 39.2 | 0.65 | 19.6 |
| Farm wage labour in the neighbouring farm | 1.65 | 5.4 | 1.5 | 5.1 |
| Carpentry | 0.25 | 6.15 | 0.15 | 5.8 |
| Making bricks | 0.00 | 3.85 | 0.00 | 5.85 |
| Bicycle (motor- cycle repair) | 1.05 | 2.3 | 1.65 | 2.5 |
| Boda-boda (motor-cycle) | 0.00 | 2.3 | 0.50 | 5 |

a. Dichotomy group tabulated at value 1.
*Multiple responses*

were cashew-nuts, cassava, coconut and paddy (MDC, 2016). These findings were reiterated in the focus group discussions (FGD) conducted in this study. Results of focus group discussions (FGD) supported the findings, for example, in one of FGDs it was agreed that:

*Majority of us were subsistence farmers and fishers, but after gas extraction operations started, we were not able to be employed because we had no education and skills needed by investors.* (FGD No.1, Mngoji Village, 18:10: 2020).

On the issue of livelihood activities before gas extraction operations in the study area, some KIIs participants' conversations centred on the lack of choice when it came to deciding on a career path. A KII participant, an old woman of seventy-year-old expressed the hardship that comes with being burdened with limited activities prospects:

*"There are no works in this community and so when you are unable of the farm, then it means that you will go hungry. Farming and fishing were the only main livelihood activities here aside sea-shell collections, and so when you are unable to farm outside the village or go for sea-shell collections along the sea shores, you will go hungry"* (A 70 years old, female, KIIs in Msimbati Village, 18:10: 2020).

Descriptions of apparent difficulties experienced in the study area appeared to spin around the absence of jobs, which according to some FGDs participants had resulted in poor living conditions for local communities who live near the gas processing plant in the study area. Some spoke of being sad in the community because they were forced to either collect sea-shells or farm or to move out, was quite open when he explained that:

*We are so sad in this community because there are no jobs. So, what I have realised is that if you do not farm or go for sea-shells collection,* *then you will just be left with nothing to do in this community* (A 62 years old, male, KIIs in Namindondi Village, 20:09:2020).

The surveyed villages showed marked differences in structural and socio-demographic characteristics (Table 3) and in the livelihood activities they did to earn an income during the survey (Table 4). For some livelihood activities, no clear difference was observed among the villages (i.e. overall livelihood activities were farming, fishing, boat driving, crop sales and fishing gear repair and petty business). The farming and fishing activities were done in different seasons. During high tides seasons, at least all respondents were engaged in fishing. But during low tides, almost all communities were engaged in farming. This led to difficulties when it came to distinguishing households engaged fully in fishing and farming as livelihood strategies.

## Changes in the livelihoods following gas extraction in Mtwara Rural district

Mtwara rural district as a rural fishing and farming subsistence economy has not escaped changes that communities are undergoing the world over. A rural area, which was formerly assured of enough fish and crops to cater to its inhabitants and neighbours before gas extraction operations, is experiencing shortages. Perceived plentiful fish catches as well as plentiful crops harvested during previous harvest seasons mainly dominated local communities' narratives of life in Mtwara rural district during the period of the fieldwork.

The results in Table 4 show the dominant livelihood activities in the study area which included: (i) Farming, (iii) Salaried employment, (iv) Investor farm wage labour, (v) Farm wage labour in the neighbouring farm, (vi) Carpentry, (vii) Making bricks, (viii) Bicycle/motor cycle repair, (ix) Motorcycle (Boda boda) and (x) Sea-shells collection along shores of Msimbati. Table 4 shows changes in livelihood activities following gas extraction operations in both closer (Namindondi and Mngoji) and away (Msimbati and Mtandi) villages from the gas processing plant. The results show a decrease in fishing activities by about three eighth for closer villages (Namindondi and Mngoji) compared to 7.9% for away (Msimbati and Mtandi) villages; a decrease in crop business by 27.98%

**Table 4: Changes in the livelihoods following gas extraction in Mtwara Rural district**

| Livelihood Activities | Closer villages (Namindondi and Mngoji) Differences between the per cents (%) | Away villages (Msimbati and Mtandi) Differences between the per cents (%) | Status |
|---|---|---|---|
| Farming | -7.7 | -3.65 | Increased |
| Fishing | 36.2 | 7.9 | Decreased |
| Petty trade (Food vendors) | 3.1 | 10.1 | Decreased |
| Boat driving | 6.95 | 1.05 | Decreased |
| Crop business | 27.98 | 12.45 | Decreased |
| Sea-shells collection along shores of Msimbati | -37.45 | -18.95 | Increased |
| Farm wage labour in the neighbouring farm | -3.75 | -3.6 | Increased |
| Carpentry | -5.9 | -4.05 | Increased |
| Making bricks | -3.85 | -0.585 | Increased |
| Bicycle (motor- cycle repair) | -1,25 | -0.85 | Increased |
| Boda-boda (motor-cycle) | -2.3 | -0.45 | Increased |

a. Dichotomy group tabulated at value 1.
*Multiple responses*

for closer (Namindondi and Mngoji) villages compared to one eighth for away (Msimbati and Mtandi) villages; decrease in boat driving by 6.95% for closer villages compared to 1.06% for away villages. These changes imply that closer (Namindondi and Mngoji) villages to gas processing plant were much affected by gas extraction operations such as dumping of mud, toxic wastes, including gun-powder from the gas processing plant and heat generated during gas tanks cleanliness. These findings are cemented by the findings obtained through KIIs in this study. For instance, one of the KII in his account of life in the Mtwara rural villages before gas extraction said:

*Formerly when we had visitors in this village, they were so happy because the fishermen got a lot of fish catch* (KIIs in Msimbati Village, 6:10:2020).

Another KII, also confirmed plentiful fish catches that characterised past fishing trips in the following narration:

*My Son, previously (before gas extraction) if you had come to this village, you would have seen a lot of fish here, previously we didn't lack fish at all but today look at the situation* (A58 years old, male, KIIs in Mtandi Village, 7:10:2020).

They further explained that if it had been in the past before gas extraction operations, by the time we were through with the interview all they had to do were to instruct one of the young men to bring some fish to us as a gift because fish was always in plenty. People spoke with pride when they mentioned plentiful fish harvests in the past, but that mood quickly disappeared when they talked about the present situation of declined fishing and fish stocks as a result of gas extraction operations in the study area.

Another fisherman, a sixty-four-year-old, added, fishing is no longer satisfying:

*Fish catch levels have drastically reduced because for about two to three months now we have not seen any fish. Fishing is no longer pleasant. It was not the same as in the past before gas extraction operations in our village. The fishes have moved upstream because of the gas extraction operations, so when we go fishing, we do not get fish* (A 64 years, male, KIIs in Namindondi Village, 16:10:2020).

Despite these accounts that point to the fact that many participants believed there had been a change in fishing and farming activities over the years. The FGD in Mngoji village also held a contrary view, they complained about fish scarcity attributed the period of fish scarcity to the beginning of gas discovery and extraction as agreed by FGDs that:

*"Before gas extraction operations we used to get much fish when we went fishing, but since the beginning of the gas extraction operations when we go fishing, we do not get fish"* (FGD no 3. Mngoji Village, 23:10:2020).

Another KII is also of the conviction there was a link between fish scarcity and the gas extraction operations in the study area:

*"The discovery of the gas has destroyed our fishing occupation. Before the discovery of gas, when we went fishing, we used to get much fish but now with the discovery of gas, we are not allowed to fish near gas extraction wells"* (KIIs in Msimbati Village, 24:10:2020).

Consumers of fish like another KII, an unemployed seventy-two-year-old was also of the firm belief that the period of fish scarcity started with the gas extraction.

*We hardly get fish to buy nowadays since the gas extraction operations, we cannot tell if the gas extraction operations have driven away from the fish. The fishermen have also been told not to go further up. That is where they will get some fish, but they have been asked to stay away from the gas extraction wells* (A 72 years old, female, KIIs in Mtandi Village, 28:10:2020).

Table 4 shows an increase in sea shells collection by three eighth for closer villages compared to 18.95% for away villages. This imply that, currently local communities' households are engaged in collection of sea-shells instead of fishing because they are strictly prohibited to fish near onshore gas extraction wells. It also shows an increase in other non-farming activities like carpentry; bricks making; motor bike repair and motor circle (boda boda). Contrary the findings reveal a slightly increase in farming activities by 7.7% for closer (Namindondi and Mngoji) villages compared to 3.65% (Msimbati and Mtandi) for away villages. This is due to the fact that since large proportion of household heads among local community lacks training skills and profession to work with gas extraction investment and the only way to do in order to survive is to engage themselves in farming activities as farm labourer in nearby villages. This indicates that gas extraction investment had resulted in changes in the main livelihood activities for the households living closer to gas processing plant of Namindondi and Mngoji than away Msimbati and Mtandi villages.

These results mean that villages closer to gas processing plant were negatively affected on fishing activities, crop business, boat driving and negatively affected on petty business compared to villages away from the gas processing plant. These results also mean that villages closer to gas processing plant had higher livelihood diversity, especially in sea-shells collection, farming and farm wage labour and carpentry compared to villages away from gas processing plant. Before the establishment of gas processing plant, sea shells (Simbi) collection along the shores of Msimbati Bay was the second livelihood activity of all the households. After collecting the sea-shells, they sell to a Chines company in Mtwara Municipality where a kilo of sea shells was sold at 800 TZS Tanzanian shillings. The analysis revealed that sea-shells collection was the second livelihood activity in the study area replacing fishing and farming activities. The results in general show a high level of changes in livelihood activities in the study area. Three quarters of the sampled households changed their livelihood activities during 2012–2020. This implies that they continuously responded to evolving pressures and opportunities brought by gas extraction operations. However, these changes in livelihood activities may not necessarily indicate a dramatic change over a short period; rather it is an evolution and adoption process (Roy, A., and Basu, S., 2020; Benyong *et al.,* 2019). This imply that household's livelihood activities in both closer and away villages were negatively affected by gas extraction operations.

In the study area, the less compensable and most practised livelihood activity is farming. Farming remains a major pillar in the rural economy of the study areas though the share of farming dropped dramatically among households. However, farming still plays a prominent role in explaining and differentiating livelihood outcomes for each livelihood activity. Given the changes in of livelihood activities, fishing decreased about three-eighths (see Table 4) before gas extraction to 7.9% during the survey. This is also evident from other studies (e.g. Kimsun, *et al.,* (2013) when they examined rural households' sources of income and livelihood strategies in Cambodia. The changes in fishing activities were due to the fact that, after the introduction of gas extraction operations, people were strictly prohibited to continue with fishing and farming activities near gas extraction wells, gas processing plant and gas pipelines which cut across a large area of local communities.

This is contrary to the results reported in studies by Shuxin *et al.,* (2020) and Jie *et al.,* (2019) which showed that majority of local communities residing near extractive investment were happy with their livelihoods activities as their income was sufficient to sustain their life. In addition, possession of higher physical and financial capital items propels local communities near extractive investment to settle for livelihood activities that are linked with extraction investment operations. On the other hand, the households in local communities (both away and closer to gas processing plant) that engage in crop business (cashew-nuts, cassava), sea-shells collection (Simbi) and off-farm work have the potential of living well within the gas extraction operation areas compared to those engaged in farming and fishing. The authors further noted that such households require education, financial capital and engagement in their off-farm enterprises. The income of local communities away from gas processing plant was much higher than those closer to gas processing plant, and this affirms that continuous sea-shells collections livelihood activity ranks first among the livelihood activities of local communities in Mtwara Rural District.

This contradicts a report by Waleleign (2016) that the farming-based livelihood activity was less lucrative compared to petty trade based and off-farm-based livelihood activities. A reasonable clarification for this is that farming still contributes more than fishing to the total income structure of the farming-based livelihood activity in this study, while sea-shells collection and petty trade mainly constitute to the income for livelihood of local communities in the study area. More significantly, the incidence of decline in fishing activities due to gas extraction operations leads to reduction of income of the households of local communities (Milgroom and Giller, 2013; Kandulu *et al.,* 2012). It is more likely that, if the households of local communities near gas processing plant own more financial capital, they will invest more capital and labour in non-farming and non-fishing activities to maximize their total income. Therefore, by changing the livelihood activities, improving the employment skills of local communities and perfecting the incentive policy of local contents, the livelihood activities of the household of local communities could be transformed from fishing to petty trade and off-farm households.

These results suggest that exposure to gas extraction operations has mixed and multidimensional effects on the livelihood activities among local communities and had contributed to a shift away from previously main livelihood activities such as fishing and farming before gas extraction operations to other non-farming such as brick making, carpentry, motor bike repair and sea-shells collections in the area. These findings are consistent with findings of previous studies in other settings and are partly consistent with the Dutch disease process. Dutch disease is a paradoxical situation where good news for one sector of the economy, such as the discovery of natural resources, results in a negative impact on the country's overall economy. However, they challenge the common narrative that the consequences of gas extraction operations for local communities are entirely negative (Bozigara *et al.,* 2016).

**Theoretical implications**

The study was guided by the Sustainable Livelihood frame work (SLF). According to SLF, The SLF is built around the assumption that improvement of livelihood outcomes of poor people can be through understanding the five principal categories of livelihood assets namely physical, human, financial, natural and social and their ability to put these assets to productive use (DFID, 2000). The study findings have shown that, gas extraction operations have had an adverse impact on livelihood activities in general in the study area. The study has also shown that the Gas extraction investment has not contributed to improved livelihood outcome to the surrounding communities. Based on the findings, this study confirms the SLF based on the changes on livelihood activities after the introduction of gas extraction operations during the survey. The study found out that farming, fishing are no longer the major livelihood activities rural communities depends on. However local communities depend much on sea-shell collection along shores of Msimbati as their main source of income other non-farm activities. Further study findings have indicated that local communities' households closer to gas extraction processing plant have almost completely changed livelihood activities and are no longer much dependant on fishing as a source of income and food. Therefore, this study confirms SLF because local communities still depend much on natural resources for their survival.

**Conclusions and Recommendations**

**Conclusions**

The paper has attempted to examine the changes of livelihood activities as a result of gas extraction operations in Mtwara Rural district of South-Eastern Tanzania. Based on the results presented above, it is concluded that gas extraction operations have had an adverse impact on changes of livelihood activities in general in the study area. Based on livelihood activities before the introduction of gas extraction operations, it is concluded that farming, fishing, petty trade including crop sales, boat driving and fishing gear repair were the only livelihood activities done in the study area. Based on the changes on livelihood activities after the introduction of gas extraction operations during the survey, it is concluded that the identified current livelihood activities done in the study have changed. The study found out that fishing are no longer the main livelihood activities local communities depends on in the study area, a drastically decline in fishing activities due to gas operations were observed recently, decline in crop sales, though farming activities are done in other villages out of the study area. However local communities depend much on sea-shell collection along shores of Msimbati as their main source of income. Local communities close to gas extraction wells have almost completely changed livelihood activities and are no longer much dependant on fishing as a source of income and food. Further, it was found out from the SLA that there is a positive relationship between the phenomena of changes in local community's livelihood activities and gas extraction operations. In addition, due to the presence of gas extraction investment, households engage in different livelihood activities that influence their livelihood outcomes in terms of income and asset ownership. They indicate that greater non-farm livelihood activities assure income, and thereby, enables the household heads to escape from marginalized. The anti-poverty policies, creating opportunities by investing in a sustainable financial system, help thereby to expand rural non-farm livelihood activities.

## Recommendations

The results highlight the need to evaluate the long-term effectiveness of alternative livelihood activities in the local communities in the context of gas extraction operations. In order to bring equitable livelihood changes and outcomes among households' residing closer and away to gas extraction investment, it is recommended to the Local Government Authority and non-governmental organizations involved in promoting livelihood improvement through extractive investments to promote local communities households ownership of resources by allowing them to have more access and control of their natural resources including gas, land as well as addressing the constraints for household residing closer to extractive investment operations. This can also be done by strengthening local community's association through training local communities on their roles while in contract with investors. They need also to ensure that local community's a household re represented in every decision that affects their livelihoods from extractive investments, especially in considering the implementation of local content policy at local community level.

Further, redoubling efforts on investments in education and vocational training to enhance the potential of the labor force will equip the local community's population to engage in diversified income activities. Recently, researchers and policy-makers are more interested in understanding the impact of extractive investments on changes of household livelihood activities. Hence, incorporating those changes, analyzing their impact on households' well-being, and designing various coping strategies for mitigating such events would probably shed more light on poverty reduction and promotion of sustainable livelihoods in rural areas affected by gas extraction operations in Mtwara Rural District.

## Acknowledgments

The authors are grateful to all the interviewees, Mtwara Local Government Officers, Sokoine University of Agriculture and the Institute of Rural Development Planning-Dodoma who supported the study from which this paper is developed. Valuable suggestions given by anonymous referees are gratefully acknowledged.

## Conflicts of Interest

The authors declare no conflict of interest.

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# The Impact of Rice Commercialisation on Livelihoods in Kilombero Valley, Tanzania: Anybody Left Behind?

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**Abstract**

*Rice commercialisation is important in Kilombero valley because it is associated with agricultural intensification and escalation leading to increased productivity and subsequent income and livelihood improvement. However, the level of household engagement in rice commercialisation is highly dynamic depending on various factors including resource endowment, social, economic, cultural, institutional, and gender issues. Moreover, the mechanism by which different gender social groups are impacted by rice commercialisation is scantly documented. This paper, therefore, examined the impact of rice commercialisation on the livelihood of different farmers with respect to gender social groups. The empirical exercise uses a panel data set of the Agricultural Policy Research in Africa (APRA) collected in 2017 and 2019. The survey involved 537 and 801 rice farming households in the first and second wave of data collection. A mixed-methods approach involving household interviews, focused group discussion and key informant interviews (KIIs) of data collection were used. Descriptive and inferential statistical analysis were employed as tangible ways of presenting the findings. Quantitative and qualitative data were collected using a structured questionnaire, and Focus Group Discussions (FGDs). Descriptive and inferential statistical analyses were employed in the presentation of the finding. Female, youth, and small-scale farmers are the gender social groups negatively impacted with rice commercialisation compared to others, attributed by inadequate access to land and to improve agricultural inputs; reflecting that the gender gap remains a challenge in Kilombero valley. There is a need to develop friendly policy strategies that will provide equitable access to production resources and that the Ministry of Agriculture in collaboration with local government authority need to develop a new strategy that will guarantee cumulative and sound rice commercialisation improvement.*

***Keywords***: rice commercialization, gender, livelihood, marginalized, social gender group

## Introduction

Rice is among the most popular cereal crops grown next only to maize and largely produced by small-scale farmers in Tanzania. It is a crop that is more commercialised than any other staple crop in the country. According to FAO (2015), 42 percent of rice produced is sold compared with 28% and 18% of maize and sorghum respectively. Information from Tanzania's Agricultural Sector shows on the average annual rice production in Tanzania is 2.2 million metric tons and half of these are marketed (United Republic of Tanzania (URT), 2020).

During the past two decades, the demand for rice has increased steadily playing a major role in strategic food planning policies and income security in many developing countries (Achandi and Mujawamariya, 2016). In Tanzania, the Government has identified rice as a priority crop and developed the National Rice Development Strategy (NRDS) since 2009 (URT, 2019). Backed by international donors (DFID, USAID, UNDP, and FAO), the Government has made efforts to address critical constraints through an increased supply of agricultural inputs, capacity building on the use of a system of rice intensification (SRI), and installation of rural electrification all aiming at transforming rice crop from subsistence to commercialisation (Ngailo *et al.,* 2016; URT, 2019).

Rice commercialisation is associated with agricultural intensification and productivity improvements (Poulton, 2017; Djurfeldt *et al.,* 2018), and farm expansion (Isinika *et al.,* 2020), both leading to a rising marketed volume of farm produce. However, the level of production varies, based on the use of recommended agricultural inputs and technologies. For example, rice farming households who were trained on the system of rice intensification (SRI) harvested about 2.9 tonnes/acre of rice from 2.3 tonnes per ha. This is an increase of more than 8.7 percent compared to those who did not attend the training. Currently, records show that Tanzania attained rice self-sufficiency in the 2017/18 cropping season, and in the 2019/20 season, the country exports about 25% of local production (Isinika *et al.,* 2021).

Despite impressive achievements over the last decade, evidence on the impacts of rice commercialisation on the household livelihood of different gender social groups is still under debate (Barret *et al.,* 2017; Isinika *et al.,* 2020). This is frequently attributed, among other things, to the generalisation approach in research works, forgetting that diversity among farming households, in terms of resource endowment, social, economic, policy, and institutional related factors may have an implication on engagement on agricultural commercialization (Barret *et al.,* 2017). These factors may have positive or negative effects on the livelihood of the households. Similarly, gender issues and cultural constraints are not often taken into consideration in development aspects (Mosha *et al.,* 2021). Under such scenarios, it is likely that rice commercialization will impact diverse gender social groups differently.

The perception that the system of rice intensification helps to raise productivity and production, and subsequently improve food availability to farmers and actors along the rice value chains is supported by much of the literature (Barrett *et al.,* 2012; Ngailo *et al.,* 2016; Nokona *et al.,* 2018 Isinika *et al.,* 2020; 2021). There is also positively associated rice commercialisation with poverty reduction in African cases of Madagascar (Maertens *et al.,* 2012) Senegal (Maertens and Swinnen, 2009), and Kenya (Fischer and Qaim, 2012). However, none of these studies have taken the gender lens on assessing the impact of rice commercialisation on the diversity of gender social groups. This paper, therefore, discusses the impact of rice commercialisation on household livelihood focusing on who is left behind among different gender social groups in Mngeta division, Kilombero district, Tanzania. The findings from this study contribute to the existing empirical literature on who are most affected by rising agricultural commercialisation, and therefore demand for a policy that ensures inclusion of marginalised gender social groups in Tanzania as well as similar countries in Sub Saharan Africa (SSA).

## Research Methods

### Study Area

The study was conducted in Mngeta division in Kilombero valley, Morogoro region. The valley is positioned at the foot of the Great Escarpment of East Africa in the Southern half of Tanzania, about 300 km from the coast (Nindi *et al.,* 2014) and lies between longitudes 34.563 and 37.797 E and latitudes 7.654 and 10.023 S (Wilson *et al.,* 2017). The study area was selected because it is part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), an area earmarked for future investments in agriculture. According to the 2012 national census, the floodplain is home to more than 673 000 thousand people (National Bureau of Statistics (NBS), 2013), and approximately two-thirds of the population rely exclusively on smallholder farming for subsistence. The remainder supplement farming activities by raising animals for sale or weaving cloth as well as fishing. The sampling population was restricted to ten villages within a radius of 30 kilometers from Kilombero Plantation Limited (KPL) farm because it was likely that commercialisation impacts would differ across villages depending on their distance from KPL. The KPL was a large-scale rice investor who interacted with small and medium-scale farmers in their vicinity, trained them, and facilitated easy access to credits and some agricultural inputs. The selected ten villages were from three wards: (i) Mchombe (Njage, Mkusi, Ijia, Nakaguru); (ii) Mngeta (Mngeta, Itongowa, and Luvilikila: (iii) Chita (Chita and Makutano).

**Sampling Procedure and Sample Size**

The study used simple random sampling techniques to select the number of farming households to be interviewed. The data set used is a panel collected in 2016/2017 and 2018/2019. The first round of data collection covered 537 rice-producing households selected randomly from 10 villages in the Mngeta division; the sample consisted of 463 small-scale farmers (SSF) (86.2%) and 74 medium-scale farmers (MSF) (13.8%). Sexwise, the sample had 471 (87.7%) male headed households (MHH) and 66 (12.3%) female headed households (FHH). The second wave involved a total of 807 households comprising 438 (54.3%) new and 369 (45.7) old households. The decrease in the number in the second wave was due to old respondents attributed to the fact that some households migrated from the village, some were on a long journey outside their villages, and others died. The two data sets were compared in order to measure the impacts of rice commercialisation on livelihoods among different gender social groups. Table 1 provides a sample composition of the respondents.

**Table 1: Sample composition of the respondents**

| Household Characteristic | | Households 2017 number | % | 2019 Panel | New | Total | % |
|---|---|---|---|---|---|---|---|
| Sex HH head | Female | 66 | 12.3 | 59 | 70 | 129 | 16 |
| | Male | 471 | 87.7 | 310 | 368 | 678 | 84 |
| | Whole sample | 537 | 100 | 369 | 438 | 807 | 100 |
| Farmer category | SSF | 357 | 66.5 | 232 | 390 | 622 | 77.1 |
| | MSF | 74 | 13.8 | 46 | 48 | 94 | 11.6 |
| | SRI | 106 | 19.7 | 91 | 0 | 91 | 11.3 |
| | Whole sample | 537 | 100 | 369 | 438 | 807 | 100 |
| Age of HH head | Youth farmer | 131 | 24.4 | 66 | 77 | 143 | 17.7 |
| | Older farmer | 406 | 75.6 | 303 | 361 | 664 | 82.3 |
| | Whole sample | 537 | 100 | 369 | 438 | 807 | 100 |
| | Percent | 100 | - | 45.7 | 54.3 | | 100 |

***Source:*** APRA household data, 2017 and 2019

**Data Collection Methods**

The APRA study was undertaken using various research methods and techniques, including questionnaire surveys, stakeholder consultations, key informant interviews, focus group discussions, and literature reviews. A household questionnaire was used to collect quantitative data, which captured a number of variables on rice production, processing, marketing, and related outcomes. The tool collects information on household demographic data, crops cultivated, the area cultivated, input use, agronomic practices, crop yield harvested, amount consumed, sold, and stored. Specific questions were included on a checklist of questions, which were used to guide FGD and key informant interviews conducted in each village. For this paper, both quantitative and qualitative information were used.

**Data Analysis**

To quantify the possible impact of rice commercialisation on the livelihood of rice farming households, we analyzed data based on three categories, namely sex of the household head (men and women); farmer categories (small-scale, medium, and SRI farmers), and age (either youth or the elderly). Data were analysed using a combination of descriptive and inferential methods including descriptive statistics. Descriptive statistics (mean, median, and t-test) were used to compare different gender social category groups in terms of land ownership, acreage of rice planted, use of improved farming technology, and inputs and rice yields. Logit model to assess the influence of RCI and on the multi-dimensional poverty index (MPI).

**Measuring rice commercialisation index, livelihood, and its indicators**

Rice commercialisation index (RCI) computed as a percentage of rice that was marketed out of what was produced. This methodological approach has been recommended by other scholars including (Muriithi and Matz, 2015; Von Braun 1994 cited by Cazzuffi *et al.,* 2018; Isinika *et al.,* 2020). The index varies from zero where nothing was sold to one where all rice produced was sold. The index is divided into four categories: zero, low, medium, and high sales levels. The quintiles were then used as explanatory variables versus livelihood indicators for the different gender groups. The study hypothesised that engagement in rice commercialisatin will result in improved livelihood and that it will vary with the level of participation.

The most common approach in the literature to measure the level of livelihood uses income, assets, food security, (Alkire *et al.* 2015). The livelihood indicators include income, food security, and subjective wellbeing, or multidimensional poverty measured by the multidimensional poverty index (MPI) as proposed by various authors (E.g. Alkire *et al.* 2015; Poulton, 2017). The MPI has advantageous as it captures a wider range of variables including assets, health, education, and nutrition that reflect the quality of life within a household. The MPI, therefore, represents the proportion by which a household is deprived, with higher scores representing more deprivation and hence more poverty.

**Results and Discussion**

**Trend in landholdings and land size under rice production by different gender social groups**

Table 2 shows a decline in the mean land holdings and land under rice production among various gender social groups in the two cropping seasons. Female household heads and SSF had a higher (16%) decline in landholding than any other categories of gender social groups. There is also a decline in the mean area under rice cultivation. The SSF and female farmers had a more significant decline (by 14.3% and 7.7 %, respectively) than any other groups. These findings are in line with results from Focus Group Discussions (FGDs) in Mngeta, Chita, Ijia, and Makutano villages, which indicates that most of MHH had a larger land area planted with rice than FHH. The participants also reported that cultivating larger areas is important as it reduces the cost of production, calmest in farm management, hence subsequently more outputs and returns.

Surprisingly, SRI farmers had no change in the mean area under rice production, and MSF is the only group that experienced a

**Table 2: Extent of landholding and size of land under rice production by different gender social groups in the Kilombero Valley (n=517 in each category)**

| Farmer Category | | Mean land owned | | | Mean land under rice | | |
|---|---|---|---|---|---|---|---|
| | | 2017 | 2019 | % change | 2017 | 2019 | % change |
| Sex of HH head | Female | 1.9 | 1.6 | -16 | 1.3 | 1.2 | -7.7 |
| | Male | 3.9 | 3.8 | -2.5 | 2.9 | 2.8 | -3.45 |
| Farmer category | SSF | 1.9 | 1.6 | -16 | 1.4 | 1.2 | -14.29 |
| | MSF | 11.7 | 12.9 | -10.2 | 9.0 | 9.8 | +8.89 |
| | SRI | 3.5 | 3.3 | -5.7 | 2.6 | 2.6 | 0 |
| Age of HH head | Youth farmer | 2.3 | 1.7 | -26.1 | 1.6 | 1.3 | -18.8 |
| | Older farmer | 4.1 | 3.4 | -17.1 | 3.1 | 2.6 | -16.1 |
| | Sample mean | 3.64 | 2.98 | -2.3 | 2.7 | 2.2 | -19.3 |
| | Significance of difference | ** | | *** | | | |

***Source:*** APRA household data, 2017 and 2019 positive change on both landholdings and rice cultivation areas (Table 2). This implies, women and SSF were the group excluded in rice production in the study area due to limited access to land resources, and consequently less production and livelihood improvement. These findings corroborate those of Mdoe (2020) who found that households with more land have the capacity to cultivate more of the crop and expand their production to ensure adequate supply to the market. Farmers owning small farms may not be able to raise the necessary surplus to sell at the market. Likewise, Fischer and Qaim (2012) show women's involvement in the commercialisation process is affected by no or limited land holding capacity, and access to good quality seed and farm implement as a result no surplus for market.

**Trend in use of farm inputs by gender social groups normalize per hectare**

Table 3 shows variations in the use of inorganic fertiliser and herbicide across gender social groups. The panel sample data shows significant differences in the use of inorganic fertiliser between MHH and FHH and among farmer‘s categories. The decline was higher for FHH (29.4 %) compared to MHH (4.2 %); similar to MSF (48.7 %) compared to SSF (2.9 %). This is contrary to youth farmers who recorded a significant improvement (33.6 %) in the use of organic fertiliser compared to older farmers who had a decline by (5.7 %). In the farmer’s category, SRI members recorded a minor (1.1 %) improvement. The high rate of decline among FHH members is likely to reflect their poor access to or exclusion in agricultural inputs, while the inertia in the use of inorganic fertiliser by SRI members could be associated with the termination of credit support following the end of KPL. Opinion from key informants shows an increase in the use of inorganic fertiliser in Kilombero valley. This was narrated by one of the key informants, he said :

**Table 3: Changes in input use by gender social groups (normalized per hectare)**

| Farmer category | | Whole sample | | | Panel sample | | | Percent change | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2019 | Change | 2017 | 2019 | Change | Sample | Panel |
| **Inorganic fertiliser (kg/ha)** | | | | | | | | | |
| Sex of HH head | Female | 103 | 61.1 | -41.9 | 103 | 72.7 | -30.3 | -40.7 | -29.4 |
| | Male | 67 | 69.3 | 2.3 | 67 | 64.2 | -2.8 | 3.4 | -4.2 |
| Farmer category | SSF | 73.3 | 66.7 | -6.6 | 73.3 | 71.2 | -2.1 | -9.0 | -2.9 |
| | MSF | 39.8 | 61.5 | 21.7 | 39.8 | 20.4 | -19.4 | 54.5 | -48.7 |
| | SRI | 73.0 | 73.8 | 0.8 | 73.0 | 73.8 | 0.8 | 1.1 | 1.1 |
| Age of HH head | Youth | 61.9 | 83.2 | 21.3 | 61.9 | 82.7 | 20.8 | 34.4 | 33.6 |
| | Older farmer | 71.4 | 63.4 | -8 | 71.4 | 67.3 | -4.1 | -11.2 | -5.7 |
| **Sample mean** | | **69.7** | **67.8** | -1.9 | **69.7** | **70.2** | 0.5 | -2.7 | 0.7 |
| **F value** | | **0.45** | | | **0.095** | | | | |
| **Herbicides** | | | | | | | | | |
| Sex of HH head | Female | 3.2 | 4.21 | 1.01 | 3.2 | 3.8 | 0.6 | 31.6 | 18.8 |
| | Male | 3.7 | 4.1 | 0.4 | 3.3 | 4 | 0.7 | 10.8 | 21.2 |
| Farmer category | SSF | 3.3 | 4.2 | 0.9 | 3.3 | 4.1 | 0.8 | 27.3 | 24.2 |
| | MSF | 3.1 | 3.7 | 0.6 | 3.1 | 3.7 | 0.6 | 19.4 | 19.4 |
| | SRI | 3.6 | 3.6 | 0 | 3.6 | 3.6 | 0 | 0.0 | 0.0 |
| Age of HH head | Youth farmer | 3.5 | 6.2 | 2.7 | 3.5 | 7.2 | 3.7 | 77.1 | 105 |
| | Older farmer | 3.3 | 4.5 | 1.2 | 3.3 | 4.6 | 1.3 | 36.4 | 39.4 |
| **Sample mean** | | 3.3 | 4.1 | 0.8 | 3.3 | 4 | 0.7 | 24.2 | 21.2 |
| **F value** | | **24.8***** | | | **13.2***** | | | | |

***Source:*** APRA household data, 2017 and 2019

*"... this was attributed to the support and/ or credits provided by the KPL potentially leads to the substantial increase in rice yield of SRI farmers..."*.

On the other hand, we tried to analyse the use of herbicides among farmers based on different gender social groups. The changes in relation to herbicides show a significant increase in the use among youth (105 %) and older farmers (39.4 %). The findings also show a definite increase in the use of herbicides across the other remaining gender social groups (Table 3). The increase was slightly higher for MHH than FHH and slightly higher for SSF than MSF (by 24.1 to 19.4 %). The findings are in line with that of Isinika *et al.* (2020) and Doss (2018) with the opinion that increased use of herbicides has a positive implication on rice productivity. It also increases farmers' opportunity to extensification as it reduces labour costs and increases the number of harvests. The study revealed that like what reported in the use of organic fertilisers, women and MSF were the most disadvantageous groups that harvest low and hence are less likely to engage in rice commercialisation.

**Rice yield**

Figure 1 shows the volume of rice yields in Mngeta division varied among gender social groups. The MHH and older farmers had a higher quantity of rice yield than FHH and youth farmers respectively. The FHH however, had the highest change compared to their counterpart. As indicated in section 4.1, FHH and youth farmers had less access to land, and use of agricultural inputs, the challenges which have also been reported to hinder the transformation of the agricultural sector toward commercialisation. The findings further show a decline in rice yield among most farmer categories except MSF. Unexpectedly, rice yield for the SRI farmers declined in 2019 compared to the 2017 cropping season. The plausible explanation for the decline is that in later cropping season SRI had a better chance to acquire agricultural inputs, which were provided by the KLP before the company ended.

**Rice commercialisation by gender social groups**

Table 4 presents Rice Commercialisation Index (RCI) for each gender social group in the study area. Generally, commercialisation declined across all gender social groups, the highest rate of decline being among SRI members (9.8 %) compared to SSF (4.5 %) and for MSF (3.8 %). In addition, FHH experienced a higher level of decline in commercialisation than their male counterparts as well as any other groups in the panel sample. This finding indicates both the amount harvested and sold declined with time, hence having a negative impact on people's well-being. Looking at these findings, women are the ones left behind in terms of enjoying

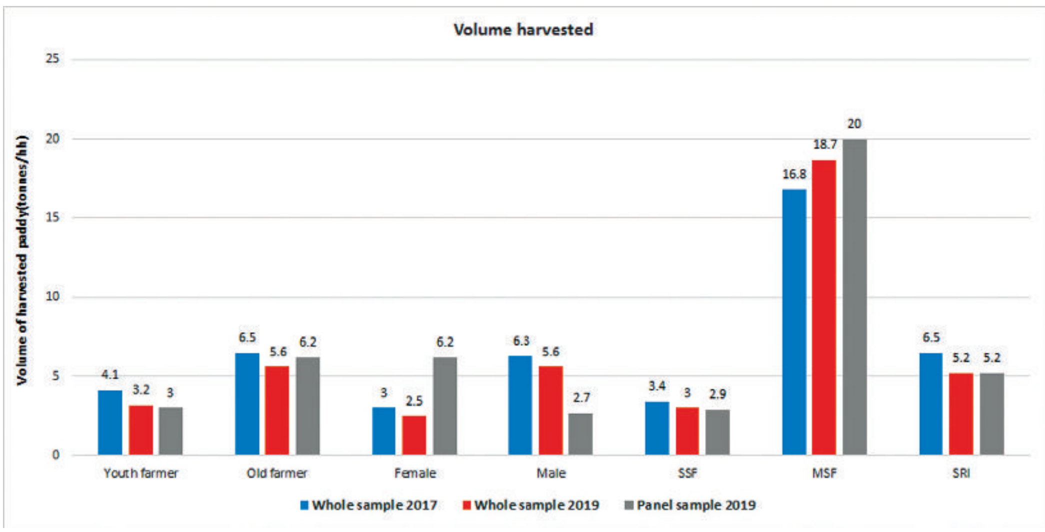

**Figure 1: Percentage of the volume of paddy harvested at the household level**

the benefits of rice commercialisation in the Kilombero valley.

The findings correlate with the qualitative findings reported during the FGD and stakeholder workshop in Kilombero district as the majority of the participants had a concern that improvement in rice farming is at a slow rate, and is unpredictable because of the change in the market price of the produce. Farmers' key concern was the unpredictability trend of rice prices in the local and national markets. Based on these findings, rice commercialisation has not yet sufficiently provided significant benefits to the majority of rice growers in Kilombero valley. The marginalised households particularly FHH, SSF, and SRI are excluded in the stream of the benefit of rice production and commercialisation. In view of these findings, there is a possibility that rice production and commercialisation in Kilombero valley is an unsustainable pathway to livelihood improvement.

The decline in the price in the current production year demoralizes farmers to produce more in the next cropping season, a challenge that needs the government of Tanzania to find the right solution, if we still need agriculture to continuously contribute to the Gross National Product. This is essential because the majority of the rural population still depend on agriculture for their economic growth, food and nutrition security.

**Food security and MPI status by gender social groups**

Food security is an important indicator of livelihood. The findings in Table 5 show a significant difference in food security among the gender social groups. Medium-scale and male, youth household heads were more food secure than their counterparts in female, SSF, and old households. This implies that attainment of food security is highly gender-dimension. The results further show a significant difference between food security and commercialization levels. Generally, households with low levels of rice commercialization were less food secure.

Using regression analysis of the determinants of livelihood outcomes – adopted from Isinika *el al.,* 2021 (Appendix 1), the findings indicated food security levels increase although at a marginal level of – 0.08 from 2017 to 2019, and this was influenced by the level of education and rice yields and commercialisation level. Food security declined for older household heads compared to youth, FHHs were food insured compared to their male counterparts and this was linked with cultural norms in relation to the land tenure system.

Figures 2a and 2b present findings on the mean MPI score and proportions of individuals with low MPI across various gender social groups. The relationship between RCI and MPI, shows that the MPI declined for all gender social

**Table 4: Rice commercialisation index (RCI) by gender social groups**

| Farmer category | | Whole sample | | | Panel sample | | | Percent change | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2019 | Change | 2017 | 2019 | Change | Sample | Panel |
| Sex of HH head | Female | 53.1 | 50.7 | -2.4 | 53.1 | 49.4 | -3.7 | -4.5 | -7 |
| | Male | 60 | 55.8 | -4.2 | 60 | 56.7 | -3.3 | -7 | -5.5 |
| Farmer category | SSF | 55.5 | 53 | -2.5 | 55.5 | 51.7 | -3.8 | -4.5 | -6.8 |
| | MSF | 65.4 | 62.9 | -2.5 | 65.4 | 64.1 | -1.3 | -3.8 | -2 |
| | SRI | 66.6 | 60.1 | -6.5 | 66.6 | 61 | -5.6 | -9.8 | -8.4 |
| Age of HH head | Youth farmer | 58.6 | 61.5 | 2.9 | 58.6 | 62.2 | 3.6 | 4.9 | 8.4 |
| | Older farmer | 59.4 | 53.7 | -5.7 | 59.4 | 54.3 | -5.1 | - 9.6 | -8.6 |
| | Sample total/ mean | 59.2 | 55.1 | **-4.1** | **59.2** | **55.7** | **-3.5** | **-6.9** | **-5.9** |
| F value | | | | | | | | | |

groups) from 2017 to 2019 cropping seasons with an exception for (RCI 20-40) which increased by about 12 %. This finding suggests that there is a fair livelihood improvement of most households in the study area, keeping other factors constant.

FHH. This means that FHH is less benefited from rice commercialisation, arguing more effort is needed to ensure their inclusion. On the other hand, the findings explained that despite SRI members having experienced relatively higher rates of decline in RCI, they still

**Table 5: Percentage of households that are food-secure and insecure by farmer category**

| Farmer category | Food-secure | Food insecure | χ2 |
|---|---|---|---|
| **Farm size:** | | | |
| SSF | 42.6 | 57.4 | 37.290*** |
| MSF | 77.1 | 22.9 | |
| **Sex of household head:** | | | |
| FHH | 31.6 | 68.4 | 10.618*** |
| MHH | 51.8 | 48.2 | |
| **Age of farmer:** | | | |
| Young | 62.3 | 37.7 | 10.369*** |
| Old | 45.2 | 54.8 | |
| **Crop commercialisation level:** | | | |
| Zero | 32.6 | 67.4 | |
| Low | 46.6 | 53.4 | |
| Median | 58.4 | 41.6 | 16.0 ** |
| High | 53.2 | 46.8 | |
| **Whole sample** | 49.0 | 51.0 | |

***Note:*** F = *; implies F value is significant at p<0.1. F = ***; implies F value is significant at p<0.01

Comparison by sex of household heads shows that MHHs experienced a higher level of MPI decline (-39.3 %) as well as the highest decline in the proportion of MPI poor. The decline in the levels of MPI means there is livelihood improvement. Likewise, the MHH had the highest decline in the proportion of MPI-poor households (28.1%) compared to maintained the highest livelihood improvement, and the plausible explanation for this is that rural households are likely to have numerous ways of livelihood diversification. Looking at the evidence on income sources, sale of crops contributes (56.8%), while non-farm and livestock - (33.8%) and (11.2 %) respectively. This finding suggests that income from other

**(a) MPI score** **(b) Percent of MPI poor households**

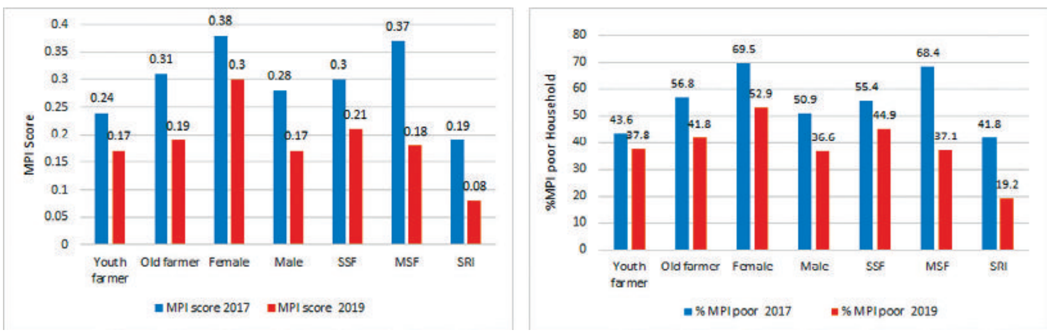


**Figure 2: Multi-Poverty Index score and proportional of poor MPI poor households**

crops (apart from rice) has a substantial contribution to livelihood improvement in the Kilombero valley.

Also, improvement in livelihoods is also linked to improving the house, the environment, infrastructures, and lifestyle. As noted in a recent study by Isinika *et al.* (2021), improvement in children's education level, improved house floor, walls, roofing, and sanitation, especially toilet has a significant role in livelihood improvement. All these values were higher in 2019 than in 2017 (Isinika *et al.,* 2021).

## Conclusion and Recommendations

Rice is the most important cash and food crop in Kilombero valley, Tanzania. The study found that commercialisation varies across gender social groups, attributed to levels of access to agricultural inputs and markets. There is a decline in the RCI in 2019 compared to 2017, associated with a decline in land under rice cultivation. Despite this decline, there is still an increase in livelihoods improvement, which is associated with increased income accrued from other farm and non-farm activities. Generally, households headed by females, youth, and small-scale farmers are the gender social groups negatively impacted due to inadequate access to land and to improve agricultural inputs. The gender gap remains a challenge in Kilombero valley. Diversification to other crops and non-farm income contributes highly to livelihood improvement than rice alone. There is a need to develop friendly policy strategies that will provide equitable access to production resources especially; and that the Ministry of Agriculture in collaboration with local government authority need to develop a new strategy that will guarantee cumulative and sound rice commercialisation improvement.

## Funding

This research was made possible by the support of the APRA; a five-year research program on rice and sunflower commercilisation and its donors - UK aid from the UK government (Foreign, Commonwealth & Development Office – FCDO, formerly DFID). The contents are the sole responsibility of the authors and do not necessarily reflect the views of the policies of IDS or the UK government.

## Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Acknowledgments

We thank the field teams for their dedication and participating rural households for their candor. The authors give special thanks to Prof. Isinika, A. for her support and encouragement in writing publishable papers throughout the research programme life time. Invaluable comments and suggestions on this paper from the APRA team members Tanzania (Prof. Mdoe, N. Prof. Mlay, G. Prof. Jeckoniah, J. Dr. Magomba and SUA Scientific Conference reviewers are gratefully acknowledged.

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## Appendix

**Determinants of Welfare outcomes – Pool Results – Marginal Effects**

| Variable | Type of Welfare outcome | | | | | |
|---|---|---|---|---|---|---|
| | MPI | | Food security status | | MDD | |
| | Coefficient | s.e | Coefficient | s.e | Coefficient | s.e |
| Year dummy (1=2020) | -0.1283*** | 0.0387 | 0.0758** | 0.0330 | -0.1299*** | 0.0362 |
| Age of household head (years) | 0.0019 | 0.0013 | -0.0006 | 0.0011 | -0.0012 | 0.0012 |
| Years of schooling of household head | -0.0503*** | 0.0074 | 0.0230*** | 0.0058 | 0.0122** | 0.0061 |
| Sex of household head (1=female) | 0.2014*** | 0.0482 | -0.1219*** | 0.0379 | -0.0619 | 0.0418 |
| Household size (count) | 0.0293*** | 0.0073 | -0.0001 | 0.0064 | -0.0000 | -0.0000 |
| Electricity status of village (1=yes) | -0.0834** | 0.0411 | -0.0357 | 0.0359 | 0.0617 | 0.0385 |
| Rice area (ha) | -0.0020 | 0.0050 | -.0004 | 0.0061 | 0.0009 | 0.0043 |
| Rice yield (t.ha) | -0.0356*** | 0.0132 | 0.0258** | 0.0130 | 0.0124 | 0.0089 |
| Household income (Tsh '100000') | -0.0001 | 0.0003 | 0.0002 | 0.0003 | -0.0003 | 0.0003 |
| RCI quintile dummy 1 (1=Q2) | 0.1244* | 0.0674 | -0.0382 | 0.0528 | 0.0065 | 0.0589 |
| RCI quintile dummy 2 (1=Q3) | -0.0357 | 0.0591 | 0.0876 | 0.474 | 0.1186** | 0.0525 |
| RCI quintile dummy 3 (1=Q4) | -0.0659 | 0.0588 | 0.1336*** | 0.0475 | 0.1861*** | 0.0522 |
| RCI quintile dummy 4 (1=Q5) | -0.1013 | 0.0662 | 0.0816 | 0.0541 | 0.0315 | 0.0578 |
| Farmer type dummy 1 (1=MSF) | -0.1240* | 0.0660 | 0.2057*** | 0.0681 | 0.1160* | 0.0615 |
| Farmer type dummy 2(1=RCI) | -0.1308*** | 0.0497 | -0.0736* | 0.0436 | 0.0388 | 0.0468 |

***Source:*** Isinika *et al.,* 2021

# Impact of Urban Expansion on Land Surface Temperature in Dodoma and Morogoro Metropolises, Tanzania

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**Abstract**

*The study aims to evaluate the impact of metropolitan growth on land surface temperature (LST) in Dodoma and Morogoro metropolises. The paper adopts remote sensing methods to extract and analyze time-series Landsat satellite images from 2000 to 2018. An administered taxonomy was applied to map urban land-use change. Thermal and reflectance bands analysis were employed to retrieve and compare the Surface Temperature, Normalized Difference Vegetation Index (NDVI), urban expansion patterns, and the overall growth prominence in the cities. The results highlight a negative correlation between LST and NDVI, indicating that dissipating vegetation cover within the two study areas was responsible for the increase in LST over the study period. The outcome also showed that the metropolis of the study area rapidly expanded over the evaluation period with impermeable surface from 1.6% in 2000 to 5.3% in 2018 while non-impermeable decreased from 98.4% in 2000 to 94.7% in 2018. Increasing LST of annual-average of 31% in 2000 to 32% in 2018 was mostly due to conversion to the built-up area from non-built area. Therefore, the study concludes that LST is strongly influenced by land cover dynamics. The study suggests that planning of African cities should incorporate with sustainable and resilient urban future in order to improve the planning, compactness, sustainability and resilience of the urban environment.*

***Keywords***: At-sensor brightness heat, urban planning, land surface temperature, SDGs, Dodoma, Morogoro

## Introduction

There are many factors (natural and man-made) influencing land use and cover change, climate change and other physical and human environments. Perhaps, the most significant characteristics of man's induced changes on the environment are the variation recorded in thermal properties of the built, bare-land surfaces, soil and paved impervious surfaces which result in more solar energy being stored and converted to sensible heat, and also the removal of shrubs and trees which serve as a natural cooling effect of shading and evapotranspiration (Shao and Zhang, 2016; Sumari *et al.,* 2020; Wu *et al.,* 2021) and contribute to the reduction in outgoing longwave radiation by hindering the loss of sensible heat and distribution of heat (Ifatimehin, 2007; Ifatimehin *et al.,* 2009; Meng *et al.,* 2018).

For example, Feng (2019) and Meng *et al.,* (2018) reveal that the reduction of woodland and vegetation, which produce natural cooling from shading and evapotranspiration, are shown to contribute to the intensity of Land Surface Temperature (LST). LST is crucial to land surface processes particularly the transportation of temperature between the surface ground and an atmospheric boundary layer (Wang *et al.,* 2018; Zhang *et al.,* 2017), which can be recorded and estimated in the form of sensible heat fluctuation and latent heat fluctuation, or evapotranspiration (Bosco & Thomas, 2019; Li *et al.,* 2019; Peng *et al.,* 2017). In many cases, it has been established that human population concentration severely impacts LST as population density, a social variable, defines the scale and intensity of development within a defined location (Zhou *et al.,* 2019).

Studies show that urbanization has significant impact on micro and regional climate as the concentration of populations, industrial and economic activities transform the natural landscape to areas of largely built-up and paved surfaces, consequently impacting micro (city-level) and regional climate (Addaney and Cobbinah, 2019; Shao *et al.,* 2020). Some resultant effects of this altering micro and regional climate include extreme heat waves, and variable precipitation patterns with a higher risk of urban flooding or drought (Deilami *et al.,* 2018; Li *et al.,* 2018; Weng *et al.,* 2016). Globally, extreme heat waves are linked to increased heat-related mortalities and exacerbation of existing heath conditions such as respiratory and cerebral diseases (Analitis *et al.,* 2014; Lin *et al.,* 2009). While climate change and extreme heat waves resulting from LST are a global phenomenon, the impacts are not evenly distributed. Vulnerable and poorer regions such as Africa are heavily impacted due to poor land use planning, deficiency of basic infrastructure and services such as quality housing, water, and inefficient health care delivery system (Korah and Cobbinah, 2019). The ability to quantify urban growth and its relationship with LST distribution is crucial to developing sustainable and resilient communities and cities in line with achieving Sustainable Development Goal (SDG) 11. However, there is limited research examining spatio-temporal patterns and LST in African cities.

In situations of rapid and often unrecorded land use change, observations of the ground from space provide objective information and synoptic coverage of human consumption of the land. The application of remotely sensed data simplifies the synoptic analyses of earth observation, planning, and change at towns/cities, and regional scale over time (Cai *et al.,* 2017, Sumari *et al.,* 2017). Such data also provide an important link between intensive, localized ecological research and regional, national and international preservation and management of the environment (Cobbinah *et al.,* 2017; Korah *et al.,* 2017; Xu *et al.,* 2019a, 2019b). In addition, the synoptic coverage and accurate analysis presented by remote sensing (RS) data and Geospatial Information Science (GIS), respectively provides the basis for its adoption in estimating LST by several works (Hassaan *et al.,* 2019; Jeevalakshmi *et al.,* 2017; Peng *et al.,* 2017; Wijeratne *et al.,* 2018; Zhou *et al.,* 2019, 2014). Essentially, remote sensing is the main source for LST estimation at the regional and global scales (Wijeratne *et al.,* 2018) where as local level estimations may rely heavily on field data (Wang *et al.,* 2018).

Therefore, the main purpose of this research was to examine the rate of LST as influenced by changes in land cover in Dodoma City Council (DCC) and Morogoro Municipal Council (MMC). The specific goals of the study were to identify LST for the highest urban growth in the study areas, and to compare spatial and temporal variation of LST as a red-flagged indicator of unsustainable urban development in DCC and MMC, a situation that applies to most cities in sub-Saharan Africa. The study fills a useful knowledge gap for Tanzanian r as it aims at fulfilling a number of indicators for SDG 11 which collectively seek to “make cities and human settlements inclusive, safe, resilient and sustainable” by year 2030.

## Materials and Methods

### The Study Site

This study was conducted in Dodoma City Council (DCC) and Morogoro Municipal Council (MMC) as part of Dodoma and Morogoro regions, respectively, in Tanzania as shown in Figure 1. The geographical location of Dodoma region is in the central part of mainland Tanzania between latitude 40 and 70 South, and longitude 350 and 370 East. Administratively, the region is divided into seven districts as follows: Bahi, Chemba, Chamwino, DCC, Kondoa, Kongwe, and Mpwapwa (URT, 2010; URT, 2013). MMC is one of the nine districts in Morogoro Region. It is located between 370 East and 60 South of the Equator. Other districts include Kilosa, Ifakara, Kilombero, Malinyi, Mvomero, Gairo, Ulanga and Morogoro Rural.

The environment subtype of köppen climate taxonomy for Dodoma is "Bsh" or a mid-latitude steppe and desert climate. With an average annual temperature of 22.8°C, the warmest (19.40C) and coolest (19.40C) months are November and July, respectively. The average annual precipitation in Dodoma is 563.9 mm, with an average of 42 days of rain (Weatherbase Dodoma, 2020). Meanwhile, the environment subtype of köppen climate taxonomy for Morogoro is "Aw" or a tropical savanna climate (Weatherbase Morogoro, 2020). The average annual temperature in Morogoro is 23.9°C with January as the warmest month (26.1°C), while July is the coolest month (21.1°C). The average annual precipitation in Morogoro is 889 mm, with an average of 60 days of rain annually.

October 2008, October 2016 and October 2018 for DCC of dry season to investigate the rate or urban temperature within each city. All Landsat images were gathered from the path/row number 168/064 and 167/065 for DCC and MMC (Table 1), respectively, with the same spatial resolution. Pre-processing such as radiometric and geometric correction were performed using ERDAS Imagine 2015 and ArcGIS 10.5. Seven land cover types (built-up, agriculture, water, woodland, bareland, wetland, and forest)

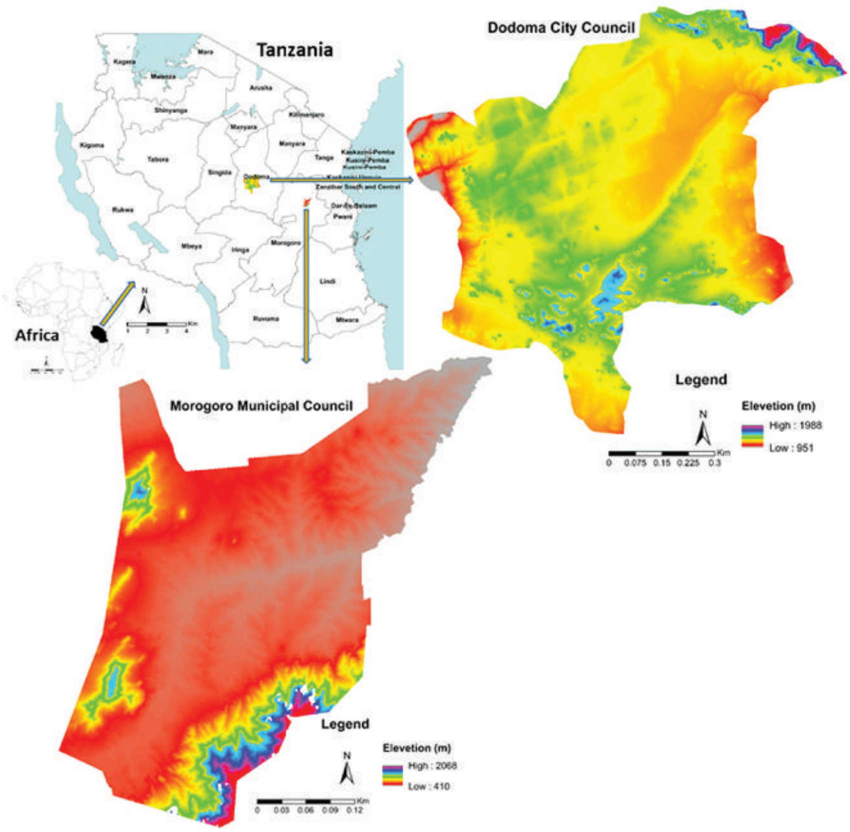


**Figure 1: The study-setting showing, Dodoma City Council (DCC) and Morogoro Municipal Council (MCC)**

**Remote Sensing Data and Data processing**

Cloud-free, Landsat 30m resolution satellite images were used to conduct urban heat study in DDC and MMC. Hence, the Landsat 30m products were obtained from http://earthexplorer.usgs.gov/ website of United States Geological Survey (USGS) for the years July 2000, September 2007, September 2017, and August 2018 for MCC and September 2000, (NAFORMA, 2015) were identified through visual analysis and knowledge of the area. Random forest supervised image classification was used for image classification, which is most frequent and comprehensively been used in image classification methods in remote sensing (Shao *et al.,* 2016).

The classification accuracy assessment was implemented for each land cover type using

**Table 1: Administrative Information of the study areas**

| Area | Location Path/Row | Land Area (Km$^2$) | Wards | Estimated population 2002-2016 | June-Oct (max & min temp) | Jul-Oct (mm) precipitation |
|---|---|---|---|---|---|---|
| DDC | 168/064 | 2,576 | 37 | 326,811-454,128 | 31-18$^{O}$C | 0.03-2.08mm |
| MMC | 167/065 | 540 | 28 | 227,921-359,684 | 35-24$^{O}$C | 17-25mm |

training sampling points integrated with Google Earth Engine (satellite imagery) (Sumari *et al.*, 2020; Shelestov *et al.*, 2017). The result showed that the producer accuracy and user accuracy of all cities was higher than 87% (Fig. 11), which can achieve the correctness requirements for the land use change assessment.

$$L_\lambda = M_L Q_{cal} + A_L \tag{1}$$

Where, $L_\lambda$ indicates the Top-of-Atmospheric (TOA) spectral intensity $\left[\frac{Watts}{m^2 * Srad * \mu m}\right]$; $M_L$ is band-precise multiplicative rescaling factor

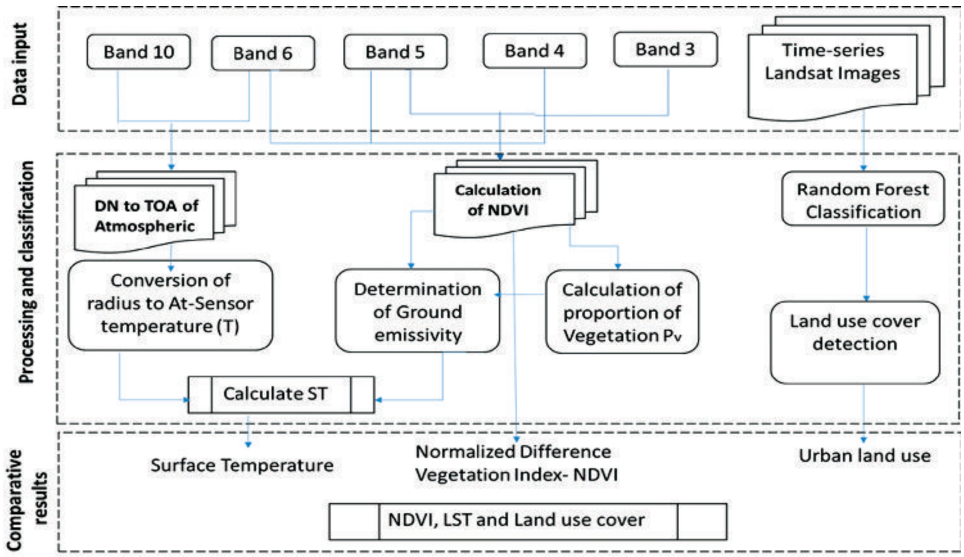


**Figure 2: Workflow adopted for the study areas**

**Spatial-temporal dynamic of LST**

The LST extraction approach used in the study is presented in Figure 2 above. Firstly, imagery is preprocessed using radiance scaling factors in statistic file then transformed to the digital number value of the pixels to the top-of-atmosphere (TOA) radiance through equation 1, and equation 2 to TOA reflectance values in equation 3, then conversion to At-Sensor brightness heat using equation 4. Finally, the LST, spatial patterns of land cover change were analyzed. The LST, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built Index (NDBI) were achieved using equations 5, 6 and 7.

from the statistical file, $A_L$ is band-precise additive rescaling factor from the statistical file; $Q_{cal}$ is Quantised and adjusted standard pixel value (DN).

$$P_\lambda = M_p Q_{cal} + A_p \tag{2}$$

Where, $P_\lambda$ represents the TOA without adjustment for solar angle; $M_p$ is band-precise multiplicative rescaling factor from the statistic, $A_p$ is band-precise extract rescaling factor from the statistic; $Q_{cal}$ is Quantized and calibrated standard product pixel value (DN); were a rectification for the solar angle is qn. 3.

$$P_\lambda = \frac{P'_\lambda}{\cos\theta_{SZ}} = \frac{P'_\lambda}{\cos\theta_{SE}} \tag{3}$$

Where, $p_\lambda$ indicates TOA earthly reflectance; $\theta_{SZ}$ is local angle of sun elevation which is provided in the statistic file; $\theta_{ZE}$ is zenith angle;

Conversion to At-Sensor brightness heat, TIRS band data were transmuted from spectral radiant to intensity temperature using eq.4 thermal constants delivered in the statistic file.

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)} \tag{4}$$

Where, T represents the At-Sensor intensity heat (K); $L_\lambda$ is TOA spectral brightness $\left[\frac{Watts}{m^2 * Srad * \mu m}\right]$; $K_1$ represent the constant thermal conversion from the statistic file, $K_1$=666.09 and $K_2$=1282.71 for Landsat 7 (band 6) data while for Landsat 8 (band 10) $K_1$=774.88 and $K_2$=1321.08

Then we applied the equation 5 to calculate LST;

$$LST = BT/1 + W * (BT/P) * \ln(e) \tag{5}$$

where: BT is At-Sensor brightness heat, W= wavelength of absorbed radiance (Landsat 8: band 10 and band 6); P=h*C/S (1.438*$10^{-2}$) mk)=14380, Plank's constant h=6.626*$10^{-34}$) Js, Boltzmann constant S=1.38*$10^{-23}$) ) J/K and Velocity of bright C=2.998*$10^8$ m/s. ln(e) is land cover from NDVI, where; e=0.004Pv+0.986 and Pv indicates the quantity proportion of the vegetation eq. 6

$$Pv = \left(\frac{NDVI_{max} - NDVI_{min}}{NDVI_{max} + NDVI_{min}}\right)^2 \tag{6}$$

Where: $NDVI_{max}$ is Normalized Difference Vegetation Index maximum for vegetation and $NDVI_{min}$ is Normalized Difference Vegetation Index minimum. Similarly, through eq. 7 we investigate green vegetation and crops patterns based on the reflectance,

$$NDVI = \left(Band_{NIR} - Band_{RED} / Band_{NIR} + Band_{NIR}\right) \tag{7}$$

Where: $Band_{NIR}$ (near-infrared) is surface reflectance of band 4 of TM/ETM plus, and $Band_{RED}$ is the surface reflectance of band 3 of TM/ETM plus images.

## Results

### Spatial pattern of the LULC in DCC and MMC

The spatial-temporal pattern of LULC of DCC and MMC from 2000 to 2018 (Fig. 3 and Fig. 4) indicates that there have been rapid land use and cover modification and alteration over the 18-year study period. The details for DCC show that while built-up and agricultural

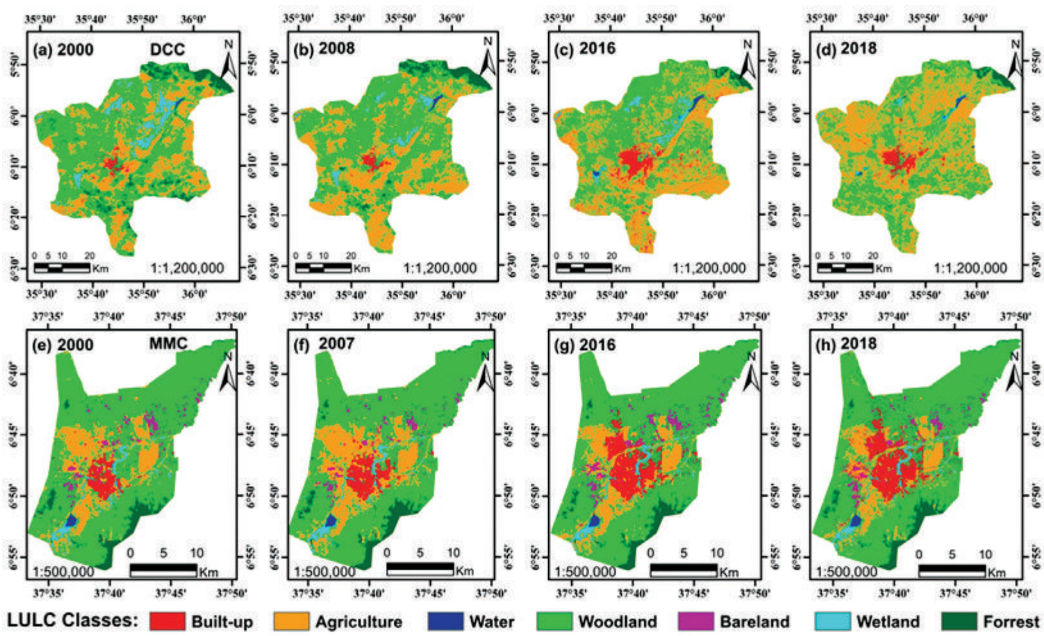


**Figure 3: Spatial distribution of land cover map for Dodoma and Morogoro**

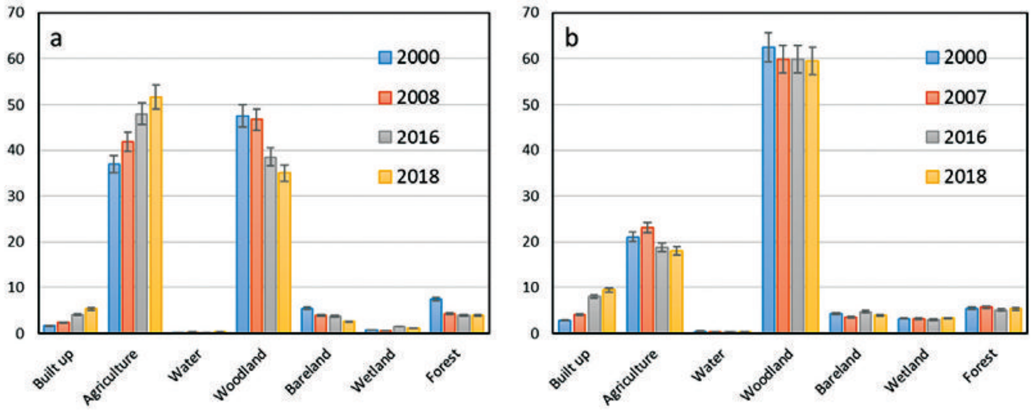


**Figure 4: Rate of change for each LULC class in (a) DDC and (b) MMC**

land increased (from 1.6% in 2000 to 5.3% in 2018 and from 37% in 2000 to 51% in 2018, respectively), woodland and forest land cover categories declined consistently (from 47.5% in 2000 to 33.5% in 2018 and from 7.5% in 2000 to 4.3% in 2018, respectively) over the study period. The greatest transformation for built-up land use (over 37 km$^2$) took place between the short periods of two years (2016 to 2018) while the entire land use, the woodland cover recorded the greatest decline (over 220 km$^2$) between 2008 and 2016. In the case of MMC, the built-up category is by far the most expansive land cover type over the 18-year study period with a total expansion area of over 34 km$^2$. Over the same period, agricultural land declined by almost 17 km$^2$. Comparatively, the land use and cover of DCC recorded a more drastic transformation than that of the MMC.

**Urban Expansion, Population Growth in DCC & MMC**

The metropolitan mark (Fig. 5 and Table 2) shows that much of the metropolitan development took place northward of both cities. For DCC, the ultimate urban expansion was recorded from 2016 to 2018 and from 2008 to 2016 converting an area of 38 km$^2$ and 40 km$^2$, respectively. This pattern is correlated with population increase (Fig. 6) detailed during the same period where the MMC recorded an increase in population from about 190,000 in the year 2000 to over 310,000 in 2017, while DCC recorded a population increase from about

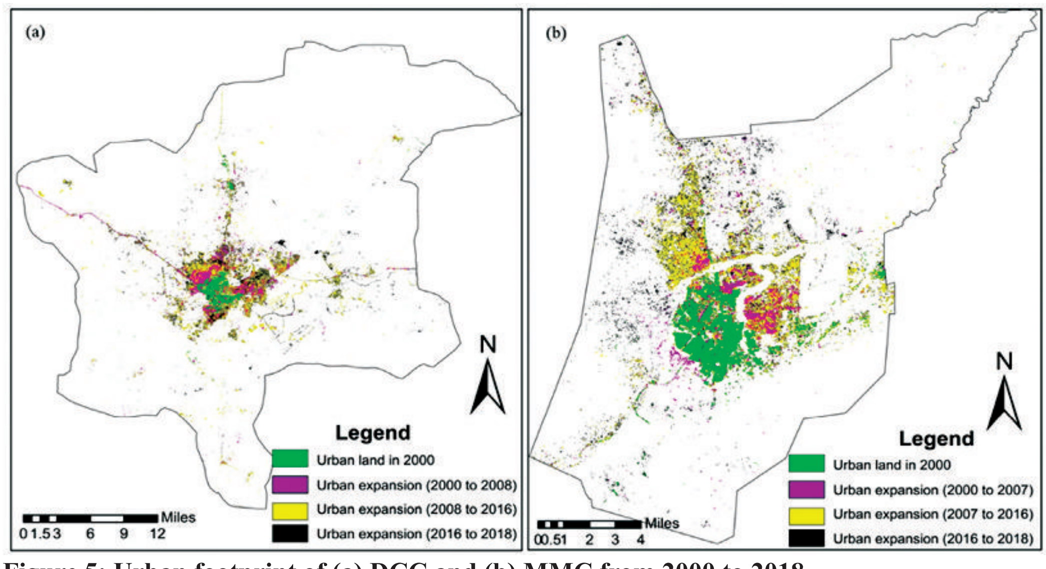


**Figure 5: Urban footprint of (a) DCC and (b) MMC from 2000 to 2018**

**Table 2: Urban land (Km²) and proportion (%) of the urban expansion from 2000 to 2018**

| City | Urban Land Area (Km²) | | | | Urban Land Expansion (%) | | | |
|---|---|---|---|---|---|---|---|---|
| DCC | 2000 | 2008 | 2016 | 2018 | 2000-2008 | 2008-2016 | 2016-2018 | 2000-2018 |
| | 43 | 62 | 102 | 140 | 0.7 | 1.6 | 1.4 | 3.7 |
| MCC | 2000 | 2007 | 2016 | 2018 | 2000-2007 | 2007-2016 | 2016-2018 | 2000-2018 |
| | 15.5 | 21.9 | 43.3 | 51.1 | 1.2 | 3.9 | 1.5 | 6.6 |

310,000 in the year 2000 to 450,000 in 2017. A very high variance dependency (0.9994 and 0.9996 for DCC and MMC, correspondingly) is established between population growth, as an independent variable, and urban expansion, as a dependent variable (Fig. 6). Moreover, the correlation between urban development (roads, buildings, impervious surfaces, etc.) and increased heat island or surface temperature have been established by several studies including Yang *et al.,* (2019) and Zhou *et al.,* (2019).

indication of healthy vegetation) than degraded areas. Relatively, the. maximum NDVI values were recorded in MMC. In general, extraction of NDVI pixels for our region of interest (ROI) provides values that range from a low of -0.17 to a maximum of 0.77 for DCC and a low of -0.18 to a maximum of 0.97 for MMC. According to Cao *et al.* (2018), NDVI values of +1 (0.8 - 0.9) signify dense forests, >0.3-0.5 represents medium vegetation and >0.1 to 0.3 represents low vegetationThe applicability of NDVI in this study is thought to be relevant for the reason that

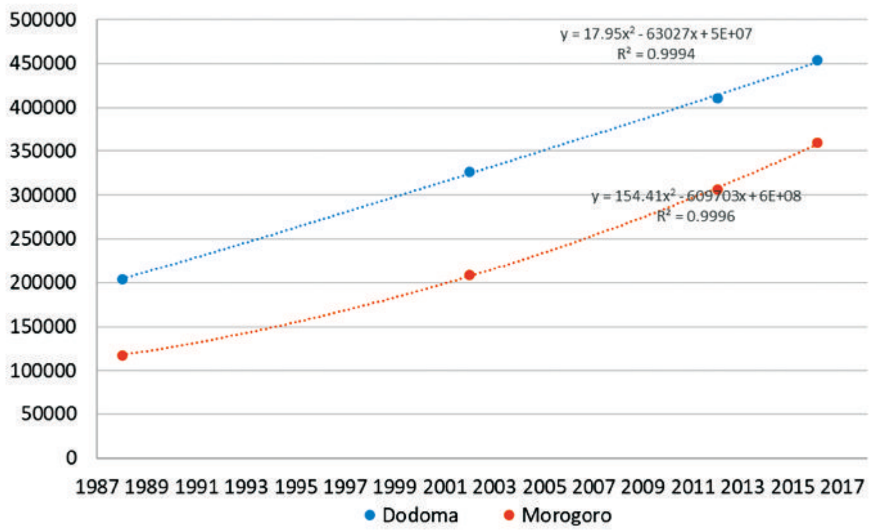


**Figure 6: Population growth trend for DCC and MCC**

**The Estimation of NDVI and spatial distribution of LST**

The NDVI indices and LST have been mapped across the two metropolitan centers (Fig. 7 & 8). NDVI have been improved and taken up to the experimental amount of urban land. Assessments of vegetation in the study area were performed as a step towards the fortitude of the vegetation health over the period of eighteen years' time-period. Figure 7 shows that the healthy and non-degraded component of the study area discovered high NDVI (an

the amount and quality of vegetation present within the MMC and DCC are significant factors, and can be used to infer general vegetation situation which in turn serve as an inferential basis for moisture content levels of soils (Ujoh *et al.* 2019; Xiong *et al.* 2017). The NDVI maps show a constantly and sequentially a slighter difference between the near-infrared and the red reflectance, hence implying smaller vegetation index over the study years (from 2000 to 2018) for both locations.

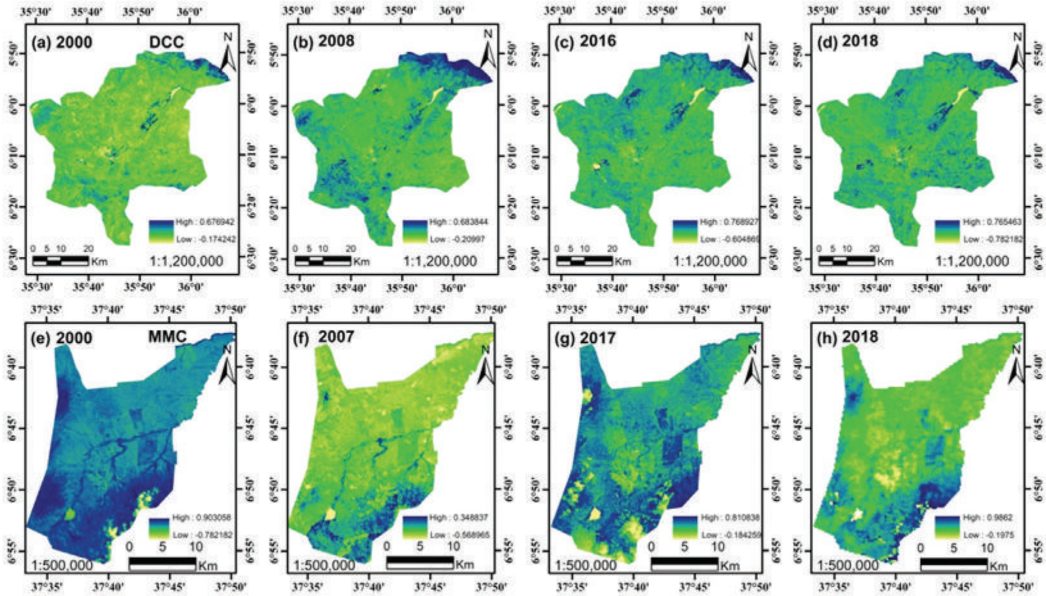


**Figure 7: Spatial distributions of the NDVI of DCC (a, b, c, d) and MMC (e, f, g, h)**

The LST maps (Fig. 8) reveal minimum and maximum temperatures of 6°C and 54°C in DDC and MMC with a high proportion of temperature levels ranging from around 28°C to 35°C. The industrial land cover taken on for this study refers to the overall metropolitan surface land cover, which includes concrete and corrugated building roofs, streets, and other pervious and impervious surfaces within the two metropolitan centers. The results show that the built-up land cover has time after time extended from 1.6% in 2000 to 5.3% in 2018, in tandem with surface temperature increase within the same period.

In examining the different dynamics, which interplay in increasing the LST in some cities, a major focus was given to urban environmental components (such as NDVI, land-use, and population density) that determine temperature variation. Although, the study considered land-use changes in the urban area as the major factor driving LST, results of analyses of satellite images in Dodoma show higher LST values

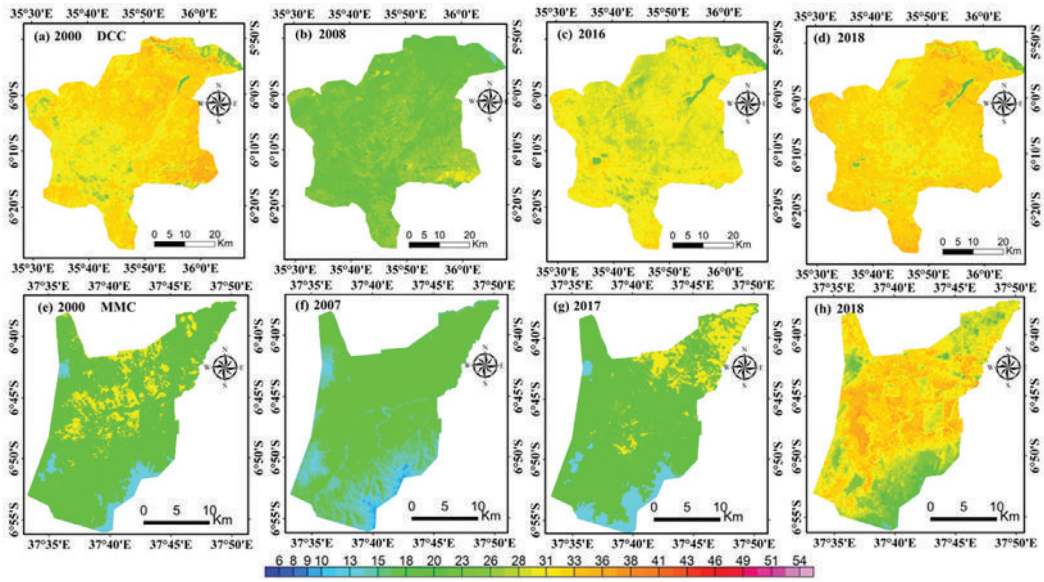


**Figure 8: Spatial distributions of the LST of DCC (a, b, c, d) and MMC (e, f, g, h)**

in 2018 than 2000, while both urban areas have more built-up in the year 2018 than 2000. According to Table 2, land-use change pattern of those areas were distressed by the increase of LST value in 2018.

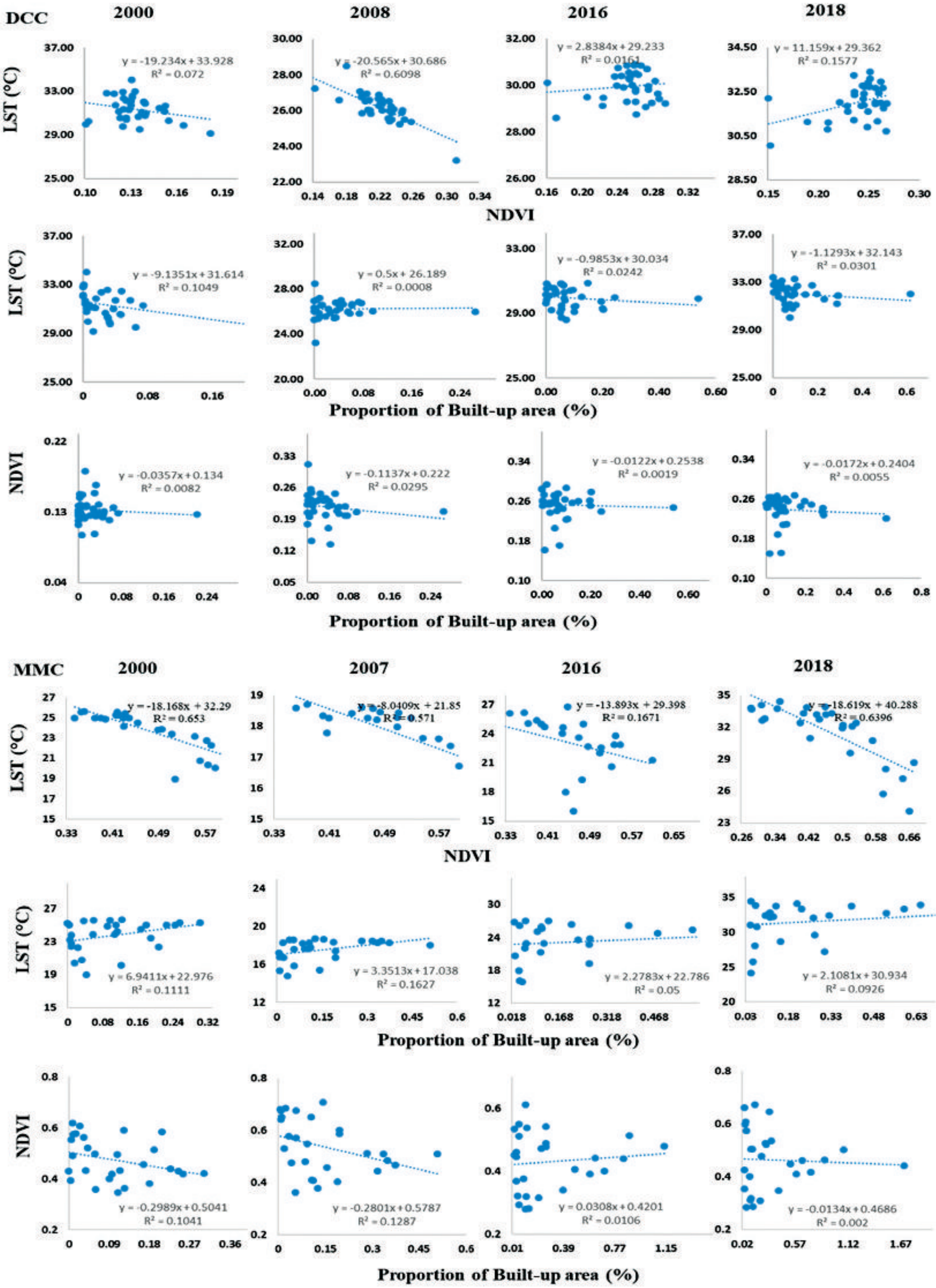


**Figure 9: The correlation coefficient of the average LST, the NDVI and the built up percentages for DCC and MMC**

**Correlation Coefficient of NDVI, LST and Built-up for DCC and MMC**

The correlation coefficient is used in this study to calculate the strength and direction of the relationship between LST and NDVI, LST and built-up area, and NDVI and built-up area for DCC and MMC. The results (presented as Fig. 9) show that the strength of relationship between NDVI and LST for year 2008 in DCC is relatively stronger negative (at -0.061) implying that the two variables are strongly correlated in opposite directions. In essence, as the value of NDVI increases, that of LST decreases and vice versa. The correlation coefficient results for LST and built-up area, and NDVI and built-up area for DCC show statistically insignificant results. For MMC, the results of the regression of correlation analysis between LST and NDVI from 2000 to 2018 as dependent variable (N=number of Wards), exhibits a strong positive relationship for the years 2000 ($R^2$=0.65), 2007 ($R^2$=0.57) and 2018 ($R^2$=0.64). However, for the correlation between LST and built-up proportion, the strength of the relationship is positively weak, meaning that although the relationship is statistically insignificant in terms of strength, an increase in LST means there is an increase in built-up area and vice versa. Similarly, the relationship between NDVI and built-up land cover for MMC is a negative one, in spite of its statistical insignificance of the producers and user's accuracy assessment of classified Landsat images that are statistically significant and acceptable for further analysis by urban planners and environmental experts (Fig. 10).

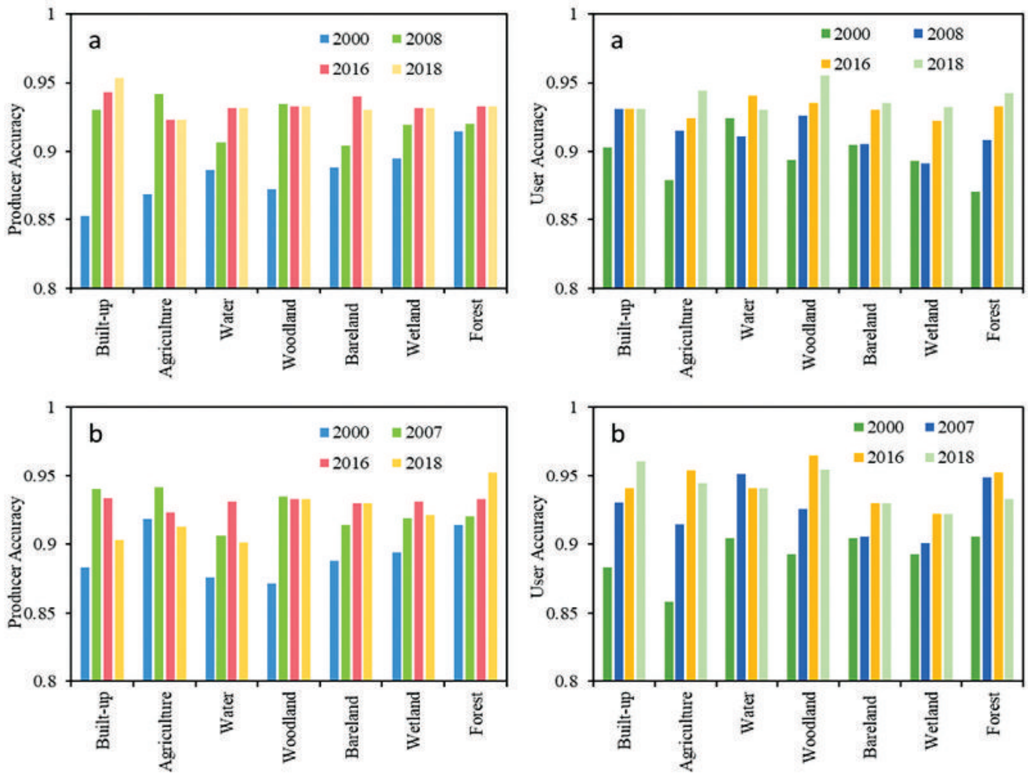


**Figure 10: The percentage of accuracy assessment for each classified classes in (a) DCC and (b) MMC**

**Discussion**

Urban expansion is one of the most significant components of global change responsible for modification of the land-use surface, species diversity, and quality of human life (Lourenço *et al.,* 2018). It is expected that an improved knowledge of urban expansion and global heat will contribute to emerging a more sustainable environment for rapidly expanding urban areas. Using Multi-temporal Landsat TM/ETM+ imagery, land use change detection techniques were applied to quantify urban expansion patterns as well as its impacts on Land Surface Temperature (LST). Rapid increase of built-up area from 2000 to 2018 in DCC and MMC was determined. The percentage of urban expansion from 2000-2008, 2008-2016, 2016-2018 for DCC was 0.7, 1.6, 1.4, 3.7%, respectively, and from 2000-2007, 2007-2016, 2016-2018, MCC increased by 1.2%, 3.9%, 1.5%, 6.6%, respectively. The impact of urban expansion was the decrease of agriculture land, woodland and forest area in both two cities. For example, Sumari *et al.,* (2019) shows that in Morogoro urban the most significant land use change was the conversion from farmland to built-up area. Urban expansion which arisen mostly around the midpoint of the city (city center) was associated with population growth and economic development. Essentially, the population of Morogoro Municipal was 227,921 and 359,684 thousand while in Dodoma City Council was 236,811 and 454,128 from 2002 and 2016. Rapidly increasing population prompted the expansion of urban land cover and the conversion of agricultural land and forest to impermeable surface. Therefore, these impermeable surfaces have relatively higher LST, which may lead to temperature increase in the long run. (Weng *et al.,* 2019; Weng and Fu, 2014; Zhou *et al.,* 2014)

Given the rate of expansion of Morogoro and Dodoma urban areas triggered by the increasing urban population, there is a corresponding intensity in demand for resources including energy, water and land which collectively heightens the need to improve urban management and planning for sustainability (Gao *et al.,* 2015). For example, it is becoming increasing necessary for cities to adopt smart and sustainable approaches through the usage of renewable energy sources rather than remnant fuel powered energy sources that cause pollution. More specifically, urban planning strategies need to account for different consequences that address urban growth patterns and reverses declining/worsening micro-climatic conditions.

## Conclusion

This study has investigated the outcome of urban expansion on the land surface temperature of Dodoma and Morogoro urban areas with a number of observations gathered from the study. Firstly, both towns have experienced rapid growth due to increase in population between the periods 2000 to 2018. Secondly, there has been remarkable degradation of vegetation land cover areas in favour of increased built-up areas. The outcome shows that, the land surface temperature of Morogoro municipal and Dodoma city were amplified through the study period with a high LST of (>23$^{o}$C). The results also show that NDVI and LST present a negative correlation, while built-up areas and LST reveal positive correlation, which confirms that the densely built-up and residential areas have recorded high increase in LST. To address these challenges, it is pertinent that future urban city designs and planning should incorporate greening. Finally, the study revealed that the rising population growth and urban expansion directly affect the increase in built-up areas, which consequently lead to an increase in LST.

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# Chicken Maternal Lineage Retained Long Historical Relationship Between Zanzibar and Oman

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**Abstract**

*The aim of this study is to appreciate the long historical relationship between Zanzibar and Oman, through the investigation of maternal lineage of chickens found in Zanzibar and Oman. Earlier traders and explorer from Arabia, Persian Gulf, West India and China probably visited Zanzibar as earlier as the 1st Century AD. Oman in Southern Coast of the Arabian Peninsula at the Persian Gulf played a tense relationship between seafaring and commercial people in Indian Ocean. Furthermore, the history of Zanzibar is directly linked to Oman, after Oman Empire expelled and ended the Portuguese dominance of the Indian Ocean trade routes. In 1650 Oman becomes one of the main maritime and mercantile powers in the Persian Gulf and in the Indian Ocean. The sultans of Oman ruled over a substantial part of the Swahili Coast along the Indian Ocean from 1689-1856, controlling elaborate trade routes and cash crop plantations in East Africa. In the mid-1800s, they moved their seat of power from Muscat, Oman, to Stone Town, Zanzibar, and ruled as a constitutional monarchy. This historical relationship can be traced from maternal lineage of chickens that currently exist in Zanzibar and Oman. The mitochondrial genome has been the most widely used system for the investigation of the evolutionary history of species. The high rate of sequence divergence and its uniparental, maternal inheritance can retain evolution relationship as genetic fossils. The Phylogenetic network and Medial-Joining network analysis revealed strong association of evolution relationship between chicken ecotypes from Zanzibar and Oman. The prominent ancestral haplogroups indicated strong association of these chicken populations that were descended from the common ancestry. The Maritime trade interactions and consequences of Oman sultanate regimes in Zanzibar could significantly contributed to the ancestral relationship that existing today between Zanzibar and Oman Chickens.*

***Keywords***: Zanzibar, Oman, Mitochondrial DNA, Phylogenetic network, Medial-Joining network

## Introduction

Zanzibar is an autonomous part of the United Republic of Tanzania that counted with famous tropical Spice Islands and a world heritage site, located merely twenty miles off the east coast of Africa. Zanzibar is a popular archipelago in the Indian Ocean that consists of two main islands of Unguja and Pemba, together with many other smaller islands. Zanzibar played significant roles in the pre-historical activities on east coast of Africa due to its access to traders and several adventurers comes to exploring Africa continent. The islands of Zanzibar were prime gate way to East Africa and strong base for traders voyaging between the African Great Lakes, the Somali Peninsula, the Arabian Peninsula, Iran, and the Indian subcontinent (Shariff, 2018). Occupants of coastal and islands of Swahili coast in East Africa were involved in long distance trade with the Indian Ocean world during the later first millennium CE (Prendergast *et al.,* 2017a). Throughout this time, they used monsoon winds to sail across the Indian Ocean to land at the sheltered harbour located on the site of Zanzibar. The first mention of Zanzibar comes from the Greek mariner's guide, Periplus of the Erythraean Sea, which was written around 50 AD. Referred to as Menouthais, the island described as being ‘low and wooded, in where there are rivers and many kinds of bird and the mountain tortoise'. According to the 16th

Century explorers, Zanzibar (Zanjibār in Arab and Zang-bār in Persian) was referred by Arabs and Persians as East African Coast that running from Kenya to Mozambique.

The long historical relationship between Zanzibar and Oman, currently can evidently be observed in islands of Zanzibar from old artefacts', historical architectural, vintage furniture and crafts, food, agricultural, language, cultural practices and affinity relationship among Zanzibarian and Omanian people. Oman is a country located on the Southern Coast of the Arabian Peninsula at the confluence of the Persian Gulf and Arabian Sea in Western Asia. It shares land borders with Saud Arabia, the United Arab Emirates and Yemen, and it shares maritime borders with Iran and Pakistan. Oman is the oldest independent state in the Arab world that has been ruled by the Al-Said family since 1744 and form Al Busaidi dynasty in the Sultanate of Oman until to date. The Omani Sultanate was a major maritime force from 17th to 19th centuries, which established its dominance in the Indian Ocean sea routes after defeating the Portuguese. Muscat and Oman extended its conquests to Zanzibar, other parts of the eastern coast of Africa and portions of the southern Arabian Peninsula.

From the late 17$^{th}$ century, the Oman Sultanate was a powerful empire which has much influence in the Persian Gulf and Indian Ocean. Oman Empire becomes a powerful state that take control on maritime trade all along from vast strips of southwest Iran, most of the north-eastern and southern parts of the Arabian Peninsula, and much of the Horn of Africa coast and all the way down till Northern Mozambique (Vernet, 2009; Shariff, 2018). In the mid of 17$^{th}$ century Zanzibar becomes part of Oman territory and started to be fully controlled by sultanate regimes from Oman until mid of 20th Century. From 1698, Zanzibar was under the control of the Sultanate of Oman Saif bin Sultan, the Imam of Oman who started to strengthen and developed an economy of trade, infrastructures and cash crops in the Zanzibar islands. The clove, originating from the Moluccan Islands (Indonesia), was introduced in Zanzibar by the Omani sultans. The plantations of spices were later intensified and hence moniker of the Spice Island name.

Sayyid Said Bin Sultan Al-Bu Said was the last ruler of the united Omani Empire from 1806 to June 1856 (Srinivasan, 1998). He appreciably turned his great attention to East Africa for the purpose of establishing political and economic power in the region. By the year 1828, Said bin Sultan succeeded to create a flourishing commercial empire along the East African coast, in which made Zanzibar the principal power in East Africa and the commercial capital of the western Indian Ocean (Rhodes *et al.,* 2015). In 1840 he officially moved his capital from Muscat to Stone Town in Zanzibar Island, which also allows him to reinforce the security and administration of his territories on the East African coast (Al-Farsi, 1989). Said bin Sultan allows this archipelago to become the principal port on the East African coast and economic centre of the Arab Trades that favoured from its geographical location (Srinivasan, 1998). During his ruling time, Zanzibar received a lot of influence and interactions from Oman. His regime emphasized on the massive growth of spices in the Islands and made Zanzibar to be the centre of the profitable spice trade between countries and regions bordering the Indian Ocean. Said bin Sultan ordered the landowners of the islands of Unguja and Pemba to cultivate cloves, which eventually became an economic mainstay of Zanzibar (Al-Farsi, 1989). By the 1860s, Zanzibar had become the world's major producer of cloves (Fage and Roland, 1976).

Said bin Sultan introduced liberal customs policies to attract foreign merchants at Swahili coast in East Africa. He also allowed Indians to trade in Zanzibar, who brought the administrative and financial skills that were essential in developing a trading centre (Sheriff, 1971). The Island emerged as an inter-port for international trade for having deep and wider harbour, with well suited to monsoon winds directions that facilitate the linkage of maritime routes between East African coast, Persian Gulf and India (Sheriff, 1987). Furthermore, Zanzibar offered a protected and defensible harbour, conducive environment for trade, favourable climate, and fertile soil. These features would enhance Zanzibar's attractiveness as a trading centre and farming, thereby significantly contributing to Said's wealth (Al-Farsi, 1989). After the death of Said bin Sultan in 1856, the empire was divided between his sons into two sultanates, where Sultanate of Zanzibar that occupied African section was ruled by Majid bin Said, and Sultanate of Muscat and Oman on the Asian section ruled by Thuwaini bin Said.

The existed long relationship between Oman and Zanzibar might allow the exchange of domestic animals. Zooarchaeological studies in Zanzibar tracing earlier introduction of Zebu cattle (*Bos indicus*) and domestic chickens (Gallus gallus) with Asian taxa (Horton, 1996; Chami 2001; Lyimo *et. al.,* 2013; Boivin *et. al.,* 2013). Several studies shows the spread of chickens around the world are intimately linked to the movement of people, since chickens are not migratory birds (West and Zhou, 1998; Tixier-Boichard *et al.,* 2011; Storey *et al.,* 2012; Thomson *et al.,* 2014, Lyimo *et al.,* 2015). Interestingly, several genetic studies using mitochondrial DNA (mtDNA) that accessed the dispersal pattern of chickens from their centres of origin, have shed light on prehistoric human migration, trade routes, and cross cultural diffusion (Gongora *et al.,* 2008; Muchadeyi *et al.,* 2008; Razafindraibe *et al.,* 2008; Dana *et al.,* 2010; Storey *et al.,* 2012; Peters *et al.,* 2016).

Earlier traders and explorer from Arabia, Persian Gulf, West India and China probably visited Zanzibar as earlier as the 1st Century AD. The Arabian Peninsula has played an important role in the dispersal of commodities, plants, crops and animals between India and Africa (Boivin *et al.,* 2010; Groucutt and Petraglia, 2012). They used monsoon winds to sail across the Indian Ocean and landed at the sheltered harbour in Zanzibar. Different scholars reported that domestic chicken in Zanzibar, were introduced during maritime exchanges (Boivin *et al.,* 2014; Prendergast *et al.,* 2017b; Crowther *et al.,* 2018). The aim of this study is to examine the relationship of maternal lineage between Zanzibar and Oman chickens that could be associated with the long interaction between these two countries. Mitochondrial DNA sequences can be used to estimate phylogenetic relationships among individual taxa and perform molecular phylogenetic evolution analysis (Vogel *et al.,* 2011; Zhang and Zhang, 2013). The evolution relationship of individual could be traced from the control region of mitochondrial DNA (D-loop region), which has higher evolutionary rate compared to genomic DNA. The mutations that accumulate sequentially along maternal lineages allows associating them with populations from different geographical regions of the world (Ingman *et al,.* 2000; Herrnstadt *et al.,* 2002).

## Methodology

A total of 138 mtDNA sequences of eight ecotypes from Zanzibar and Oman chicken were studied. Two ecotypes of Pemba (PEMB) and Unguja (UNGJ) were named after their main islands of Zanzibar (Msoffe *et al.,* 2004; Lyimo, *et al.,* 2013), and six ecotypes of Oman chickens, that is Musadam (MU), Batinah (BT), North Hajar (NH), East Hajar (EH), East Coast (EC) and Dhofar (DF) were sampled and named after major agroecological zones existed in Oman (Al-Qamashoui *et al.,* 2014a).

## Mitochondrial DNA Sequences

For the six populations of Oman chickens, DNA was extracted using standard silica-column based commercial kits (D-Neasy Blood & Tissue Kit, Qiagen, UK). A 550 bp fragment from mtDNA D-loop region was amplified by PCR using two primers L16750 (5'-AGGACTACGGCTTGAAAAGC-3) and H522 (5'-ATGTGCCTGACCGAGGAACCAG-3'). PCR were performed in a 25 µl volume [1x reaction buffer, 75mM MgCl2, 5mM of each dNTP, 10pM of each primer, and 1U of Taq polymerase (SABC Inc.)] following 35 cycles of 1min at 94°C, 1min at 63°C, and 1min at 72°C. PCR products were then purified and sequenced in both directions (forward and reverse) using the Big DyeTM Terminator v.3.1 Cycle Sequencing Ready Reaction on an ABI PRISM 3100 sequencer (Applied Biosystems, Warrington, UK). Forward and reverse sequences were edited manually and aligned to get the consensus sequences using BioEdit 7.0.9.0 program (Hall and Carlsbad, 2011).

The generated raw sequences were edited and aligned with additional sequences using software package DNASTAR v.7.1 (DNASTAR

Inc., Madison, WI, USA) and aligned using MEGA software (Tamura *et al.* 2011). In addition, 40 mtDNA sequences of chickens from Zanzibar were retrieved from GeneBank (http://www.ncbi.nlm.nih.gov/genbank). Zanzibar chickens include 20 mtDNA sequences of Unguja ecotype and the other 20 mtDNA sequences from Pemba ecotype (Lyimo *et. al.,* 2013). The accession number in the NCBI Gene Bank of Unguja and Pemba ecotypes are given in Appendix 1 table.

**Data analyses**

All the Zanzibar and Oman chicken mtDNA sequences were aligned using the AlignIR software (LI-COR Inc.). Extra nucleotide bases were trimmed from all sequences to make a homogeneous length of 350 bp. Extra nucleotide sequences that were outside the nucleotide sequences of the D-loop region were excluded from analysis. Number of haplotypes between Zanzibar and Oman chickens were estimated by DnaSP 6.12.03 (Rozas *et al.,* 2017). Median-joining networks were constructed to determine the evolutionary relationships of mtDNA chicken haplotypes following the algorithms of Bandelt *et al.* (1995), using Network 4.6.1.0 software (http:// https://www.fluxus-engineering.com/sharenet.htm). Phylogenetic networks based on the Neighbour-Joining (NJ) among mitochondrial sequences of Zanzibar and Oman chickens was inferred using SPLITSTREE4 4.16.2 software (Huson and Bryant, 2006).

**Results**

The Phylogenetic analysis and haplotypes distributions revealed three distinct clusters among Zanzibar and Oman chickens. The Neighbour Joining network represents two main clusters that have mixed chicken ecotypes from Zanzibar and Oman, while the distant isolated third cluster has only Oman chickens of Musadan and North Hajar ecotypes (Fig. 1). The most prominent cluster in the phylogenetic network contains greater number of chickens, which includes all chicken ecotypes from Zanzibar and Oman.

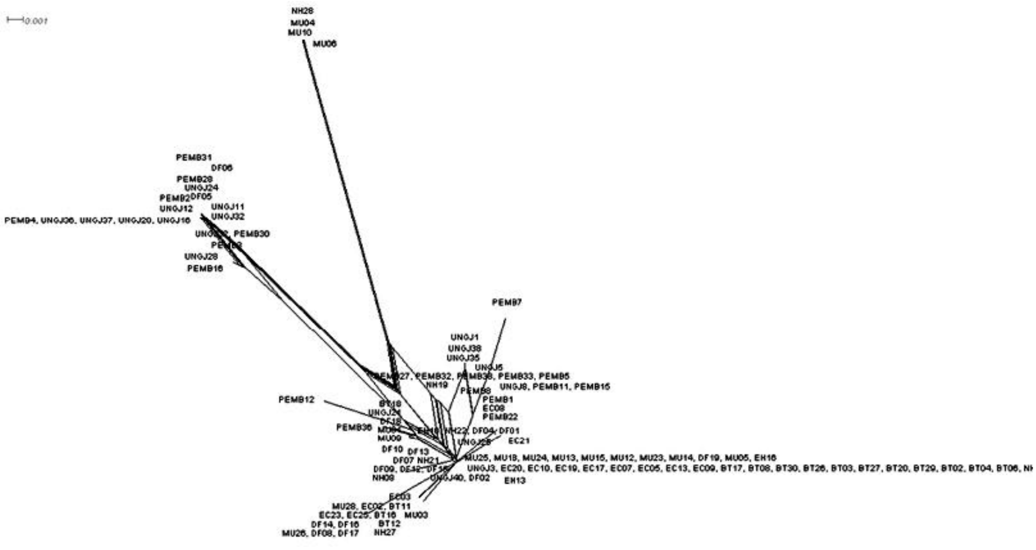

**Figure 1: Neighbour-joining network showing the maternal evolution relationships between Zanzibar and Oman chickens**

Twenty four polymorphic sites that lead to nineteen haplotypes definition were observed in Zanzibar and Oman chicken ecotypes. The median-joining (MJ) network analysis of the mtDNA D-loop haplotypes observed in Zanzibar and Oman chickens were clustered into three distinct clades, which were identified as A, B and C (Fig. 2). Clade B and C, which includes Zanzibar and Oman chickens were found to be most ancestral that contained torso structure with ancient haplotypes, which are dominated with higher appearance (79.7%)

from all haplotypes (Appendix 2). Clade A is the smallest (2.9%) haplogroup and the most recent cluster with two chicken ecotyapes Musadam and North Hajar from Oman. Clade B is the most prominent cluster (78.94) with greater number of haplotypes and all chicken ecotypes. The three prominent haplogroups (68.1%) with similar haplotypes that share common ancestor with a single nucleotide polymorphism mutation, accommodated chicken haplotypes from Zanzibar and Oman (Appendix 3). The largest haplogroup (46.4%), which found in Clade B, contained all chicken ecotypes from Zanzibar and Oman. The second largest haplogroup (11.6%) found in Clade C, comprised Unguja and Pemba ecotypes from Zanzibar, and Dhofar ecotype from Oman. The third largest haplogroup (10.2%) located in Clade B consisted of Unguja and Pemba ecotypes from Zanzibar, and North Hajar, East Hajar, East Coast and Dhofar ecotypes from Oman. In this study, the phylogenetic network gives comparable insight to the similarities in mtDNA as in Median-Joining Network, where very similar individuals with the same evolution history cluster together.

has been greatly considered an essential tool for studying origins, migration patterns, and demographic history of a given population (Torroni *et al.,* 1996). The variation in mtDNA sequences can be used to construct phylogenetic networks that potentially displaying the relationships among sequences and estimating the time of appearance of mutations associated with each haplotype (Bandelt *et al.,* 1999). In this study, Zanzibar and Oman chickens have indicated a closer evolution relationship from both phylogenetic and Median-Joining network of the mitochondria DNA haplotypes. The chicken haplotypes from both Zanzibar and Oman were assigned into three most prominent haplogroups. These specific haplogroups indicate a single line of descendant from the maternal lineage (Malhi *et al.,* 2002; Starikovskaya *et al.,* 2005; Sandoval *et al.,* 2018).

The existence of most common ancestral haplotypes from Zanzibar and Oman could be associated with the long historical interactions from maritime trading network and the influence of sultanate regimes along the Swahili coast. In the history of chickens' dispersal, it

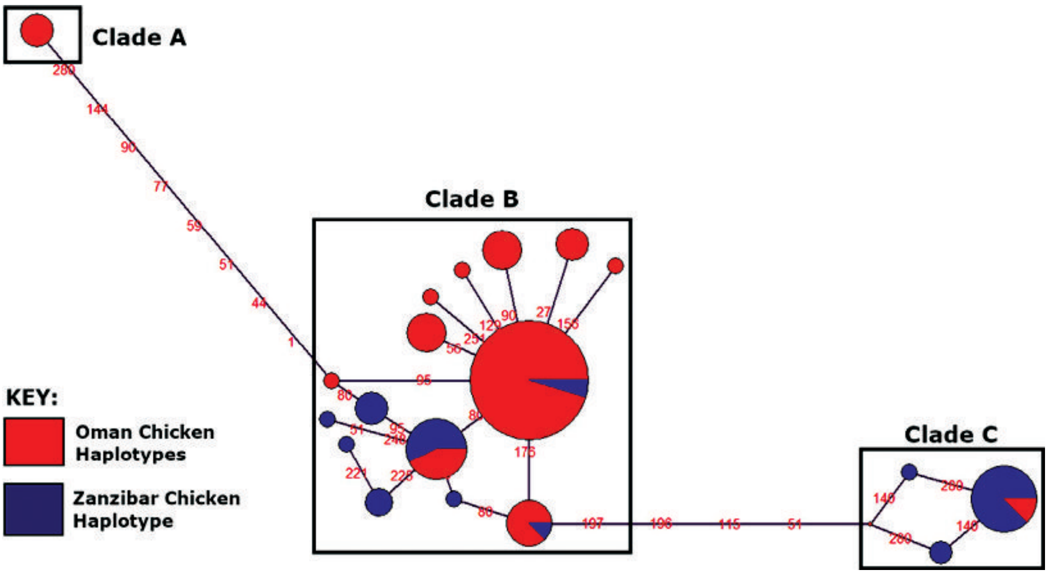


**Figure 2: Median-joining network profiles of 19 haplotypes observed in Zanzibar and Oman Chickens. Note that the circle size corresponds to haplotype frequency and the number between the haplotype nodes refers to the position of nucleotide mutations**

## Discussion

Mitochondrial DNA (mtDNA) analysis has been revealed that coastal maritime trading networks around the Indian Ocean were the main responsible means for the introduction of chicken into Eastern Africa (Williamson 2000; Blench 2003; Muchadeyi *et al.,* 2008; Mtileni *et al.,* 2011; Mwacharo *et al.,* 2011). The Arabian Peninsula is thought to have played a major role in the diffusion of livestock across the Indian Ocean. The history of Oman is the history of the tense relationship between seafaring and commercial people. For centuries the Arabs sailed with the Monsoon winds from Oman to trade at Swahili coast. Although Zanzibar had few resources of interest to the traders, but it offered a good location from which to make contact and trade with the towns of the Swahili Coast. These movements might substantially contribute to early introduction of chicken to Zanzibar.

Dhorfa and Musadan chicken ecotypes from Oman, were found to be most distributed Median-Joining clades and most sharing haplotypes with Unguja and Pemba chicken ecotypes from Zanzibar. Previous study reported by Al-Qamashoui *et al.,* (2014b), verified Dhofar and Musandan ecotypes represented largest contributions of diversity in Oman chicken populations using microsatellite markers. These chicken ecotypes reflect more or less similar heterozygosity to Unguja and Pemba chicken ecotypes from Zanzibar, with the same set of microsatellite markers (Lyimo *et al.,* 2013). The expected heterozygosity in Dhofar and Musadan were $0.67 \pm 0.027$ and $0.65 \pm 0.028$ respectively, while for Unguja and Pemba were $0.63 \pm 0.016$ and $0.67 \pm 0.016$ respectively.

## Conclusion

The interactions and close associations between Oman and Zanzibar are highly reflected in ancient maternal lineage of chicken ecotypes currently existing in Zanzibar and Oman. This could be greatly contributed from the maritime trade influence and the long persistence of sultan regimes operated in Zanzibar.

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## Appendices

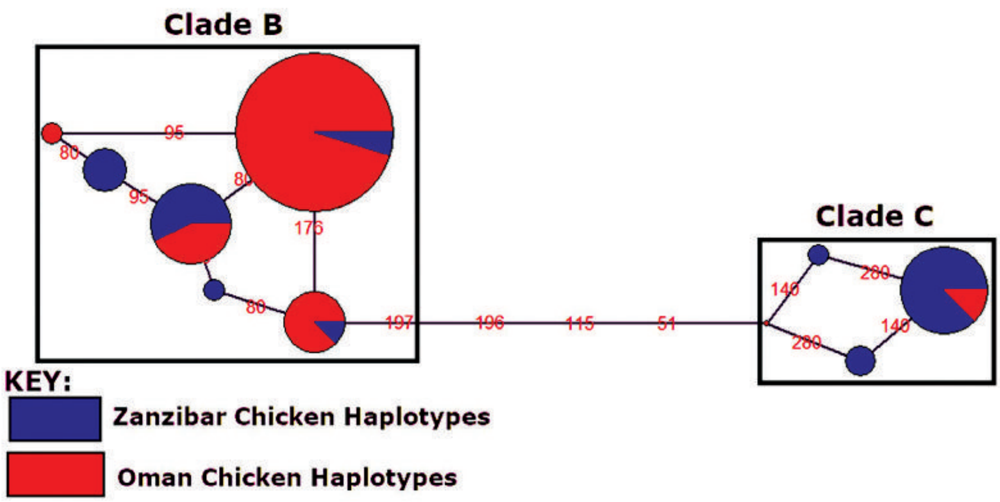
**Appendix 1: Mitochondrial DNA Sequence accession number of Zanzibar chickens from National Centre for Biotechnology Information (NCBI) Gene Bank**

| SN | Abbreviation | Ecotype | Accession Number |
|---|---|---|---|
| 1 | UNGJ1 | Unguja | KP067513 |
| 2 | UNGJ11 | Unguja | KP067514 |
| 3 | UNGJ12 | Unguja | KP067515 |
| 4 | UNGJ21 | Unguja | KP067516 |
| 5 | UNGJ22 | Unguja | KP067517 |
| 6 | UNGJ24 | Unguja | KP067518 |
| 7 | UNGJ25 | Unguja | KP067519 |
| 8 | UNGJ28 | Unguja | KP067520 |
| 9 | UNGJ31 | Unguja | KP067521 |
| 10 | UNGJ32 | Unguja | KP067522 |
| 11 | UNGJ35 | Unguja | KP067523 |
| 12 | UNGJ36 | Unguja | KP067524 |
| 13 | UNGJ37 | Unguja | KP067525 |
| 14 | UNGJ38 | Unguja | KP067526 |
| 15 | UNGJ8 | Unguja | KP067527 |
| 16 | UNGJ16 | Unguja | KP067535 |
| 17 | UNGJ5 | Unguja | KP067536 |
| 18 | UNGJ3 | Unguja | KP067542 |
| 19 | UNGJ20 | Unguja | KP067543 |
| 20 | UNGJ40 | Unguja | KP067544 |
| 21 | PEMB1 | Pemba | KP067497 |
| 22 | PEMB11 | Pemba | KP067498 |
| 23 | PEMB15 | Pemba | KP067499 |
| 24 | PEMB16 | Pemba | KP067500 |
| 25 | PEMB2 | Pemba | KP067501 |
| 26 | PEMB22 | Pemba | KP067502 |
| 27 | PEMB27 | Pemba | KP067503 |
| 28 | PEMB28 | Pemba | KP067504 |

| SN | Abbreviation | Ecotype | Accession Number |
|---|---|---|---|
| 29 | PEMB30 | Pemba | KP067505 |
| 30 | PEMB31 | Pemba | KP067506 |
| 31 | PEMB32 | Pemba | KP067507 |
| 32 | PEMB36 | Pemba | KP067508 |
| 33 | PEMB38 | Pemba | KP067509 |
| 34 | PEMB4 | Pemba | KP067510 |
| 35 | PEMB5 | Pemba | KP067511 |
| 36 | PEMB8 | Pemba | KP067512 |
| 37 | PEMB12 | Pemba | KP067531 |
| 38 | PEMB3 | Pemba | KP067532 |
| 39 | PEMB33 | Pemba | KP067533 |
| 40 | PEMB7 | Pemba | KP067534 |

***Source:*** Lyimo *et al.,* (2013)

**Appendix 2: Median-joining network of Zanzibar and Oman Chickens display the ancestry mtDNA haplotypes**



**Appendix 3: Haplotype frequency in each of the chicken ecotype from Zanzibar and Oman**

| Haplotype | Zanzibar Chickens | | Oman chickens | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | UNGJ | PEMB | MU | BT | NH | EH | EC | DF | |
| 1 | 3 | 1 | 10 | 11 | 11 | 15 | 8 | 5 | 64 |
| 2 | 9 | 5 | | | | | | 2 | 16 |
| 3 | 4 | | | | | | | | 4 |
| 4 | 1 | 1 | | | | | | | 2 |
| 5 | 1 | 8 | | | 1 | 1 | 1 | 2 | 14 |
| 6 | 1 | 1 | | | | | | | 2 |
| 7 | 1 | | 2 | 1 | | | | 4 | 8 |
| 8 | | 1 | | | | | | | 1 |
| 9 | | 1 | | | | | | | 1 |
| 10 | | 1 | | | | | | | 1 |
| 11 | | 1 | | | | | | | 1 |
| 12 | | | 2 | 1 | 3 | | | | 6 |
| 13 | | | | | | | 1 | | 1 |
| 14 | | | 1 | 1 | | | 2 | | 4 |
| 15 | | | 1 | 1 | | | | 4 | 6 |
| 16 | | | 3 | | 1 | | | | 4 |
| 17 | | | | | 1 | | | | 1 |
| 18 | | | | | | 1 | | | 1 |
| 19 | | | 1 | | | | | | 1 |
| | 20 | 20 | 20 | 15 | 17 | 17 | 12 | 17 | 138 |

***NB:*** *In the bracket below, define the abbreviations of the relevant chicken ecotypes: UNGJ (Unguja), PEMB (Pemba), MU (Musadam), BT (Batinah), NH (North Hajar), EH (East Hajar), EC (East Coast) and DF (Dhofar)*

# The Potential of Riparian Forests in Anthropogenic Stressed River Ecosystems

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**Abstract**

*The study was conducted to examine riparian vegetation species, anthropogenic interactions, and the due impact on the Ngerengere River riparian ecosystem in Tanzania in view of riparian forests potentials on river ecosystems. Vegetation data were collected by belt transect and field observation, and socio-economic data by household interview methods. Upon descriptive and content analyses, Pennisetum purpureum, Phragmites mauritianus, Typha domingensis, Phragmites australis, Cyperus rotundus, Sesbania sesban and Ficus sycomorus constituted the riparian zone. Most of them (80%) were grass, affected by cultivation (54%) and sand extraction (34%), causing vegetation extinction (36%), riverbanks collapse and increased sedimentation (31%). Highly vegetated areas had clean water and were ecologically stable. Riparian forests were sought vital for sustainable management of river ecosystem through enhanced carrying capacity, water cleansing and banks stabilization.*

***Keywords***: Climate change, Nature-based solutions, Ngerengere River, Riparian vegetation, Sustainable development

## Introduction

Riparian forest implies a naturally wooded or forested area of land along natural water bodies. They constitute biotic communities on the shores of streams and rivers. Their aquatic - terrestrial systems interfaces are termed as riparian zones (National Research Council, 2002; Naiman *et al.,* 2005). Likewise, vegetation within the riparian forest, forming a riparian zone are called riparian vegetation, an essential component of fluvial system (rivers, streams, and associated features) serving for multiple socio-ecological and hydrological functions (National Research Council, 2002; Naiman *et al.,* 2005; Dufour *et al.,* 2019). Riparian forests provide innumerable physicochemical and biological roles to associated water bodies' hydrology. Physically, they alter river-flow conditions by protecting banks and colonizing deposits hence inducing river metamorphosis, enabling floodwater storage in the floodplain. Simultaneously, they chemically support biogeochemical cycles within the river ecosystem and improving water quality in agricultural watershed with non-point source pollution through sediment trapping and nutrients removal commonly by denitrification (Dufour *et al.,* 2019). Riparian forests are biologically species rich (Dufour *et al.,* 2019; Trimmel *et al.,* 2018). They thus enhance corridor dispersal, biodiversity and habitat (de la Fuente *et al.,* 2018). In a socio-cultural context, they improve human well-being by providing several ecosystem services including water purification. During low flow, they shade the channel hence decreasing the rate of evaporation and water loss, while during flooding they buffer flood storm from the channel towards the floodplain by decreasing the incoming storm water velocity (Dufour *et al.,* 2019).

As of Malan *et al.* (2018) and de Sosa *et al.* (2018), the ecohydrological role of riparian vegetation are somewhat not widely recognized in some areas, leading to degradation through human influence within the riparian zone. This increases riverbank erosion, sediment deposition and reduces filtration capacity of fluvial ecosystem to incoming surface runoff (Malan *et al.,* 2018; Trimmel *et al.,* 2018; Chua *et al.,* 2019).

Considering the socio-ecological and hydrological roles played by riparian forests in the river ecosystem, they are a scientifically applicable and adaptable tool for river ecosystem management (Dufour *et al.,* 2019; Malan *et al.,* 2018; Chua *et al.,* 2019). This has risen a need for an integrated nature-based management approach that effectively make use of natural ecosystems in managing river ecosystem. Ecosystem based or sometimes referred to as a Nature based solutions approach is defined by the International Union for Conservation of Nature (IUCN) as actions employed to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while providing human well-being and biodiversity benefits (Cohen-Shacham *et al.,* 2016).

A potential linkage of nature based solutions to several aspects of sustainable development has been established (Fig. 1). The link shows the possible societal challenges that can be addressed.

Nature-based solutions address several societal challenges and sustainable development goals (SDG). These include SDG 6 (clean water and sanitation for all), 13 (climate action), 14 (life under water) and 15 (life on land) while at the same time indirectly supporting other goals (WWF, 2020; Vasseur *et al.,* 2017). Chief target link to economic development is introduced to show the interlinkage of several interventions and multiple developmental goals to achieve reducing poverty (SDG 1) and creating decent jobs (SDG 8) (Vasseur *et al.,* 2017).

Ecohydrology is among such nature-based approaches whose target is to increase stability and carrying capacity of river ecosystem through riparian forests where hydrology and biota influence each other, hence the term dual regulation (Zalewski, 2000; 2002: 2003; de Sosa *et al.,* 2018). It regulates ecological processes within the water cycle to enhance ecosystem

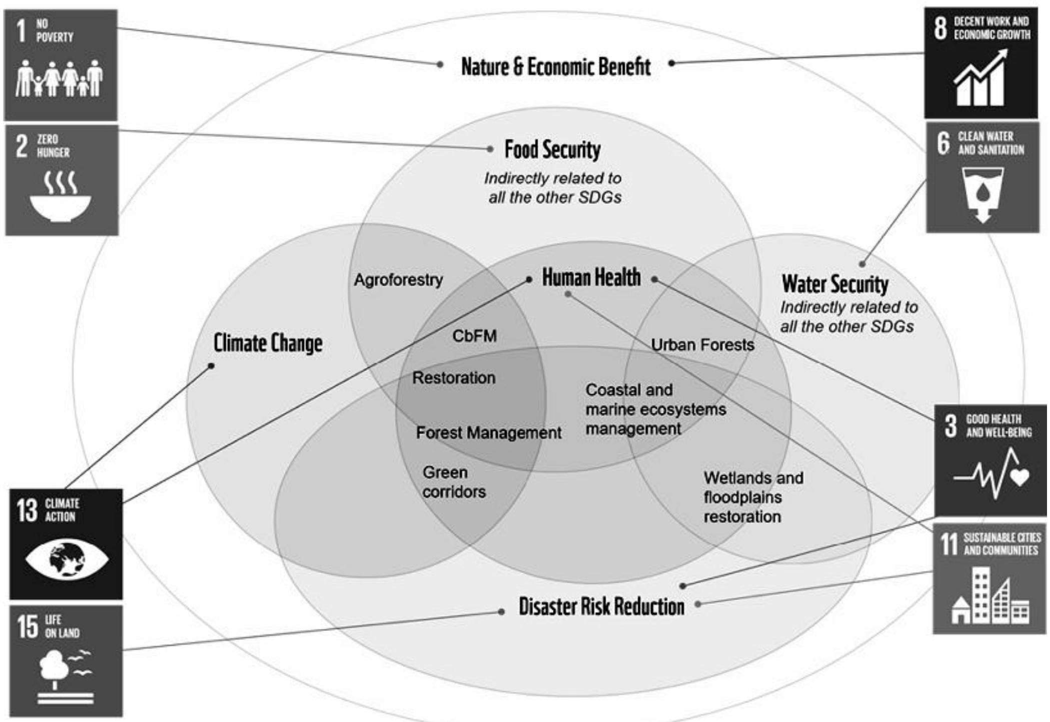


**Figure 1: Nature based solutions linkage to sustainable development**
***Source:*** WWF, 2020

stability (Zalewski, 2000; 2009; 2012; 2013). This approach guides the application of biota in managing river ecosystems against degradation through ecological and hydrological processes (Zalewski, 2002; Lalika, 2020; Raphael and Lalika, 2020).

It operates through framework, target and methodological principles (Zalewski, 2000). The framework principle describes the river ecosystem as the superorganism influenced by water circulation which regulate ecosystem processes. Water and temperature constitute the major driving factors, the dominant abiotic hydrologic processes in freshwater ecosystems. The target describes the natural resilience against stress due to biological interaction of biotic and abiotic components of the riparian forests and river ecosystem (de Sosa *et al.,* 2018; Zalewski, 2002). It thus provides the basis for enhancing the absorbing capacity of the river ecosystem against human impacts through well-maintained riparian forests. The methodology emphasizes the use of ecosystem properties to bring about sustainable management (Zalewski, 2000; 2002).

In most African countries, including Tanzania, there has been a high pace of population growth causing severe stress to river ecosystems through human activities (Lalika, 2020). Consequently, river ecosystems, riparian forests and fluvial zones are pressurized by cultivation practices, livestock grazing, poles harvesting and sand extraction (National Research Council, 2005; Naiman *et al.,* 2005; Malan *et al.,* 2018; Raphael and Lalika, 2020). Tanzania has many rivers including Ngerengere, which forms one of the major ecosystems within the large Wami/Ruvu Basin. Its catchment covers about 2780 km$^2$ with about four tributaries from Uluguru Mountains. Due to fertility potential, its flood plain is under several land uses that affect its stability (IUCN, 2010; Mero, 2011).

Due to its ecological, socio-economical and hydrological roles, several studies have been done to assess the water flow in several river basins in Tanzania (IUCN, 2010). Most of them had a particular focus on water quality and climate changes issues (IUCN, 2010; Mero, 2011; Natkhin *et al.,* 2013; Shagega *et al.,* 2018). This study was done to ascertain the potential of riparian forests (vegetation) to the river ecosystem by examining the distribution of available riparian vegetation species, human activities conducted within the riparian zone and their associated impacts, both to riparian vegetation and the river ecosystem.

## Materials and Methods

### Description of the study area

The study was conducted along Ngerengere River in Morogoro Municipality, Tanzania. Ngerengere River lies within Ngerengere sub-catchment of the Ruvu catchment in the Wami/Ruvu Basin (Eeden *et al.,* 2017) (Fig. 2) between

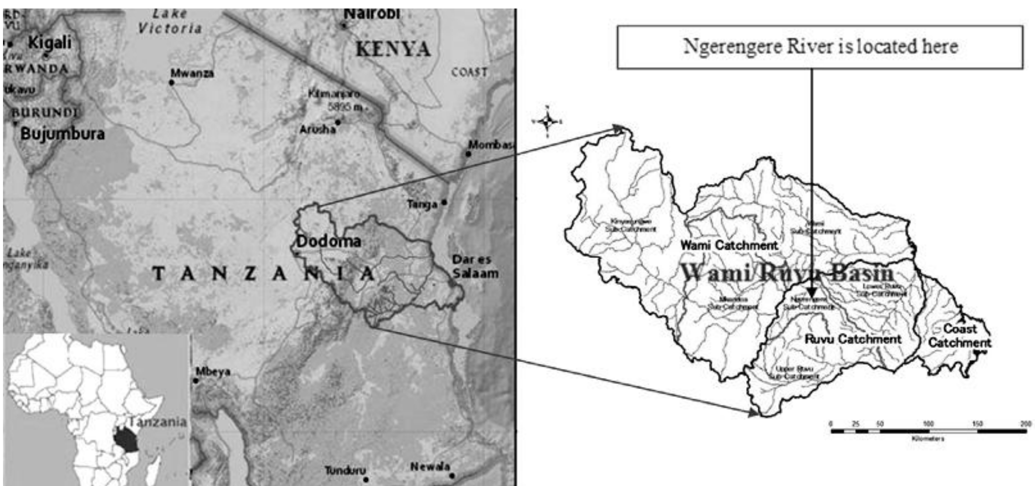


**Figure 2: Location of Ngerengere River in Tanzania**
***Source:*** (Eeden *et al.,* 2017)

latitudes 6°30'00" and 7°10'00" South and between longitudes 37°58'26" and 38°31'30" East with an area of about 2780 km$^2$. It originates from the Uluguru mountains, extending to other parts (urban and rural) of Morogoro Region (Mero, 2011). Within the catchment, is the Mindu Dam, the main freshwater source for Morogoro Municipality serving for other socioeconomic activities of local inhabitants, like agriculture and fishing. The river forms the inflow of the dam, in its upper stage, and extends downstream as the outflow, passing through Mazimbu Darajani street. It finally joins the lower Ruvu River that heads to the Indian Ocean. The mean annual rainfall varies between 800 and 1000 mm increasing to 2000 mm in the vicinity of the Uluguru Mountains where the river originates (Natkhin *et al.,* 2013; Shagega *et al.,* 2018).

**Sampling strategy and data collection**
**Biological data**

The study used belt transect method for vegetation sampling along the river continuum in the Mazimbu Darajani area. With this method, a five metres belt transect (wide) and about 2 km long was established alongside the river within the riparian forest zone. Within this stripe, twenty sampling stations were systematically established at a 100 m interval from one another with the aid of a Geographical Positioning System (GPS) device. At each introduced point, sampling was done within a 2 m radius around throughout with all categories of vegetation (grass, shrubs and higher trees) being sampled. After sampling, field identification was done at least with a local name level, completely unidentified. Partially identified vegetation was taken for further identification to Sokoine University of Agriculture's Ecohydrology experts.

**Socioeconomic data**

A simple random probabilistic sampling procedure was used during collection of household data by means of household questionnaire. This technique was adopted to avoid bias in selection of study respondents such that each household had an equal chance of being involved in the study. Questionnaires were administered to selected households to gather data on human interaction with the riparian ecosystem and associated impact. Field observation as a verification to anthropogenic undertakings within the riparian forest ecosystem was also used. The researcher observed cultivation styles, how farms were prepared, water diversion from the river and the tools used. Checklist for key informants was used to elicit baseline information on the evolution of the river in response to activities carried out along it in the riparian zone. Further details to disclose the changes arising with time as human activities progress were explored by structured interviews with native elders, known to have resided in the study area for about fifty years, and some for their entire life.

**Data analysis**

The data analysis plan involved descriptive analysis for quantitative socioeconomic data and content analysis for qualitative data from interviews and direct observation. Descriptive analysis was done to quantify proportions in terms of frequencies and percentage by using the Statistical Package for Social Science (SPSS-version 20) and Microsoft Excel. Responses from interviews and observation were examined to capture themes presented therein.

**Results**
**Major plant species found**

Species assumed an irregular pattern of distribution. Table 1 highlights the composition and proportions of the major riparian plant species around Mazimbu Darajani area (part of lower Ngerengere River ecosystem) where sampling was done. It illustrates that, the riparian forest zone of the Ngerengere River ecosystem is composed of major seven riparian vegetation species (Phragmites, Elephant grasses, Reeds, Sesbania, Sedges, Ficus and Bulrush) ranging from grass, shrubs, and some higher trees, as shown below.

A large part of Ngerengere River riparian zone is covered by phragmites due to their high regeneration potential, when compared to other species. They usually grow in thickets with harsh hairs on their surface. Elephant grasses have harsh and erectile hairs too, offering them,

**Table 1: Major riparian plant species Ngerengere River riparian ecosystem**

| Category | Common name | Botanical name | Abundancy (% occurrence) |
|---|---|---|---|
| Grass | Phragmites | *Phragmites mauritianus* | 25 |
| | Elephant grasses | *Pennisetum purpureum* | 22 |
| | Reeds | *Phragmites australis* | 22 |
| | Sedges | *Cyperus rotundus* | 08 |
| | Bulrush | *Typha domingensis* | 03 |
| Shrubs | Sesbania | *Sesbania sesban* | 14 |
| Trees | Ficus | *Ficus sycomorus* | 06 |

***Source:*** Field data

as phragmites, a defensive mechanism. These account for a relatively higher abundancies of phragmites and elephant grasses. Reeds on the other hand are not mostly preferred for livestock fodder, accounting for its observed high abundance. They experience slight disturbances, except during farm preparation where they are cleared with sedges (hence its low abundancy) as weeds. Bulrush (commonly Typha) dominate the flooding zone where paddy fields are established. These fields are completely cleared for rice cultivation and thatches, hence their low abundance. Due to anthropogenic disturbance in the riparian zone, most sites were unfavourable for Sesbania and Ficus, commonly due to unstable soil and slopes observed in the study area. Uncontrolled cultivation practices within the riparian zone contributed for the observed low abundance of Ficus (Table 1) and generally trees, as shown in Table 2 categorical percentage proportions of available species of riparian plants.

**Table 2: Proportion of Ngerengere River riparian vegetation species ecological categories**

| Vegetation category | Percentages (%) |
|---|---|
| Grass | 80 |
| Shrubs | 14 |
| Trees | 6 |

***Source:*** Field data

While grasses dominate other types of riparian plants, low percentage abundance (6%) of trees implies low regeneration and resistance on disturbance.

**Anthropogenic influences in the riparian ecosystem**

Figure 3 presents the major forms of human alterations and interaction in the Ngerengere River riparian ecosystem.

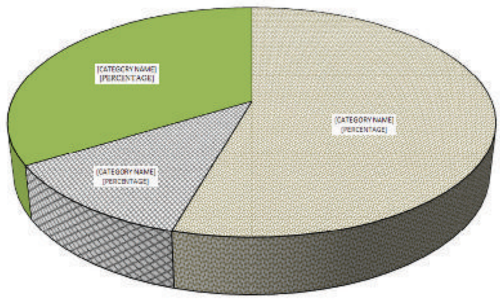


**Figure 3: Major forms of human alteration in Ngerengere riparian ecosystem**
***Source:*** Field data

The anthropogenic stressor to Ngerengere River riparian zone includes cultivation practices accompanied by application of fertilizers and mechanized tools (generator and water pumps for diverting water to agricultural fields). The major crops include rice, maize, vegetables, and horticultural crops along the river. Grazing activities also pose another threat by clearing for livestock fodder and pasture. Since a large proportion of vegetation around are grass (Table 1 and 2), they are thus in danger of disappearing unless interventions (that emphasize stopping grazing activities to reduce pressure and anthropogenic stress) to manage them are in place.

**Impacts of anthropogenic activities to riparian forests ecosystem**

Human activities conducted within the riparian zone cause several adverse impacts to both plant species and the river ecosystem. For instance, inappropriate application of organic and inorganic fertilizers cause pollution and thus affect water quality. Table 3 highlights these effects as pointed out by respondents and evidenced by observation across the riparian forest zone of the study area.

**Table 3: Proportion of responses on the impacts of anthropogenic activities to the river and riparian vegetation (n=100)**

| Effect to the river | Responses (%) | Effect to riparian vegetation | Responses (%) |
|---|---|---|---|
| Accelerated sedimentation | 31 | Plant disappearance | 36 |
| Reduction in volume | 23 | Deforestation | 23 |
| Bank erosion | 20 | Unplanned burning | 22 |
| Water pollution | 18 | Morphological changes | 17 |
| Change in River stream | 08 | NA[1] | 02 |
| **Total** | **100** | | **100** |

[1]Not aware of riparian vegetation

***Source:*** Field data

As indicated in Table 3, there is a close increasing parallel relationship between the impacts occurring to riparian vegetation in reflection to the river stability. The percentage severity levels of the impacts assume the same magnitudes ranges for both riparian vegetation and the river. This illustrates the relationship between proper management, conservation of riparian forests and the sustainability of the river ecosystem. Having 2% out of all randomly interviewed respondents unaware of riparian vegetation and how they are impacted by human behaviour worsen the threats to riparian vegetation. For that matter, some people degraded vegetation by ignoring their potential to the river ecosystem and contribution to their livelihoods and well-being.

Those areas with abundant riparian vegetation had both stable banks and clean water compared to where they were cleared out. This was the indication of the potential role of these vegetation species to both water cleansing and stabilization of the riverbanks. Regardless of such observation, the only management option encountered on site was dredging. During rainy period, excavated sediments and mud returns to the river, leading to further sedimentation. Dredged sediments were retained from returning to the river only where there was vegetation on the sides of the river. The situation also revealed a need for natural solutions like enhancing riparian buffer to enhance natural carrying capacity of the river ecosystem.

**Discussion**

**Riparian forests and Hydrology**

The riparian forest zone of Ngerengere River is among the anthropogenically influenced ecosystems as found in other studies (Shagega *et al.,* 2018). Undefined and irregular pattern of riparian forest (GLOWS-FIU, 2016) worsens anthropogenic conducts within this zone along the river channel. Consequently, riparian forests keep on decreasing, by being cleared for domestic use and agricultural fields establishment. These are also cited drivers of their degradation across the world (National Research Council, 2005; Naiman *et al.,* 2005; Dufour *et al.,* 2019; Malan *et al.,* 2018; Naiman and Decamps, 1997). The findings of this study imply a remarkable interaction of riparian forests with the geomorphology, soil dynamics, hydrological and biotic features (Fig. 4) influencing spatial and temporal variation, as proposed by Naiman and Decamps (1997). All these account for inherent physical and morphological heterogeneity of the riparian vegetations across the globe with respect to time and space (National Research Council, 2005; Naiman *et al.,* 2005; de Sosa *et al.,* 2018). With exception of Ficus, riparian vegetation of the study area was different from that found in India (Amitha, 2003), while coinciding with those in other parts of Wami/Ruvu River Basin, Tanzania (GLOWS-FIU, 2016). The variation might be attributable to differences in soil and other hydro-geo-morphology of an area.

mainly agricultural production.

Riparian forests act as nutrient filters, sinks and transformers, acting to reduce nutrients loaded in the river stream (Chua *et al.,* 2019; Raphael and Lalika, 2020; Zalewski, 2003; Naiman and Decamps, 1997). Through filtration, they remove up to 15% of the non-soil-bound phosphorus. As a nutrient sink, they uptake about 88% and 76% nitrogen and phosphorous respectively from surface run-off flowing through them and groundwater moving across the roots (Chua *et al.,* 2019).

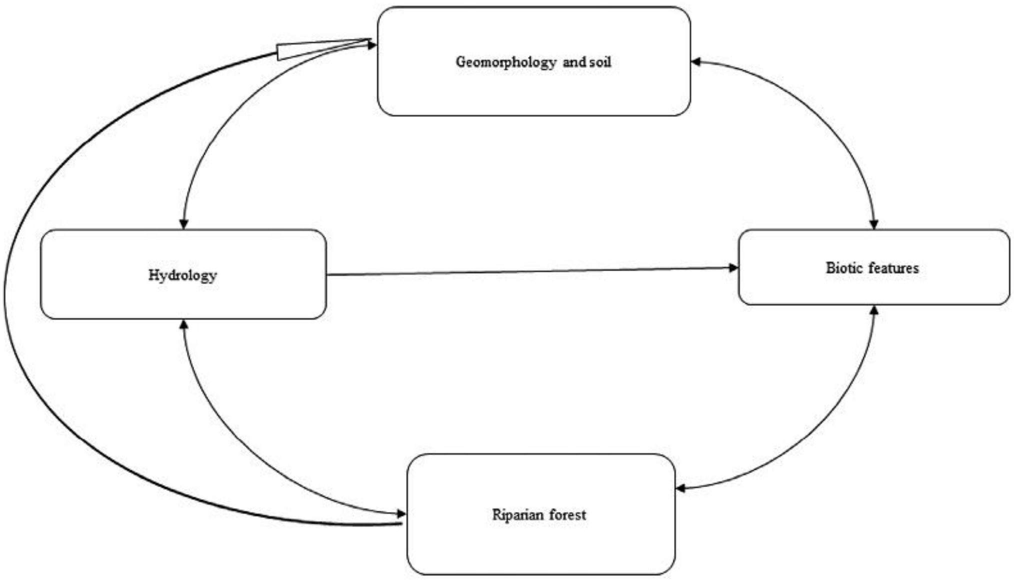


**Figure 4: The interaction between riparian forests and abiotic factors**
***Source:*** Amitha, 2003

Riparian forest plays key hydro-morphological roles to stabilize the river ecosystem, more specifically the riverbanks and flow regulation. Previous studies have acknowledged their significance in holding soil particles thereby controlling bank erosion, reducing incoming and in-stream storm velocity (Hultine, 2004). They are also important for water cleansing through retaining suspended particles and sediments, and enhancing in-stream biodiversity aquatic invertebrate sustenance.

Like other riparian ecosystems around the globe (National Research Council, 2002; Naiman *et al.,* 2005; Dufour *et al.,* 2019), riparian species along Ngerengere River are influenced by several anthropogenic activities. Due to high moisture content and fertility potentials (Dufour *et al.,* 2019), many riparian zones are subject to anthropogenic interactions

Due to good pasture, livestock grazing forms one of the common land use types in riparian ecosystems (Pinchak *et al.,* 1991; Jemison and Raish, 2000; Dufour and Rodriguez-Gonzalez, 2019). High abundance of elephant grasses and phragmites favour grazing activities (Jemison and Raish, 2000). Other activities that lead to degrading riparian forests and the river ecosystem include charcoal burning, sand mining and brick making (Dufour and Rodriguez-Gonzalez, 2019; Dufour *et al.,* 2015; Kondolf *et al.,* 2007; Brown *et al.,* 2018). The associated impacts include bank and riverbed erosion, deposition and sedimentation, reduction in river depth and water pollution, thus complementing to other studies (Naiman *et al.,* 2005: Brown *et al.,* 2018). Other reported significant drivers of influence include bioclimatic regimes (Bendix and Stella, 2013), morphological pattern (Corenblit *et al.,* 2015) and unlawful water abstraction (Dufour *et al.,* 2019). While bioclimatic factors alter the quantity and timing of water availability and post-floods disturbance relaxation times, morphological pattern creates a physical template for vegetation colonization, growth and drives disturbance regimes (Bendix and Stella, 2013; Corenblit *et al.,* 2015).

In appraising the role of riparian forests, a study on riparian vegetation's influence on Fitzroy basin's water quality revealed poor water quality in streams with poor riparian vegetation (Chua *et al.,* 2019; Dodds and Oakes, 2008). Polluted water with poor riparian vegetation, contrary to their counterpart across Ngerengere River, justified the essential hydrological role of riparian vegetation to water quality. Rivers and stream sites with low riparian vegetation abundance are thus more vulnerable to pollution due to agricultural land use (Dodds and Oakes, 2008). For that similar situation, degraded riparian sites and low-ordered streams in Queensland are considered priority sites for quick restoration and rehabilitation to maintain ecosystem structure, assemblage and enhancing ecological health (Pert *et al.,* 2010), while hydrologically anticipating downstream water quality and stream flow improvement (Chua *et al.,* 2019; Pert *et al.,* 2010).

Upholding the role of riparian plants and vegetation, several scientific investigations have called for enhancing natural forest ecosystems along waterways (Chua *et al.,* 2019; Zalewski, 2013). With the prevalence of riparian vegetation degradation mainly by anthropogenic influences in Ngerengere River catchment as in some other areas like Fitzroy (Chua *et al.,* 2019), it is of great recommendation that proper watershed management be integrated with conserving riparian zones to achieve sustainable freshwater ecosystems management using natural ecosystems, with riparian vegetations (forests) being the frontline.

**Nature-based solutions in the context of sustainable economic development**

Integrated governance and management of water resources through application of nature-based solutions and ecosystemic approaches contribute significantly to complying with SDGs by enhancing natural ecosystems, water resources management and water safety (UNESCO 2011; Vasseur *et al.,* 2017; Albert *et al.,* 2020; Dickens *et al.,* 2020). The application of nature-based solutions has a potential for delivering integrated ecosystem services, biodiversity net gain, promoting human health and well-being and empowering local people (Kabisch *et al.,* 2016). Simple techniques include enhancing native vegetation and ecosystem absorbing capacity to control soil erosion and reduce water runoff along road embankments and watershed restoration to improve water quality and availability (Vasseur *et al.,* 2017; WWF, 2020).

One potential element of natural riparian forests enhancement approach, as evidenced in the study area, appreciates over time (WWF, 2020). Vegetation grows denser, becoming resilient over time while supporting some other livelihood potentials compared to artificial structures which need a closer maintenance and replacement. Nature-based solutions can help reversing degradation while resolving some societal challenges such as climate change, food, and water insecurity and natural disasters (UNESCO 2011; Cohen-Shacham *et al.,* 2016; WWF, 2020). Consequently, the interventions used can also generate a range of benefits to nature and the economy by promoting natural capital.

**Conclusion**

Cultivation practices stand-out as the major driver of ecosystem degradation. Clearance and disturbance of riparian vegetation affect the hydrology and water resources by reducing the river flow, depth, and water quality. The threats of anthropogenic conducts were sedimentation and enhanced deposition-causing pollution to the river. These effects will become more severe due to ongoing riparian degradation following the high pace of population growth. The failure of existing management approaches calls for a natural riparian forest ecosystem enhancement measures (like enhancement of the buffer zone) to curb ongoing degradation by enhancing the carrying capacity and ability to withstand stress. Once the created buffer zone is stabilized, activities like gardening on the riverbanks become limited by the trees, causing them to cease, reducing degradation and pressure on the river. This counts for cost-effective approach that help in maintaining natural ecosystems diversity.

**Acknowledgments**

Authors are grateful to the UNESCO Chair on Ecohydrology and Transboundary Water Management of Sokoine University of Agriculture for supporting this study. They are also thankful to Fátima Noronha from the University of Algarve for her linguistic check on this paper. A significant role of the reviewers and editors is highly appreciated too.

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# Influence of Exogenous Variables on Interaction of Small Scale Farmers with other Actors in Agricultural Projects: a Case of RIPAT-SUA Project in Morogoro Region, Tanzania

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**Abstract**

*Exogenous variables have the potential to influence interactions but have received little attention in the literature. Guided by Ostrom's Institutional Analysis and Development (IAD) framework and social exchange theory (SET), the study described the patterns of farmers-other actors' interactions, and determined exogenous factors influencing interactions using RIPAT-SUA project as a case study. Quantitative and qualitative data were collected through questionnaire survey and Focus Group Discussion (FGD)/key informant interview respectively. Multiple regression and content analysis were used to analyse quantitative and qualitative data respectively. Farmers-other actors' interactions in agricultural projects increase with a decrease in distance from the market. Diversity of crops/livestock produced and the number of resources shared by actors had statistically significant influence on interactions. The RIPAT approach plays a crucial role in shaping the interactions; it influences the type of actors the farmers interact with and the pattern of interactions. The findings support the IAD and the SET, which, respectively, postulate that biophysical conditions (in this case proximity to market), and cost and rewards (in this case resources shared) are driving forces for farmers' interactions. Rather than referring to it just as cost and rewards as the SET does, it should be explicit that both material and social benefits are important in shaping interactions. The study recommends ensuring that agricultural interventions are rewarding to farmers. Designing and implementation of agricultural projects ought to employ the RIPAT approach to spur fruitful interactions.*

***Keywords***: Interactions, small-scale farmers, actors, RIPAT, projects

## Introduction

In Sub-Saharan Africa (SSA), small-scale farming is a key component for food security, economic development and sustainable livelihood. Among other things, agriculture has a great importance in the production of foods and income generation in SSA. Small scale farming is estimated to represent 80% of all smallholder farmers in SSA and serves as economic stability for small scale farmers' in the area (Freeman and Qin, 2020; Aref, 2011). Despite the importance of agriculture in a developing country, access to agricultural information, agricultural inputs/ resources and markets is limited in the rural areas where most of the agricultural activities are done (Abdul-rahaman and Abdulai, 2018; Mojo *et al.,* 2017). These challenges stimulated governments, development agencies and agro-inputs firms to form farmer groups to smoothen the flow of information, knowledge sharing, resources flow, and market information flow from one farmer to another.

Farmers involved in agricultural activities have different knowledge, production experience and agricultural information. Under this condition, farmers' interact to learn from one another. Interaction of farmers involves the exchange of resources and information, which probably influence farmers' decision to participate in agricultural projects or group activities (Duinen *et al.,* 2012). Famers rely on interaction with various actors (fellow farmers, buyers, agro-inputs firms, NGOs, agricultural professionals/researchers) for information pick up, resources sharing, and knowledge sharing (Warnet, 2015; Duinen *et al.,* 2012). This makes different projects implementing organizations like Research, Community, and Organizational Development Associates (RECODA) and Sokoine University of Agriculture (SUA), together implementing RIPAT-SUA project, to collaborate with local government authorities, different stakeholders and farmer groups which in turn increases interactions.

Rural Initiatives for Participatory Agricultural Transformation (RIPAT) approach uses farmer groups for training, transferring information, resources, and sharing market information (Vesterager *et al.,* 2013). Projects guided by the RIPAT approach collaborate with extension officers, local government authorities, farmers, buyers and village leaders, and this, in turn, increases the interaction among farmers and other actors. Therefore, the study considers interaction as one of the appropriate ways for farmers to access/share ideas, knowledge, resources and information from different actors.

Farmers' decisions, whether to participate in project activities or not, and actions, are motivated by their interactions with other actors[1], among others. Studies done in the farmer groups field indicate that farmers' social interaction had a positive effect on farmers' adoption of new technology and increase in farm productivity (Freeman and Qin 2020; Mojo *et al.,* 2017; Ayalew *et al.,* 2016; Warnet, 2015; Muanga and Schwarze, 2014; Mashavave *et al.,* 2013; Duinen *et al.,* 2012). Since interaction is important for participation in agricultural projects, and subsequently, the adoption of new technologies, a thorough exploration of farmers' interactions with other actors is imperative.

In Morogoro Municipal Council and Mvomero Districts, where the study was conducted, farmers interact with different actors and this differs by the specific location of the farmer. In this area, RIPAT-SUA project, which served as a case in this study, was being implemented. The RIPAT-SUA project was designed to cover villages located along the land catena of the Uluguru Mountains, including the lowland, midland and highland areas. Relevant questions here are, firstly, whether there is any difference in interaction across the slope and, secondly, what are the factors influencing farmers' interactions. Therefore, the paper attempted to: (i) examine the association between interactions and the farmer's location (ii) describe the patterns of interactions between farmers and other actors (iii) determine the influence of various factors, including types of information shared, resources shared, diversity of income-generating activities, diversity of crop/livestock produced, and distance to the market, on farmers' interactions. These factors have the potential to influence farmers' interactions but have received little attention in the farmer groups' literature.

Identification of the variables to be studied was guided by the Ostrom's Institutional Analysis and Development (IAD) framework and the theory of social exchange According to the IAD, action situation (space where individuals, groups, NGOs and institutions interact) influences farmer's decision to participate in groups / agricultural projects. The action situation[2], on the other hand, is influenced by external forces such as biophysical conditions (climatic condition, the status of road infrastructure, soil property, and slope) surrounding the actors (individuals or groups), characteristics of the community, interaction with actors from outside the community and institutions (including religious and educational institutions, policies, norms, and beliefs) (Ostrom, 2011). The social exchange theory proposes that actors possess different levels of information, power and motivation that influence their decision making and interaction (Thomas and Thigpen, 1993). The theory views human interaction and exchange a kind of result-driven social behaviour related to cost and rewards (SWDG, 2019). An individual farmer will make a decision based on a certain benefit found in agricultural project through interaction with different social actors (institution, researchers,

[1] *Actors refer to individuals, groups, NGOs or other organizations/ institutions. In this study an actor shares information and/ or resources with farmers.*

[2] *Action situation refers to social space where individual interact, exchange goods/services, and solve problems.*

buyers and agro-company) which offer different benefits (training, access to credit, market and agricultural inputs) to the farmers.

## Methodology

The study was conducted in Morogoro Municipal Council and Mvomero Districts, which were purposively selected because RIPAT-SUA project was being implemented in the area (Fig. 1). The project covers 7 villages (Mnyanza, Tangeni, Mlali, Kipera, Kinyenze, Pekomisegese, and Changarawe) from Mvomero District and 9 streets (Ruvuma, Kauzeni, Magadu, Konga, Mzinga, Mfine, Towero, Mundu and Kivaza) from Morogoro Municipal Council which together form a total of 22 farmer groups, each with 25-30 members (RIPAT-SUA Project, 2021). The community in the selected study area depends mainly on agriculture as a source of their income and means of livelihood (Malisa *et al.,* 2017).

RIPAT-SUA project is a SUA-RECODA[3] collaborative project, implemented in the lowland, midland and highland areas of the Uluguru Mountains within Morogoro Municipal Council and Mvomero Districts following the RIPAT approach. The project started in February, 2018 with eight farmer groups. RIPAT approach is a participatory extension approach that aims to close the agricultural technology gap (Vesterager *et al.,* 2013). According to Larsen and Lilleør (2016), the stated overall development goal of RIPAT is to reduce poverty and improve food security among smallholder farmers by facilitating high and sustainable levels of adoption of improved agricultural and livestock technologies disseminated through local farmer groups. Founded in

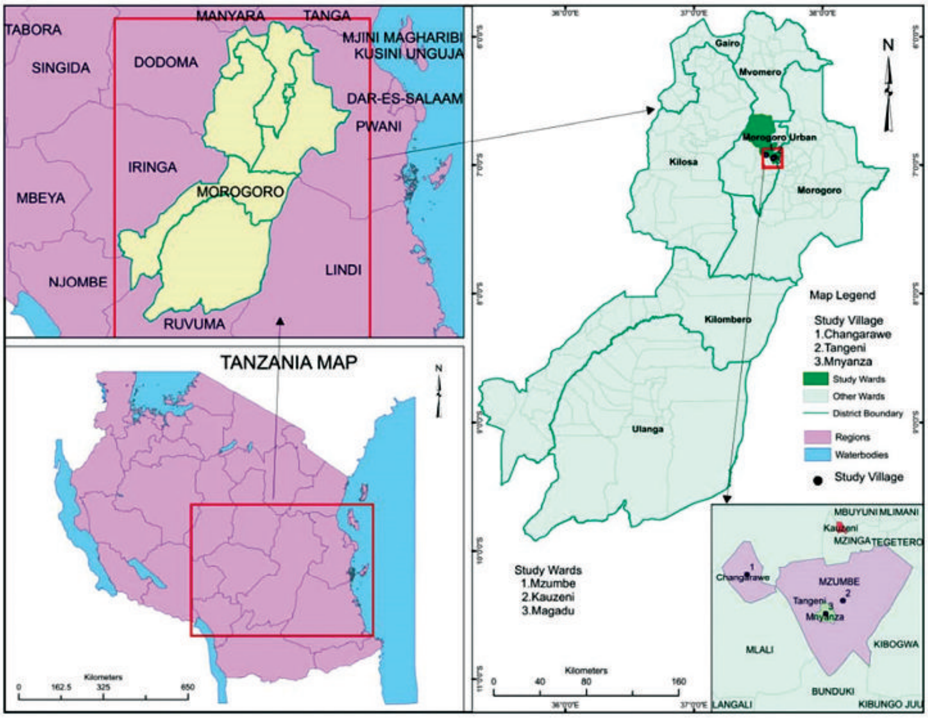


**Figure 1: Map of Morogoro Municipal Council and Mvomero Districts showing the study area**

[3] *SUA-Sokoine University of Agriculture-is a Tanzanian public University whose mission is to promote development in agriculture, natural resources and allied sectors through training, research and delivery of services. RECODA-Research, Community and Organizational Development Associates-is a Tanzanian NGO established in 2000 with the aim of bridging the technology gap in development through research, consultancy, capacity-building, and facilitation of community-based projects.*

2006 in a partnership between the Rockwool Foundation and RECODA, RIPAT approach is founded on three cornerstones, which are creation of a vision of better future through sensitization of communities to the potential for change and the mobilization of farmers to take charge of their own development; establishment of farmer/producer groups with good leadership to enable the transfer of appropriate agricultural technologies through participatory demonstration learning technique, and ultimately the establishment of producer association to leverage marketing skills and opportunities; and close collaboration with local government authorities, village leaders and government agricultural extension officers to ensure the project sustainability and further spreading to the wider community (Vesterager *et al.,* 2013). Farmer groups and associations, and collaborations that are part and parcel of the RIPAT approach, necessitate interaction of farmers with other actors. The study intended to explore the patterns and determinants of such interactions.

The study adopted both qualitative and quantitative approach for data collection. The study population consisted of all group members of the RIPAT "start" groups under the RIPAT-SUA project. The study focused on the RIPAT "start"[4] groups because farmers in the groups had already spent more than one year of membership in the group and had interacted with different actors within and outside their groups. Out of 22 farmer groups under the project, eight (8) groups were purposively selected based on their being the RIPAT-SUA "start" groups. The rest of the groups were formed during the RIPAT "spreading" phase and were less than one year old during the time of data collection for this study.

A list of farmer group members from the project's RIPAT "start" groups was obtained from the group leaders. Respondents were randomly selected from the list using "=Rand ()" command in Microsoft Excel to generate a random number from each group. In each group, the random numbers generated were arranged from the smallest to the largest number whereby the first 15 members (at least 50%) were selected making 120 respondents and questionnaire was administered to them. Focus Group Discussions

**Table 1: Description of the predictor variables**

| Variables | Measurement |
|---|---|
| Age of the farmer | Number of years since born |
| Sex of the farmer | 1= Male, 0= Female |
| Accessibility of the farmers' location (road condition) | 1 = road passable throughout the year and 0 = road not passable throughout the year |
| Institutions/organizations available | Number of the institutions available in the farmers' location measured as a continuous scale |
| Distance from the market | Time farmers used to walk from home to the nearest market measured at the scale level |
| Diversity of income-generating activities | Number of income-generating activities done by farmers measured at scale level |
| Diversity of crops/ livestock produced | Number of livestock species/crops varieties produced by farmers measured at the scale level |
| Number of resources shared by the actors | Number of resources supplied to the farmers measured at the scale level |
| Diversity of information access | Number of information sources farmers have access to, measured at the scale level |

[4]*RIPAT "start" phase involves formation of groups to participate in the RIPAT project from the start while RIPAT "spreading" involves expansion of the project area through formation of new farmer groups in villages adjacent to the RIPAT "start" groups' villages. RIPAT "spreading" is implemented one to two years after project start (Vesterager et al., 2013)*

(FGDs) were conducted using three groups from the RIPAT "start" phase making a total of 24 participants. Each of the FGDs comprised 8 participants with slightly more females than males. One group was selected from each of the three distinct altitudes of the land catena of the Uluguru Mountains where the project was being implemented.

Data were collected through questionnaire survey, FGD and Key Informant Interview (KII) in which project manager, project facilitator from RECODA and a lead farmer were interviewed. Using questionnaires, quantitative data were obtained from group members, while qualitative data were gathered through FGD and KII with the aid of FGD guide and checklist of questions respectively.

Data collected using questionnaire were coded and entered in IBM SPSS (version 20). To ensure the quality of data, data cleaning was done. Frequencies, percentages and mean were used to describe the patterns of interactions. Cross-tabulation was used to establish the association of the interaction and farmer's geographical location. A multiple regression model was used to estimate factors influencing interaction in agricultural projects. Before analysis, predictor variables were checked for multicollinearity and variables with less than 0.1 tolerance value and VIF of more than 10 were not included in the regression model (Daoud, 2017). The dependent variable, interaction of farmers with other actors, was captured as a continuous variable using a composite index whereby the number of information type shared, frequency of information flow and number of actors present in the farmers' location were combined. The equation is presented hereunder based on Healey (2013) and Field (2009) who asserted that multiple regression model with more than one predictor variables can be written as:

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_nX_n+\epsilon \quad (1)$$

Whereby Y=farmer's extent of interaction, captured as continuous variable, and $X_1$, $X_2$, $X_3$, $X_4$, $X_5$,...$X_n$ are predictor variables used in the model, whose description is indicated in Table 1.

## Results and Discussion

### Association between interaction and farmers' location

The RIPAT-SUA project was being implemented in the lowland, midland and highland areas which differ by institutions available, community attributes, biophysical conditions, and information flow. These variables were hypothesized to potentially influence farmers' interactions. Interaction of farmers in the agricultural project was measured by combining the number of actors, the number of information type shared and frequency of information flow to the farmers. Levels of interaction among the respondents were categorized into "low" (those scoring 13-27) and "high" (those scoring 28-44) using the mean score (Table 2).

The results show that there is a significant association between interaction and location of the group members at 10% significance level. The results show that majority (66.7%) of farmers located in the highland area, that is, Mnyanza village and Mgambazi Street had lower interaction level as compared to other villages (Tangeni and Changarawe villages). The main reason for the low interaction could

**Table 2: Farmers' interactions by location**

| Location of the farmer | Village/Ward | Sample size | Level of interaction | | $\chi^2$ | Sig |
|---|---|---|---|---|---|---|
| | | | Low (13-27) | High (28-44) | | |
| Highland | Mnyanza village & Mgambazi street | 45 | 30(66.7%) | 15(33.3%) | 5.253 | 0.072 |
| Midland | Tangeni village | 30 | 12(40.0%) | 18(60.0%) | | |
| Lowland | Changarawe village & Kauzeni street | 45 | 24(53.3%) | 21(46.7%) | | |
| **Total** | | **120** | **66(55.0%)** | **54(45.0%)** | | |

***Source:*** Field data (2019)

be the relatively low number of actors found in the area and poor road infrastructure restricting the movements of different actors to the area. The highest interaction (60%) was observed in the midland area while in the lowland area, the proportion of farmers belonging to high levels of interaction was 46.7%, which is a medium position when compared with the rest of the areas (Table 2).

A possible explanation for the highest interaction among farmers located at the midland (Tangeni village) is that the village possesses a market where farmers, especially those from Tangeni and Mnyanza villages, meet with buyers from Morogoro town and other areas at least twice a week to sell their crops and buy some items. At Tangeni market different actors, including farmers, buyers, input suppliers, domestic item dealers, transporters and tax collectors, meet and share miscellaneous information, including agriculture-related ones. The findings agree with those reported by Mutenje *et al.* (2016) which showed that market area is a centre for sharing information with different actors (inputs supplier, buyers, and other farmers). Besides, Tangeni village has a Roman Catholic Church which serves people not only from the village but also from the neighbouring villages. People meet at the church at least every Sunday.

In the lowland area, there was high number of institutions/organizations, including a University, schools, churches, and NGOs, but lower levels of interaction compared to the midland area, though relatively higher than that of the upland area. This is probably to do with the nature of the institutions present. It was observed that institutions which were more pronounced when it comes to causing interactions include the local markets and the Roman Catholic (RC) Church. In the study area, the RC Church and local market which bring together relatively more people are located at Tangeni village, which is in the midland area. In addition to providing an avenue for farmers to meet with diverse types of actors, the two institutions appear to be instrumental in facilitating the flow of diverse information types. Not only that but also people from the lowland area have been going to the crop market at Tangeni village to buy goods in bulk for retailing in the lowland area which in turn, increases the rate of information sharing in the midland area compared to the lowland area. A key informant from Tangeni village reported that: *"Tangeni market brings together people from all villages in Mzumbe ward, and some other wards and villages in Morogoro Municipal Council and Mvomero District respectively. In addition, some people come from as far as Dar es Salaam to sell or advertise their products at the market"* (27/2/2020, Tangeni village).

**Patterns of farmers-other actors' interactions**

Farmers' interactions are mainly about communication for information and resource sharing among farmers and between farmers and other actors in the action situation. Interaction patterns have been conceived of, and therefore, discussed in terms of: the actors involved, information/resources shared among actors, frequency of information/resources flow, the direction of information/resources flow, means of information/resources sharing and perceived strength of interactions as detailed below.

**Type and frequency of information/resources flow, and actors involved**

Farmers-other actors' interactions in the study area involved several actors. Actors with interest in agriculture, and relevant for the study's action situation, were identified by the FGD participants. They include Sustainable Agricultural Tanzania (SAT)-an NGO involved in promoting agro-ecological farming; *Mtandao wa Vikundi vya Wakulima Tanzania* (MVIWATA) meaning Network of Farmers' Groups in Tanzania, which is involved in facilitating farmers' networking; Institute for Fish Pen Production Kingolwira (IFPPK)-involved in promotion of fish farming; AKM Glitters-a company involved in chick supply; NMBU/SUA[5] a SUA and NMBU (Norwegian University of Life Sciences) collaborative

[5] *NMBU/SUA collaborative programme had phased out during the study period; however, the actor was still in the minds of the FGD participants especially because the demonstration plots supported by the actor were still around and SUA was still present though under different arrangement.*

**Table 3: Patterns of interaction: across actors' comparison**

| Interaction patterns | | Actors | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | RECODA/SUA | Extension oficers | Buyers | NMBU/SUA | SAT | MVIWATA | UNITA | IFPPK | AKM Glitters |
| Direction of information/ resources flow | From actors to the farmer | 101(78.3) | 14(10.8) | 2(1.6) | 4(3.1) | 8(6.2) | 0(0) | 0(0) | 0(0) | 0(0) |
| | From farmers to the actors | 0(0) | 2(40) | 1(20) | 1(20) | 1(20) | 0(0) | 0(0) | 0(0) | 0(0) |
| | Both ways | 19(29.7) | 21(32.8) | 16(25) | 1(1.6) | 3(4.7) | 1(1.6) | 1(1.6) | 1(1.6) | 1(1.6) |
| Frequency of information/ resources flow per year | | 47 (36.1) | 13(10) | 18(13.8) | 6(4.6) | 31(23.8) | 6(4.1) | 6(4.6) | 2(1.5) | 1(0.8) |
| Means of information sharing | Informal meetings | 29(70.7) | 7(17) | 3(7.3) | 0(0) | 1(2.4) | 0(0) | 0(0) | 0(0) | 1(2.4) |
| | Formal meetings | 44(75.9) | 10(17.2) | 0(0) | 0(0) | 4(6.9) | 0(0) | 0(0) | 0(0) | 0(0) |
| | Trainings | 47(87) | 1(1.9) | 0(0) | 0(0) | 6(11.1) | 0(0) | 0(0) | 0(0) | 0(0) |
| | Farmer to famer extension | 0(0) | 19(82.6) | 0(0) | 3((13) | 0(0) | 0(0) | 1(4.3) | 0(0) | 0(0) |
| | Farmers' study tour | 0(0) | 2(33.3) | 0(0) | 1(16.7) | 1(16.7) | 1(16.7) | 0(0) | 1(16.7) | 0(0) |
| | Exchange at the market | 0(0) | 0(0) | 10(100) | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) |
| Strength of interaction | Strong | 83(79.8) | 12(11.1) | 2(1.9) | 1(1.0) | 4(3.8) | 1(1.0) | 1(1.0) | 0(0) | 0(0) |
| | Moderate | 33(51.6) | 12(18.8) | 8(12.5) | 5(7.8) | 5(7.8) | 0(0) | 0(0) | 1(1.6) | 0(0) |
| | Weak | 4(14.8) | 15(55.6) | 4(14.8) | 0(0) | 3(11.1) | 0(0) | 0(0) | 0(0) | 1(3.7) |

***NB:** In brackets are percentages*
***Source:*** Field data (2019)

project known as Enhancing Pro-poor Innovation in Natural resources and Agricultural Value Chains (EPINAV) involved in natural resources management; UNITA-a Roman Catholic sister organization; and Research Community and Organizational Development Associates (RECODA) and Sokoine University of Agriculture (SUA), which are involved in research, consultancy and outreach activities (Table 3). SUA and RECODA have been treated as one actor because they were implementing a joint project namely RIPAT-SUA project in the study area.

All these actors have been sharing a diversity of agriculture-related information and/or resources with farmers. FGD findings showed that most of the information and resources were coming from RECODA/ SUA and were meant to facilitate farmers' engagement in agricultural activities. Supply of resources is usually accompanied by information on how to use them, which in turn increases the rate of information flow to the farmers. Resources shared, which include seeds, chicks, dairy goats, piglets, and farm equipment like *chaka* (Zambian) hoes, are necessary for farmers' participation in agriculture. Supply of the resources involved linking farmers with service providers or RECODA/SUA acquiring such resources and supplying them to farmers (RIPAT-SUA project, 2019).

As for the frequency of information sharing, the highest frequency of information/ resource flow (36.1%) was depicted by RECODA/SUA followed by SAT (23.8%) while the least was AKM Glitters (0.8) (Table 3). There were fewer cases of information sharing by extension officers (10%) when compared with RECODA/ SUA and SAT. This could be due to limited number of extension officers which makes it difficult to reach many farmers. Likewise, FGD findings revealed that most of the farmers located in the midland and highland areas have limited access to extension services, which in turn decreases the rate of information flow from either side.

Higher frequency of information sharing by RECODA/SUA can be explained by the adoption of the RIPAT approach in project implementation. The RIPAT approach uses lead farmers (LFs) in bridging agricultural technology gaps to small-scale farmers (Vesterager *et al.,* 2013). Lead farmers are individuals who, during the project implementation period, are identified as people who have developed social entrepreneurship as agents for change and are among the successful farmers from within the group (Vesterager *et al.,* 2013). The major role of the LFs is to facilitate adoption and diffusion of project interventions (Ringo *et al.,* 2020). According to RIPAT-SUA Project (2021), there are 31 LFs in the project area. Explaining his role as a LF, a key informant said: *"I train farmers; I facilitate formation of groups and conduct field follow ups. In my group, I advise on compliance with our principle that each group member has to train at least three non-group members and supply them with planting materials"* (28/2/2020, A LF from Tangeni village). From the quote, it is clear that the RIPAT approach leverages the flow of information and resources.

**Direction of information/resources flow**

Information and/or resources flowed mainly from other actors to the farmers (65.2%), followed by information flowing both ways (32.3%) and lastly information flow from farmers to other actors (2.5%). This trend implies that the existing farmers-other actors' interaction is characterised by farmers acting largely as information/resources recipients. Other actors-farmers information flow was most evident for RECODA/SUA-farmers interaction (84.2%) followed by SAT and NMBU/SUA, both of which scored 66.7% (Table 4). This is logical because the three actors have been involved in training farmers as well as in provision of resources which are necessary for the adoption of the newly introduced production technologies. Therefore, they acted as the source of information/resources for farmers. Farmers-other actors' information/resource flow pattern was non-existent for the actors, like AKM Glitters, IFPPK and UNITA, whose relationship with farmers involved farmers acting as buyers of the resources. For these actors, both ways information/resource flow pattern was the exclusive pattern.

Both ways information/resource flow pattern was most evident with extension officers

**Table 4: Patterns of interaction - individual actors' comparison**

| Interaction patterns | | Actors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RECODA/SUA | Extension oficers | Buyers | NMBU/SUA | SAT | MVIWATA | UNITA | IFPPK | AKM Glitters | Total |
| Direction of information/ resources flow | From actors to the farmer | 101(84.2) | 14(37.8) | 2(10.5) | 4(66.7) | 8(66.7) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 129(65.2) |
| | From farmers to the actors | 0(0.0) | 2(5.4) | 1(5.3) | 1(16.7) | 1(8.3) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 5(2.5) |
| | Both ways | 19(15.8) | 21(56.8) | 16(84.2) | 1(16.7) | 3(25) | 1(100) | 1(100) | 1(100) | 1(100) | 64(32.3) |
| Means of information sharing | Informal meetings | 29(24.2) | 7(17.9) | 3(23.1 | 0(0.0) | 1(8.3) | 0(0.0) | 0(0.0) | 0(0.0) | 1(100) | 41(20.7) |
| | Formal meetings | 44(36.7) | 10(25.6) | 0(0.0) | 0(0.0) | 4(33.3) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 58(29.3) |
| | Trainings | 47(39.2) | 1(2.6) | 0(0.0) | 0(0.0) | 6(50) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 54(27.3) |
| | Farmer to famer extension | 0(0.0) | 19(48.7) | 0(0.0) | 3(75) | 0(0.0) | 0(0.0) | 1(100) | 0(0.0) | 0(0.0) | 23(11.6) |
| | Farmers' study tour | 0(0.0) | 2(5.1) | 0(0.0) | 1(25) | 1(8.3) | 1(100) | 0(0.0) | 1(100) | 0(0.0) | 6(3.03) |
| | Exchange at the market | 0(0.0) | 0(0.0) | 10(76.9) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 10(5.05) |
| Strength of interaction | Strong | 83(69.2) | 12(30.8) | 2(14.3) | 1(16.7) | 4(33.3) | 1(100) | 1(100) | 0(0.0) | 0(0.0) | 104(52.5) |
| | Moderate | 33(27.5) | 12(30.8) | 8(57.1) | 5(83.3 | 5(41.7) | 0(0.0) | 0(0.0) | 1(100) | 0(0.0) | 64(32.3) |
| | Weak | 4(3.3) | 15(38.5) | 4(28.6) | 0(0.0) | 3(25) | 0(0.0) | 0(0.0) | 0(0.0) | 1(100) | 27(13) |

***NB:*** In brackets are percentages
***Source:*** Field data (2019)

(56.8%) followed by SAT (25%), NMBU/SUA (16.7%) and RECODA/SUA (15.8%) in case of extension service and agricultural training-related actors (Table 4). Results show that information flow from farmers to extension officers took place mainly through farmer-to-farmer extension (48.7%), which involves extension officer visiting a farmer on-farm for advice. With this channel, the farmer explains to the extension officer his/her agricultural problems based on which the extension officer advises. The arrangement necessarily calls for an exchange and hence both ways pattern of interaction. Similar findings were observed by Development for International Department (2003), which reported prevalence of two way communication between farmers and researchers, extension staff, veterinary staff and local administrators. Both ways information flow pattern was also highly evident for buyers (84.2%) (Table 4) and this can be explained by farmers-buyers relationship involving the farmer giving commodities to the farmer and the buyer giving money to the farmer in return.

**Means of information flow and strength of farmers-other actors' interactions**

Information flow channels, which existed in the study area, include formal meetings (29.3%), training (27.3%), informal meetings (20.7%), farmer-to-farmer extension (11.6%), exchange at the market (5%) and farmers' study tours (3%) (Table 4). Formal meetings were most applicable to RECODA/SUA (36.7%) followed by SAT (33.3%) (Table 4). The RIPAT approach, which RECODA/SUA embraces, requires that project implementing organization (RECODA/SUA) meets with farmers at least once every week during the first year of the project (Vesterager *et al.,* 2013). This forms the possible explanation for higher scores on formal meetings by RECODA/SUA. Another clue to the findings is implied in the following quote by RIPAT-SUA project facilitator: *"We share information through quarterly meetings with farmers, but also individual farmers are supposed to fill quality control forms which help us to understand progress and challenges which farmers are facing"* (11/03/2020, Changarawe village).

For training, SAT scored the highest (50%) followed by RECODA/SUA (39.2%). SAT has been visiting the area for specific training and therefore, when the actor is in the study area, often times the purpose is to conduct training. On the other hand, based on KII with RIPAT-SUA Project Manager, RECODA/SUA field officers are always (at least four days a week) in the area, not necessarily for training, but for follow-ups (farmer-to-farmer extension) or meetings. The exchange at the market was only applicable for the buyers (76.9%), this been their most important avenue for exchange; market place brings farmers and buyers together. The other channels used for farmers-buyers interaction pattern was informal meetings (23.1%) (Table 4). In practice, farmers and buyers conduct their exchanges through haphazard meetings; they meet at the market without prior agreement.

As for the strength of interactions, the respondents scored their interaction with most of the actors as strong (52.5%) followed by moderately strong (32.3%) and lastly, weak interaction (13.6%) (Table 4). Majority of the respondents (79.8%) indicated that there is a strong interaction with RECODA/SUA. This was followed by 11.1% who assigned their interaction with extension officers as strong, with SAT holding the third position (3.8) (Table 4). This implies that, RECODA/SUA was closer to the farmers in terms of conducting trainings, sharing information, and providing resources that are required for farmers' engagement in agricultural activities. From the following information from Changarawe village FGD participants, the findings are vindicated: RIPAT-SUA project facilitators make a follow-up on everything they teach us and provide necessary information on different crops and livestock we produce. Not only that, but also they come to visit us in case of any emergence on crops and livestock provided through solidarity chain arrangement. Lower scores for the strength of farmers-extension officers' interaction, when compared with RECODA/SUA could be due to few numbers of extension officers in the study area which makes it difficult for them to reach every farmer.

From the discussion above, it is clear that RECODA/SUA has scored the highest in terms

**Table 4: Patterns of interaction - individual actors' comparison**

| Interaction patterns | | Actors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **RECODA/SUA** | **Extension oficers** | **Buyers** | **NMBU/SUA** | **SAT** | **MVIWATA** | **UNITA** | **IFPPK** | **AKM Glitters** | **Total** |
| Direction of information/ resources flow | From actors to the farmer | 101(84.2) | 14(37.8) | 2(10.5) | 4(66.7) | 8(66.7) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 129(65.2) |
| | From farmers to the actors | 0(0.0) | 2(5.4) | 1(5.3) | 1(16.7) | 1(8.3) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 5(2.5) |
| | Both ways | 19(15.8) | 21(56.8) | 16(84.2) | 1(16.7) | 3(25) | 1(100) | 1(100) | 1(100) | 1(100) | 64(32.3) |
| Means of information sharing | Informal meetings | 29(24.2) | 7(17.9) | 3(23.1 | 0(0.0) | 1(8.3) | 0(0.0) | 0(0.0) | 0(0.0) | 1(100) | 41(20.7) |
| | Formal meetings | 44(36.7) | 10(25.6) | 0(0.0) | 0(0.0) | 4(33.3) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 58(29.3) |
| | Trainings | 47(39.2) | 1(2.6) | 0(0.0) | 0(0.0) | 6(50) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 54(27.3) |
| | Farmer to famer extension | 0(0.0) | 19(48.7) | 0(0.0) | 3(75) | 0(0.0) | 0(0.0) | 1(100) | 0(0.0) | 0(0.0) | 23(11.6) |
| | Farmers' study tour | 0(0.0) | 2(5.1) | 0(0.0) | 1(25) | 1(8.3) | 1(100) | 0(0.0) | 1(100) | 0(0.0) | 6(3.03) |
| | Exchange at the market | 0(0.0) | 0(0.0) | 10(76.9) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 0(0.0) | 10(5.05) |
| Strength of interaction | Strong | 83(69.2) | 12(30.8) | 2(14.3) | 1(16.7) | 4(33.3) | 1(100) | 1(100) | 0(0.0) | 0(0.0) | 104(52.5) |
| | Moderate | 33(27.5) | 12(30.8) | 8(57.1) | 5(83.3 | 5(41.7) | 0(0.0) | 0(0.0) | 1(100) | 0(0.0) | 64(32.3) |
| | Weak | 4(3.3) | 15(38.5) | 4(28.6) | 0(0.0) | 3(25) | 0(0.0) | 0(0.0) | 0(0.0) | 1(100) | 27(13) |

***NB:*** In brackets are percentages
***Source:*** Field data (2019)

**Table 5: Factors influencing farmers' interaction**

| Independent variables | Unstandardized coefficients | Standardized coefficients | | t | Sig. | Collinearity statistics | |
|---|---|---|---|---|---|---|---|
| | B | Std. error | Beta | | | Tolerance | VIF |
| Institution/organizations available | 0.069 | 0.135 | 0.076 | 0.511 | 0.611 | 0.273 | 3.665 |
| Diversity of income generation activities | 0.151 | 0.774 | 0.017 | 0.195 | 0.846 | 0.793 | 1.261 |
| Distance to the market | -0.018 | 0.008 | -0.187 | -2.222 | 0.028** | 0.843 | 1.187 |
| Diversity of crops/livestock produced | 0.620 | 0.264 | 0.227 | 2.347 | 0.021** | 0.638 | 1.566 |
| Road condition | 1.920 | 1.772 | 0.153 | 1.084 | 0.281 | 0.299 | 3.350 |
| Age of the farmer | -0.024 | 0.043 | -0.046 | -0.554 | 0.581 | 0.876 | 1.141 |
| Sex of the farmer | -0.449 | 1.096 | -0.035 | -0.410 | 0.683 | 0.797 | 1.255 |
| Number of resources shared by the actors | 1.796 | 0.284 | 0.525 | 6.319 | 0.000*** | 0.865 | 1.156 |
| Diversity of information access | -0.104 | 0.496 | -0.021 | -0.209 | 0.835 | 0.570 | 1.755 |
| (Constant) | 13.164 | 3.953 | | 3.330 | 0.001*** | | |

*Dependent variable: Interaction (Unstandardized R=+0.586, R2=0.343, Adjusted R2=+0.289)*
*N.B. ***, ** are levels of significance at 1%, 5% respectively*
***Source:*** Field data (2019)

of frequency of information and resources flow, other actors-farmers resource flow pattern, and perceived strength of farmers-other actor interaction. The respondents saw RECODA/SUA as the most instrumental actor in the provision of resources and information necessary for their engagement in agricultural activities. The findings corroborate the IAD's postulation that actors interact in light of the incentives they face to generate outcomes directly in the world (Ostrom, 2011).

**Factors influencing farmers' interaction**

Predictor variables included in the regression model were having R of 0.343 and adjusted R of 0.289 which means that predictor variables were able to explain the dependent variable in the model by 34.3% and the explanatory power was 28.9% for individual predictors included in the model respectively (Table 5). Multiple regression results (Table 5) show that the following variables have a statistically significant influence on farmers' interactions: distance to the market ($p=0.028$), diversity of crops/livestock produced ($p=0.021$), and the number of resources shared by the actors ($p=0.000$). Against expectations, institutions did not have statistically significant influence on farmers' interactions. This is probably due to the fact that, institutions which act also as organizations, such as the village government, the market, and religious and educational institutions, were considered as actors and therefore formed one of the three variables which were combined to generate interaction variable (dependent variable). The study villages are barely distinct in terms of policies, rules, norms and beliefs.

Distance to the market was negatively affecting farmers' interaction with fellow farmers and other actors at 5% significant level. This means that the interaction of farmers decreases with increase in distance from the market. The result implies that as the distance from farmer's home to the market increases, the chances that a farmer will attend to the market frequently decreases and therefore the likelihood of a decrease in information flow from different actors at the market. As indicated in Table 2, farmers located in the highland area had lower interaction levels than farmers located in the midland area, which is closer to Tangeni market. The findings are similar to the observations by Ayalew *et al.* (2016) and Mutenje *et al.* (2016) that farmers located away from social services (market and other institutions like finance institutions) are less likely to get information of new crops or agricultural inputs slowing their rate of adoption of agriculture technology. The market being closer is a location advantage for the farmers to interact and share information concerning crop price, required crops/crop products and the best season to produce a certain type of crops.

Distance from the market may also imply likelihood with which agricultural activities can be rewarding because it has to do with transport cost and overall post-harvest handling cost. The proximity of market infrastructures to the farmers' location can also be looked at from the biophysical conditions' perspective, which Ostrom (2011) identifies as an important factor influencing interactions. Thus, in line with the IAD and the social exchange theory, biophysical conditions, and cost and rewards are important driving forces for farmers' interactions.

Results show further that the diversity of crops/livestock produced; in this case, farmers involved in diversifying crops/livestock were significantly affecting farmers' interaction in agricultural projects. This implies that, a farmer producing a diversity of crops/livestock will also receive and/ or share diverse information according to the crops/livestock he/she produces and hence the likelihood of higher levels of interaction than those involved in single crops/livestock. Therefore, farmers with different types of crops/livestock meet with different actors (buyers, farmers, extension officers and NGOs) for different crops/livestock leading to more information sharing compared to a farmer with fewer types of crops/livestock.

As for resources shared, the findings show that the number of resources shared by the actors to the farmers was positively affecting farmers' interaction. Often, the supply of resources to farmers is accompanied with information such as why are the resources supplied, how to use them, and what are the expected results. Thus, it is logical to contend that the more the number of resources shared the more the likelihood of high interaction levels. Also, resource supply, from the point of view of agricultural projects, could involve the supply of agricultural inputs and/ or equipment to farmers. In this case, the more the number of resources supplied by agricultural projects the more likely it is that farmers will interact more with resource suppliers and with fellow farmers. For example, through the RIPAT-SUA project, farmer groups' members have accessed several resources, including day-old chicks from AKM Glitters Company, banana suckers from biotechnology laboratory in Arusha, iron bean seeds from Tanzania Agricultural Research Institute (TARI) Selian, orange-fleshed sweet potato (OFSP) vines from SUGECO[6] and cassava stem cuttings from TARI Kibaha (RIPAT-SUA project, 2019).

Acquisition of these resources involved the interaction of the farmers with at least six service providers. The FGD findings revealed that there was a surge of farmers' inclination to the production of OFSP, thanks to the availability of the crop's market at SUGECO. This sellers-buyer relationship, between farmers and SUGECO, was driven by the existing transactions between the two actors. Elaborating their motivation for participating in agricultural projects, the FGD participants from Mnyanza village reported that some of the famers participate in groups to work together in agricultural activities, not only that we interact with different stakeholders who supply to us resources necessary for agriculture production.

From the FGD findings, it is implied in the first case (farmers-SUGEGO interaction) that the driving force for the interaction was the anticipated material benefits. In the second case, however, participation is driven by expected social gains. Thus, the findings corroborate the social exchange theory which, according to SWDG (2019), views human interaction and exchange a kind of result-driven social behaviour related to cost and rewards. However, rather than just referring to it as cost and rewards, it should be explicit in the social exchange theory that both material and social benefits are important when it comes to motivating factors for actors' interactions.

[6] *SUGECO stands for Sokoine University Graduate Entrepreneurs Cooperative*

## Conclusions

Actors with the highest scores in terms of frequency of information and resources flow scored the highest in terms of other actors-farmers' resource flow pattern; they also scored the highest in terms of perceived strength of farmers-other actors' interaction. Thus, consistent with the IAD's postulation, actors interact in light of the incentives they face to generate outcomes directly in the world. The study concludes also that exogenous factors, including biophysical conditions such as proximity to the crop market infrastructures, cost and rewards such as resources brought by actors to the action situation, and diversity of resources sought based on diversity of crops or livestock produced, influence farmer's interaction. The RIPAT approach plays a crucial role in shaping farmers-other actors' interactions; it influences the type of actors the farmers interact with and the pattern of interactions. It is through interaction with various actors and biophysical conditions at farmer's disposal that a farmer accesses information and resources necessary for their production activities. Cost and rewards offer deterrents and incentives necessary for the farmers' interactions. The findings agree with the IAD and the social exchange theory, which, respectively, postulate that biophysical conditions, and cost and rewards are important driving forces for farmers' interactions. The findings suggest that, rather than referring to it just as cost and rewards as it is in the social exchange theory, it should be explicit that both material and social benefits are important when it comes to motivating factors for actors' interactions.

The study recommends that individuals, government and non-governmental organizations involved in the promotion of agriculture ensure that the interventions promoted are rewarding to the farmer, both in the short and long-term while considering exogenous factors for farmers' participation in agricultural projects. As exemplified by the RIPAT-SUA project, interactions that are rewarding are likely to result in participation of farmers in agricultural projects. This could be through ensuring the right information and resources are shared appropriately and at the right time, and that there are avenues for information sharing. Recommended avenues include village/ward level agricultural stakeholders' meetings, which could be conducted quarterly. These meetings bring together farmers, extension officers, NGOs, and technical and political leaders. Establishment of market infrastructures in strategic locations, where farmers could reach with their products and meet with buyers, is also recommended. Since the RIPAT approach plays a crucial role in shaping farmers-other actors' interactions in a way that ensures a win-win situation among the actors, employing the approach in designing and implementation of agricultural projects would very likely spur fruitful farmers-other actors' interactions. Lastly, it is recommended that further studies be conducted to establish empirically the effect of interactions on farmer's participation in agricultural projects.

## Acknowledgements

Authors are grateful to RIPAT-SUA Project Management and the local government authorities for Morogoro Municipal Council and Mvomero Districts for availing relevant literature and for administrative support. Sokoine University of Agriculture is thanked for granting researchers' clearance whereas study participants are acknowledged for their unconditional participation in the study. Thanks are also due to anonymous reviewers of this paper.

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# SME's Perception of Product Liability on Product Innovation of Pre-packed Food Products in Tanzania

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**Abstract**

*The Tanzanian food market is saturated with processed food. The study aimed at investigating the perception of product liability rules (i.e. manufacture, design, and failure to warn defects) on pre-packed food product innovation in Tanzania. A randomly selected sample size of 100 respondents was involved in the study. Data were analysed through Exploratory Factor Analysis. Four factors namely defective manufacturing, design defect, failure to warn and product liability costs emerged to be important. Thus, the three dimensions of product liability and one dimension of product innovation emerged from the data. In the end, the study concludes that the product liability-product innovation relationship is much stronger for design defects than the manufacturing and failure to warn (labelling) defects.*

***Keywords***: Pre-packed food, product innovation, product liability, manufacture defect, design defect, labelling defect (failure to warn)

## Introduction

Food is a necessary component of our daily life, we have to eat in order to survive. Food is defined under section 2 of the Standards Act, Cap 130 of 2009 as amended by the Finance Act, 2019 to mean any substance whether processes, semi-processed or raw that is intended for human consumption, and includes drinks, chewing gum and any substance that has been used in the manufacture, preparation or treatment of food. Respectively, pre-packed food is defined to mean processed food that is manufactured to extend its shelf life, packaged, and labeled ready for offer to the consumer for direct consumption.

Generally, it is accepted that always there has been some degree of trade-off between food we eat and various health problems that are inherent in them. Article 14 of the Constitution of the United Republic of Tanzania guarantees a right to life. Right to life has been defined to include right to a safe environment and right to health in the decisions of Festo Balegele & 794 Others v Dar es Salaam City Council, misc. civil cause No. 90 0f 1991, HCTZ at Dar es Salaam (unreported) together with Felix Joseph Mavika v Dar es Salaam City Commission, civil case No. 316 of 2000, HCTZ at Dar es Salaam (unreported). On the other hand, right to health and safe food products is protected through the tort system of product liability law. A manufacturer who produces food product that causes injuries to a consumer is liable for an action for damages in tort under the common law principles of negligence, strict liability, and absolute liability as established in the case of Donoghue v Stevenson [1982] AC 532.

Damage awards that arises out of product liability has a ripple effect on the financial and non-financial incentives of a firm that can impact product innovation. It is in the interest of pre-packed food manufacturers, therefore, to establish and administer controls that ensure their products do indeed meet consumer and societal expectations of safety and quality. This work investigated on the perception of product liability on product innovation by the small and medium enterprises that are engaging themselves in pre-packed food products in Tanzania. Specifically, the study aimed at examining the perception of SMEs on the influence of the various dimensions of product liability, i.e. manufacture, design, and labelling defect, on product innovation.

**The concept of product liability and product innovation**

Product liability refers to the responsibility of a manufacturer, distributor, supplier, retailer, and others who make products available to the market to compensate for injury caused by defective products that it has placed into the hands of the consumer. On the other hand, product innovation refers to the introduction of new or improved products. Simply put, product innovation involves changes in the products that are offered by a firm that implies an improvement in the firm's offerings. Product innovation includes an array of changes from break through discoveries to incremental improvements in manufacture, design, and labelling of the product.

Product innovation involves risks that are always associated by the changes of technology and introduction of new ideas. These imminent risks inherent in the product innovation process are what forms the core purpose of product liability law. Product liability law has been designed to compensate victims on the one hand and to motivate manufacturers of goods to manufacture safe products on the other hand. Product liability law is one of the ways through which our societies enforce consumer protection.

**Product liability law in Tanzania**

The Law Reform (Fatal Accidents and Miscellaneous Provisions) Act, Cap 310 R.E. 2019 provides an avenue for consumers to sue manufacturers and suppliers of defective products for damages resulting from sustaining personal injuries. The court in B.A. Minga v. Mwananchi Total Service Station, Shinyanga & Total (T) Limited, [1972] HCD n241, the Court reiterated its position that for the claim of the negligence to sustain, the plaintiff is supposed to establish that the respondent owed a duty of care, there was breach of the duty of care, and as a consequence of the breach the plaintiff suffered harm or loss to his person or property.
In Coca Cola Kwanza Limited v. Bilson Mbezibwa, civil appeal No. 33 of 1999, HCTZ at Dodoma (unreported), the High Court upheld the decision by the District Court that granted damages to the respondent who suffered injury as a consequence of drinking a soft drink that was manufactured by the appellant. It was held that the appellant did negligently manufacture the drink that was consumed by the respondent quoting with approval the decision in Donoghue v Stevenson by Lord Atkin, who observed that a manufacture of products who sells the products in a form that he wishes to reach the ultimate consumer in the form that left his premises without any reasonable possibility of intermediate examination, and without any knowledge that his failure to exercise reasonable care in the manufacture of the product would result into harm or loss to consumers life or property, owes a duty to consumer to take all reasonable care in the manufacture of the product.

Court decisions in the cases of Manager of Imara Guest House v Egnas Kaganda, [1980] TLR 40, and the case of Abdulahi Mohamed Isman (administrator of estate of Mariam Abdulahi Mohamed Isman) v KILEM Engineering Co. Ltd, Benitho Thadei Chengula, MEWA Consulting Engineering Co, and Ilala Municipal Council, civil case No. 92 of 2014, HCTZ at Dar es Salaam (unreported), and Wilfred Mkubwa v SBC Tanzania Limited, civil appeal No. 150 of 2018, CAT at Mbeya (unreported), stresses on the liability for failure to exercise duty of care towards your neighbours (negligence).

**Theoretical propositions of product liability law**

Product liability law has been developed with the general idea of promoting efficient levels of product safety with the ultimate end of consumer protection. Product liability was expected to result into spurring of product innovation as a remedy of increasing product safety and minimizing lawsuits. Proponents of the theory assumed that product safety and product innovation would thrive under the developed product liability laws, that, with the new developments manufacturers would search for the newest and best technology and raw materials to mitigate the product liability problems (Steering Committee on Product Liability and Innovation, 1994). However, this has not happened; on the contrary, product innovation has always been defeated, in many occasions, consumers are in a difficult situation as compared to the period before the beginning of the product liability revolution.

On the one hand, those who supports the current product liability regime asserts that product liability costs furnish incentives to manufacturers to produce safe products and discouraging unsafe products. Many consumers have praised the recent rapid growth of product liability court processes as an efficient mechanism for consumer protection. It is also claimed that product liability regime exposes information concerning hazards and discourages undesirable corporate social behavior including failure to disclose food contents. The law has shifted the liability from the buyer who was supposed to inspect and satisfy himself on the dangers that were imminent on products to the manufacturer who can subsequently be held accountable for unreasonably dangerous defects in a product.

Critics of the current liability regime insists that it is the well-being and safety of every consumer that is at stake. It is their argument that product liability costs decrease the potential of availability of products, escalate prices, depress innovation, and sabotage economic prosperity by stimulating product safety that fall short of the social costs. I tis urged that efforts by firms to limit their product liability or eliminate it altogether may result to serious losed to consumers for shortage of vital food products following withdrawal of some of food products from the market. Critics further contend that the high number of monetary awards awarded by the courts may impact firms' willingness to manufacture new and riskier technologies without regard to the fact that the said technologies might be superior compared to the previous products (e.g. Parchmovsky and Stein (2008)).

**SME's perception of product liability on product innovation in Tanzania**

Although number of papers addressing the relationship between product liability and product innovation continues to grow, currently there is lack of sufficient empirical evidence to determine the perception of product liability on product innovation by the SMEs engaging in pre-packed food products. The understanding of the perception of financial and non-financial implications of product liability on product innovation by SMEs engaging in pre-packed food production in Tanzania remains patchy. Robson *et al.* (2009) observed that there is a limited empirical evidence on the influence of product liability on product innovation especially in developing countries. Moreover, Nichter and Goldmark (2009) establishes that there is lack of enough empirical evidence about the link between product liability and product innovation by SMEs world over.

The study was conducted against this background. It follows therefore, that the subsequent study investigated and empirically examined perceptions of product liability on product innovation in Tanzania. The main purpose was to assess the effects of perceptions of liability arising out of product manufacture, design, and failure to warn defects on product innovation considering the variety of liabilities, their dynamic relationships, and their ambivalent impacts. The study focused on SMEs that are engaging in the production and processing of pre-packed food products in Tanzania because they are the manufacturers of most of pre-packed food products that are consumed in the Tanzanian food market.

**Methodology**

The general objective of the study was to examine perception of product liability on product innovation of Small and Medium Enterprises engaging in pre-packed food products in Tanzania. Specifically, the study intended to examine perception of defective manufacture on product innovation by SMEz, to examine perception of design defects on product innovation by SMEs, and to examine perception of warning defects on product innovation by SMEs.

Three hypothesis were developed from the reviewed literature and tested in this study, H1: manufacturing defects are perceived to undermine product innovation by SMEs engaging in pre-packed food products. H2: design defects are perceived to undermine product innovation by SMEs engaging in pre-packed food products. H3: Warning defects are perceived to undermine product innovation by SMEs engaging in pre-packed food products.

The study conceptualized that the dependent variables of product liability that are defective manufacture, defective design, and defective warning impacts product innovation intensity of SMEs. Product liability costs arising out of SMEs compliance with food and health laws and regulations, compensation to injured consumers, and damages awarded by the courts undermines the SMEs decisions to produce pre-packed food products thus a direct impact on the SMEs product innovation intensity.

The study involved a total of 100 SMEs in Morogoro. SMEs were randomly selected fro each fifth pre-packed food product that was found to be displayed in super markets and mini markets in Morogoro. Snow balling technique was also used to identify pre-packed food manufacturing SMEs whose products were not immediately found in the selected markets. Sampling adequacy of data was then performed to determine its relevancy in permitting EFA to be executed. To affect the same, sampling adequacy was measured through sphericity tests of Kaiser-Meyer-Olkin and the Bartlett's test. Adequacy of the data was confirmed to allow EFA to be conducted with the scores of KMO statistic=7.55; Approx. Chi-Square=2389.685; Degree of freedom=231; p=< 0.0001. According to Field, (2005), the KMO static close to 1 indicates an adequate sample while the Bartlett's test should be significant for factor analysis to be executed.

Defective manufacturing, design defect, failure to warn and product innovation are the four factors that were extracted from the data. Consequently, three dimensions of product liability and one dimension of product innovation were extracted from the data. The analysis shows that all factors had a midpoint scale mean value score of more than 4. The implication is that there is an increase of SMEs that are encountering pre-packed food product liability in their efforts to innovate pre-packed food products. The significance of mean values was checked through Analysis of Variance (ANOVA). Each of the four factors that are the defective manufacturing, defective designing, failure to warn and product innovation were subjected to ANOVA. The results depicted no any significant difference among the factors, this indicated a very good reliable measurement of the study constructs for analysis.

**Table 1: Average inter-item correlation**

| Factor | DM1 | DD1 | FW1 | PD1 |
|---|---|---|---|---|
| Defective manufacturing | **0.592** | | | |
| Defective design | 0.268 | **0.619** | | |
| Failure to warn | 0.183 | 0.199 | **0.670** | |
| Product innovation | 0.123 | 0.291 | 0.204 | **0.711** |

***Note:*** *Diagonal elements in bold represent the Average Variance Extracted (AVE)*

The relationship of the dependent variables that are the manufacture defect, design defect, and failure to warn defect shows that the regression line had the ability to account for the total variation of the variables. The total variance of the dependent variables was between 0 and 1 as symbolized by the significance value (R Square). The standardized coefficients of the variables in had a significance value ranging between 0.25 and 0.30 which means that 25 to 30 percent of the total variance in pre-packed food product liability has been explained to have a strong relationship.

Research hypotheses $H_1$, $H_2$, and $H_3$ were tested using regression analyses. The results are presented in the table below.

As presented in the above table, manufacturing defect positively predicts product innovation ($\beta$=0.451, t=7.111, p<0.001). $H_1$ is therefore supported. Design defect was found to positively predict product innovation of the firm ($\beta$=0.216, t=2.745, p=0.007). $H_2$ is, therefore supported. Although positive, the prediction of

**Table 2: ANOVA Table**

| | Under standardized Coefficients | | Standardized Coefficients | | | |
|---|---|---|---|---|---|---|
| **Type of liability** | **Model** | **B** | **Std. Error** | **Beta** | **t** | **Sig.** |
| *Manufacture Defect* | 1 (Constant) | 12.906 | 5.034 | | 2.564 | .012 |
| | DM1 | .157 | .147 | .107 | 1.068 | .288 |
| | DM2 | .226 | .214 | .114 | 1.052 | .295 |
| | DM3 | .942 | .287 | .343 | 3.280 | .001 |
| | DM4 | .882 | .422 | .208 | 2.090 | .039 |
| *Design Defect* | 1 (Constant) | 22.103 | 4.879 | | 4.530 | .000 |
| | DD1 | .491 | .224 | .340 | 2.195 | .031 |
| | DD2 | .251 | .217 | .151 | 1.153 | .252 |
| | DD3 | .006 | .321 | .002 | .018 | .986 |
| | DD4 | .121 | .468 | .031 | .259 | .796 |
| *Failure to Warn* | 1 (Constant) | 51.369 | 14.632 | | 3.511 | .008 |
| | FW1 | .602 | .347 | .459 | 1.737 | .121 |
| | FW2 | -2.619 | 1.201 | -1.332 | -2.182 | .061 |
| | FW3 | 1.588 | 1.618 | .476 | .982 | .355 |
| | FW4 | 2.531 | 1.216 | .756 | 2.082 | .071 |

*Dependent variables: Manufacture defect, design defect, and failure to warn*

failure to warn defect on product innovation was found to be insignificant (β=0.087, t=1.028, p=0.305). $H_3$ is, therefore, not supported. This means that labelling defects have a small impact on product innovation as comared to manufacturing and design defects.

## Results

Data analysis considered three distinct measures of the expected effects of product liability on product innovation: manufacturing defect, design defects, and failure to warn or labelling defects. The premium variables constitute more meaningful product liability measures of the product innovation intensity faced by firms. Efforts by firms in avoiding product liability through improving product safety and quality increases production costs thus making it difficult for SMEs to compete in the market. On the other hand, financial compensation resulting out of injuries caused by defective products adds to the load of costs that impacts SMEs innovation intensity.

Manufacture defect was found to positively predict product innovation of SMEs. Manufacture defect primarily focuses on defective products that deviates from the production line and the way the products are manufactured as compared to design defects that focus on the idealization and perfection of the product. The relationship between these two variables has been found to be nonlinear. The nonlinearity of this effect is exhibited by the coefficient on the squared product liability safety, quality, defects, and liability costs variables, that is negative and significant (at the

**Table 3: Results of regression analysis**

| | *Prediction* | *β* | *t* | *p* | *Hypothesis* |
|---|---|---|---|---|---|
| $H_1$ | Manufacturing defect → product innovation | 0.451 | 7.111 | 0.000* | $H_1$ is supported |
| $H_2$ | Design defect → product innovation | 0.216 | 2.75 | 0.007 | $H_2$ is supported |
| $H_3$ | Failure to warn defect → product innovation | 0.087 | 1.028 | 3.05 | $H_3$ Not supported |

*β* = standardized Beta coefficient, t = T statistic, p = probability, * = p value less than 0.001

0.5 confidence level) in three of the four cases at low risk levels. Thus, empirically, it is very clear that manufacture defects are perceived to undermine product innovation by SMEs engaging in pre-packed food products.

Design defect was also found to positively predict pre-packed product innovation of SMEs involved in the study. SMEs have incentives to invest in new or improved pre-packed food products at a very low level of design liability costs. This is the result of the design safety incentives in which the increase in design liability costs has a net effect on a decrease on innovation of pre-packed food products. Perception of the impacts of design liability on product innovation were found to be much stronger as compared to manufacture defect and failure to warn defect. As differentiated with manufacture liability, design liability of pre-packed food products is directly linked with the manufacture of the product. Innovation properties of a new or improved food product like the taste, aroma, texture, ingredients and raw materials to be used in the pre-packed food product are largely decided and controlled by the manufacture of the product.

The prediction of failure to warn defect on product innovation was found to be insignificant although it is positive. This means that SMEs perceives that consumers are not interested with labelling of the pre-packed food products and instructions that are contained in the labels such as the ingredients, chemical contents, preservatives, shelf life of the product, instructions on the use and the like. Most SMEs are thus not investing much of their funds in labelling of the products and provision of sufficient information to the consumers on the risks that are inherent in the products.

The empirical magnitude of product liability on product innovation can be depicted from the regression of product innovation and losses occasioned to consumers as analyzed in Table 2. A fall of product liability costs from their mean of 0.6 percent to zero would lead to a reduction of product innovation intensity of 0.19 that approximates to 12 percent of the innovation intensity of the SMEs. Practical effects of pre-packed food product liability are indicated by this linear extrapolation.

**Discussion**

SMEs are of overwhelming importance in Tanzania on several economic and social grounds. SMEs are the biggest source of employment in pre-packed food business in the country that provides food and livelihood to the country's workforce. Efforts to push the support of SMEs competitiveness and growth, moreover, is an avoidable option. The subsequent policy shift has been highly influenced by the 5th round governmental focus and initiatives on trade and investments that foresees a rapid growth of small-scale industries across the country. Much of these small-scale industries that are run by SMEs are thought to invest in pre-packed food business basing on the country's historical background of promoting agriculture as the backbone of the economy since its independence in 1964. A reorientation of the perception of SMEs of pre-packed food product liability and pre-packed food product innovation to underpin the ongoing social economic developments within the country to enable the development of SMEs and innovation of pre-packed food products is wanting.

Generally, SMEs involved in the study perceives that product liability undermines their product innovation process and is one among their growth challenges. They are concerned that the same liability rules that are applicable to large business establishments are applicable to them with the same legal force. They urge that large business establishments have financial muscles to address for product liability costs through various mechanisms such as insurance covers, outsourcing of some of their operations, price setting, and healthy financial budgets for settlements out of the court together with payment of compensations and damages award by the courts.

It is the perception of the SMEs that product liability costs arising out of compliances with food, health and environmental standards and compensations out of damages awarded by the courts positively affect their product innovation intensity. Local government authorities and regulatory authorities such as the Tanzania Bureau of Standards (TBS), Occupational Health and Safety Authority (OSHA), and responsible line Ministries are imposing extra costs on the SMEs in pre-packed food production for testing, certification, accreditation, and licensing of pre-packed food products. These costs add to the huddle of obstacles that impends the SMEs decisions to pre-packed food product innovation. This perception may reflect a product withdrawal effect on pre-packed food product innovation or a strong negative influence of the unfortunate effects of product liability on product innovation at elevated levels of product liability.

SMEs perceives pre-packed food product liability as a barrier that posits??? chilling effects on their product innovation process. The SMEs are afraid of introducing to the market new and improved pre-packed food products with different and improved composition of ingredients, taste, aroma, texture, and different uses as compared to the traditionally offered products. This withdrawal effect from the market option to a large extent affects the SMEs on the one hand, and to a larger extent, the consumers who are deprived from pre-packed food essentials of their daily life. In the final analysis, the pre-packed food product liability rules are perceived by the SMEs to retard the innovation process and undermine the consumer food product needs and wants at the same time.

Thus, pre-packed food product innovation intensity is likely to rapidly develop in the country if a policy and legal reform has to be put in place to balance the needs of the SMEs to develop their product innovation intensity alongside with the need to protect the safety of consumers.

Policy reforms has to consider our local business environment and the level of technology in handling a manufacturer liable for defective pre-packed food product. A strict adherence to the standards of pre-packed food product liability that are applicable in the developed world like the United States and the European Union are likely to retard our technological development, industrial revolution, and trade of essential pre-packed food products.

## Conclusion and Recomendations

The study had the general objective of obtaining empirical evidence of the perception of product liability on product innovation considering the case of SMEs that are engaging in the manufacture of pre-packed food in Tanzania. Specifically, the study aimed at gathering empirical evidence of the perception of SMEs on defective manufacture, design, and labelling or failure to warn on the dangers that are imminent in their products. Three research questions and hypothesis were formulated to that effect. The gathered evidence suggests that of all the three variables of product liability, i.e. manufacture, design, and failure to warn defects, liability arising out of the design defect negatively influences pre-packed food product innovation of SMEs. The study shows that liability costs incurred by the SMEs in respect design defects are much higher as compared to the liability costs arising out of the manufacture and failure to warn defects. This implies that, in one way or the other, the consumers of food products in Tanzania are not very much aware of the other grounds of manufacturer's liability on manufacture defects and failure to warn defects. The extent and the effect of product liability on product innovation is predicted to grow significantly as soon as the society will be aware of these other grounds of liability.

The evidence shows that product liability costs incurred by SMEs positively impacts product innovation of the SMEs. These SMEs have a potential of increasing their product innovation intensity in the event that their product liability burden is lowered. Thus, product intensity of the SMEs can substantially be increased by a reduction of the product liability costs. This calls for a realignment of the product liability laws and policies in our country so as to spur product innovation of pre-packed food products alongside the main objective of consumer protection. The relationship between product liability and product innovation is much powerful for design defects than the manufacturing and labelling defects. This relationship adds into the recent literature that points to the direction of hailing the expansion of the design defect liability as compared to the manufacture and warning defects. The theory has increased the role of the principles of product liability in the safeguard of the interest of consumers against defective products.

The researcher's analysis underpins the

contention that pre-packed food product liability deters pre-packed food product innovation by the SMEs. The pre-packed food product liability system and its developments impacts the speed and direction of innovation of pre-packed food products. This signals an indication that the pre-packed food product liability policies pose notable dynamic impacts on pre-packed food product innovation incentives that exceeds the short-term impacts and objectives of consumer protection and others. Thus, it is crucial to recognize and estimate the effects of pre-packed food product liability on pre-packed food product innovation in evaluating the costs and benefits of product liability policy reforms and their impacts to SMEs.

There are several limitations to this study although it makes notable empirical contribution to the current literature on the empirical evidence of SMEs perception of pre-packed food product liability on pre-packed food product innovation. The study was conducted in Morogoro only, that is a single region within Tanzania. The researcher recommends for more similar studies to be conducted in other regions within the country and other developing countries so as to map the extent and direction of the impacts of product liability on product innovation. Although the results mesmerize on the theory that product liability predicts product innovation of SMEs, yet, the results have not focused into the factors that impacts the adoption of product liability concept in pre-packed food value chains. It is further suggested that future studies should also focus on the factors that influence the adoption of product liability at the level of the SMEs. An understanding of these influencing factors will enable to inform the direction of policy and legal reforms that will balance the interests of SMEs to innovate and develop on the one hand and consumer protection through food safety on the other.

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# Intra-Household Decision Making on Production and Income Generation Options among Women in Mara Region, Tanzania

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**Abstract**

*Women's ability to make decisions on production matters and income generation in the household is crucial to reduce gender based violence, improve women's production ability, improve livelihood of household members and reduce poverty among women and a country in general. The study examined the contribution of Cassava Adding Value for Africa II project towards empowering women cassava producers to make decisions on production matters and income generated from cassava crops. The study was conducted in Rorya, Bunda and Serengeti Districts in Mara Region where the project was implemented. The study employed census method whereby data were collected from all the three project Districts and wards. A total of 246 women participants and those who did not participate were randomly selected. The proportion of 50% was applied to select the participants from the sampling frames of women who participated in the project and those who did not. A questionnaire was used to collect quantitative data and Focus Group Discussion and Semi-structured interviews were used to collect qualitative data. Quantitative data collected using questionnaires were used to compute levels of women empowerment. Furthermore, chi-square tests were run to reveal if there were any associations between socio-economic characteristics and level of women empowerment. The results showed that women who participated in the cassava value chain intervention project were categorized into high level of women empowerment compared to women who did not, and who were categorized into low level of women empowerment. These findings suggest that agricultural training provided by CAVA II project exposed women to new, updated and improved methods of cultivating cassava. The findings show further that women with five or more acres of cultivating cassava were categorized into high level because they possessed more acres, plus the training received from the project which resulted into high cassava yields. The findings also show that age had an association with the level of women empowerments whereby women between the ages of 35 and 55 were classified as having a high level of women empowerment, which was linked to their age. This shows that in patriarchal society, women of this age, whether married or not, were considered mature enough to make judgments. In comparison, women and girls between the ages of 15 and 34 were not allowed to make decisions in the home that affected productivity and income. The other significant association revealed by the study was between farm and wage labor activities and level of women empowerment. The findings show that women who were farmers and employed were categorized into high level of women empowerment as compared to women who were only livestock keepers. It is therefore can be concluded that interventions which target women in agricultural production can increase their empowerment status hence influence their decision making in production and use of resources required from production activities. It is therefore recommend that Government and Development partners programmes should design and implement project which will enhance women empowerment and which in turn will increase their participation in decision making at the household levels. This will lead to improved livelihood and reduction of poverty in farming communities in Tanzania.*

***Keywords***: Women empowerment, intra-household decisions, production, income, options

## Introduction

Empowerment has been defined as the continuous process that alter individual's lives through increasing critical consciousness, with a focus on the capability to choose, through both individual and collective actions. Intellectuals such as (Cornwall, 2016; Batliwala, 2010; Kabeer, 1999; and Rowlands, 1995;) established that empowerment is not something that can be done to or for anyone else but relatively, is an expansion of women's consciousness and capacity to act, both individually and collectively to transform lives. Empowerment is not equivalent to having unlimited options and unrestricted freedom to choose whatever one wants. As argued by Kabeer (1999) that choices can be done through three interrelated dimensions: agency, as the process by which choices are made and individuals' sense of self-worth; resources, the medium through which agency is exercised and achievements, the outcomes of the agency.

Similarly, women empowerment is viewed as the ability of women to make individual and joint decisions within the household (Johnson *et al.,* 2016; 2017). However, bargaining power within a household is the crucial indicator of women empowerment and its outcome on the welfare of the entire family (Padmaja *et al.,* 2018). Moreover, Jeckoniah *et al.* (2012) argued that the imperative attribute of women empowerment is the position where they are able to make decision and have influence within the household and their decisions are respected at household level and community in general.

Intra-household decision making can be well understood as negotiation among family members on how to allocate financial resources within the same household (Sultana *et al.,* 2013). In the same line, Diego and Quentin (2010) argued that decision making and resources allocations within the household are imperative for economic and human development. That is, such decisions have huge impact on the welfare of individuals at the household level and at the community level in general. Sultana *et al.* (2013) argued that, women's preferences and responsibilities for making decisions within the household do influence economic outcomes. Also, Njuki *et al.* (2016) claimed that women decision making and the increase of their bargaining power within the household depends largely on women's control over income from agricultural activities particularly the intra-household allocation of income between men and women, and the ability to make decisions about purchases.

Moreover, Seebes (2011) argued that gender inequality within the household has effects on the women welfare. She pointed out that if women will have low bargaining power, low access to resources and household income, then it is more likely that they will have low bargaining power outside their homes such as accepting low wages at work places. In line with this, Akhtar *et al.* (2018) in Pakistan revealed that major decisions on family wellbeing, cropping pattern and marketing of produce are made by men. The same was argued by Shibata *et al.* (2020) that the decision within the household about the adoption of new agriculture innovation is mainly done by men without asking permission from their wives. However, their wives must seek permission from their husbands when introducing new innovations which is due to the fact that husbands are bosses and the wives are subordinates since new innovations require financial resources to buy seeds, materials and pay casual labour, which in most cases are provided by men. In addition, it was also revealed that decisions on innovation output like how to spend income from innovation is entirely done by men.

Furthermore, as revealed by (Sultana *et al.* 2013; Kabir and Jahana 2013), education and employment levels, income and other socio-economic factors do hinder women's participation in decision making in the household. That is, the authors argued that land ownership, occupation pattern and involvement of women in cooperative and Non-Governmental Organisations (NGO) which educate them on their rights, self-awareness and decision making have positive influence on women's ability to participate in decision making within the household. However, the authors emphasized that there are other entrenched factors that deeply affects women's ability to participate in decision making like traditional, beliefs, attitude and practices.

In addition, as argued by Malghan *et al.* (2017), intra-household inequality is not well researched by the current inequalities discourses. There are also few researches on a study of the household as a social unit where inequalities are taking place. Besides, as argued by Laven *et al.* (2009) value chain intervention on gender and empowerment do have positive changes for women on issues like access to capital, training and extension and decision making in the production process in the household. However, the author did not establish whether women empowerment through value chain approach have any impact to women farmers in making decisions around production matters and income generated within the household level. This study therefore tries to fill knowledge gap by examining the contribution of the Cassava Adding Value for Africa. (CAVA) II project which opted the value chain approach to implement its activities in Mara Region. These strategies were implemented to empower women smallholder famers to make decision around production activities and the use and control of income generated from cassava production in their household.

## Materials and Methods

### Description of the Study Area

The study was conducted in Mara Region using the case study of the Cassava Adding Value for Africa (CAVA) II project. Mara region is located in the Northern part of Tanzania Mainland. The region is located between Latitudes 1°0´ and 2°31´ and Longitude 33° 10´ and 35°15´. It contains 3 010 150 square kilometres in total whereby, 10 584 square kilometres of such being water area. There are six administrative districts within the region: Musoma Urban, Musoma Rural, Tarime, Rorya, Serengeti and Bunda URT (2012).

Mara Region has a total of 128 383 households which is equivalent to 83.8% of root and tubers crop growers in Mara region (ibid). Cassava being the leading crop grown in Mara region the CAVA II project decided to implement some interventions to increase its production. The project aimed at boosting the economy of cassava farmers particularly women and the vulnerable groups. Out of the six districts, the CAVA II project was implemented in three of them: Rorya, Bunda and Serengeti. The economy of these districts is mainly dependent on three sectors namely agriculture, livestock keeping and fishing. These sectors employ more than 81% of the total adult residents. These districts were selected because it was CAVA II project implementation area.

### Research Design and Sampling Frame

#### Research design

The study employed a cross-sectional design which allowed data to be collected at one point in time. This technique was useful for a descriptive study as well as for determination of relationship between variables (Kothari, 2004). This design was also useful as it allowed data to be collected using tools like questionnaire for collecting quantitative data and focus group discussions and semi-structured interview for collecting qualitative data. In addition, the method allowed the collection of data from a large number of respondents within a short period of time (Creswell, 2014).

#### Study population and sampling frame

The study population for this study was women who participated and those who did not in CAVA II project. To make it possible to identify the different elements in the target population the sampling frame were the villages from the three Districts where the project was implemented and three non-project wards as shown on table 1.

#### Sampling technique and sample size

The study employed census method because data were collected from all the three Districts and wards where the project was implemented. Census method is a situation when all items are covered, no element of chance is left and highest accuracy is obtained (Kothari, 2004). This sampling technique allowed complete enumeration of all people in the population.

The census method allowed the researcher to select all three Districts namely: Rorya, Bunda and Serengeti Districts in which the CAVA II project was implemented. Furthermore, from each District, the researcher selected all the wards in which the CAVA II project specifically was implemented. These included Ikoma in

**Table 1: CAVA II project implemented areas and proposed control areas**

| **Project implemented areas** | | |
|---|---|---|
| **District Council** | **Wards** | **Villages** |
| Rorya | Ikoma | Nyamasanda |
| Bunda | Guta | Guta |
| | Sazira | Misisi |
| | Nyamang'uta | Kaloleni |
| Serengeti | Manchira | Bwitenge |
| | Morotanga | Morotonga |
| **Non-project areas** | | |
| Rorya | Katare | Ikoma |
| | Kisorya | Gobire |
| Bunda | Nyamansura | Nyasura |
| | Isenye | Mcharo |
| Serengeti | Runga'abure | Nyamirama |
| | Isenye | Isenye |

Rorya District; Guta, Sazira and Nyamang'uta in Bunda District; and Manchira and Morotanga in Serengeti District. From these Districts all women who participated in the project were interviewed. The proportionate of 50% was applied to select the participants from the sampling frames of women who participated and those who did not participate in the project. Therefore, a total of 246 respondents were randomly selected from the sampling frame of all women who participated and those who did not participate in the CAVA II project in the study area.

A sample determination formula by Kothari (2004) was used to arrive at the sample size for this study as presented in Equation 1.

$$n = \frac{z^2 \times p \times q}{e^2} = \frac{1.575 \times (0.01) \times (1-0.01)}{0.01} = \frac{0.0246}{0.0001} = 246 \ldots(1)$$

Where: n=sample size of women farmers, $z^2$=Desired confidence level, p=0.01 (Sample

**Table 2: Number of women participants and non-participants in each study village**

| **Project implemented areas** | | | |
|---|---|---|---|
| **District Council** | **Wards** | **Villages** | **Number of women** |
| Rorya | Ikoma | Nyamasanda | 20 |
| Bunda | Guta | Guta | 20 |
| | Sazira | Misisi | 23 |
| | Nyamang'uta | Kaloleni | 20 |
| Serengeti | Manchira | Bwitenge | 20 |
| | Morotanga | Morotonga | 20 |
| **Non-project areas** | | | |
| Rorya | Katare | Ikoma | 20 |
| | Kisorya | Gobire | 20 |
| Bunda | Nyamansura | Nyasura | 20 |
| | Isenye | Mcharo | 20 |
| Serengeti | Runga'abure | Nyamirama | 23 |
| | Isenye | Isenye | 20 |

proportion), q=Precision rate or accepted error and e= level of precision.

**Data Collection**

Data were collected from April to June 2020 for both qualitative and quantitative ones. Quantitative data were collected using a questionnaire which was composed of closed-ended questions. The sampling unit was an individual woman who participated in the CAVA II project and those who did not. The aim was to get data which will provide sufficient information on the contribution of CAVA II project on intra-household decision making power on production activities and income generation between women participants and non-participants.

Qualitative data were collected using focus group discussions (FGD). A total of three FGD's were conducted and each FGD composed of six women who only participated in the project. The FGDs covered issues like how women were making independent financial decisions before and after CAVA II project implementation, the extent of women empowerment on the use of income from cassava production after CAVA II project implementation, and the impact of the project on increasing cassava production.

**Data Analysis**

Quantitative were used to compute the levels of women empowerment scores. The scores were then derived from the women's empowerment index. The scores were further categorized into low (0.0–0.5), medium (0.6–0.7), and high (0.8–1). This categorization was in line with the guidance of the United Nations Development Programme (UNDP) Human Development Index (HDI) (UNDP, 2018: 123: Alkire and Santos, 2010: 19) whereby the HDI scores also lies between the value of zero and one. Furthermore, Chi-square test was run to reveal if there were associations between socio-economic characteristics and level of women empowerment.

In addition, Content Analysis (CA) was done for qualitative data. The exercise of familiarization and organization of the data were followed by transcription. The process of developing themes was done repeatedly for each transcription then the researcher merged these sets together while reviewing the identified categories and themes. When discussing the results these findings were compared with information extrapolated from quantitative methods.

**Results and Discussion**

**Levels of Women Empowerment**

The study assessed the levels of women empowerment in the project area and the results as presented in Table 3 show that there is a difference in the levels of women empowerment in intra-household decision making power on production activities and income generated between women who participated in CAVA II project and those who did not. The results revealed that women who participated in the project were classified as high level of empowerment compared to their counterparts. The noted differences might have been attributed by the effects of CAVA II project intervention activities in cassava value chain development which in turn influence women empowerment.

**Table 3: Extent of women empowerment in intra-household decision between CAVA II project participants and non-participants (n = 246)**

| Variable level of empowerment | Participants % | Non-participants % |
|---|---|---|
| Low | 16.9 | 83.1 |
| Medium | 48.6 | 51.4 |
| High | 67.4 | 32.6 |
| **Total** | **100** | **100** |

In addition, women who participated in the project reported that they were empowered to make independent decisions on production matters because of the improved methods of cultivating cassava which were introduced by CAVA II project. One of the improved methods of cultivating cassava introduced by CAVA II project was proper land preparations. That is before the project, women were partially clearing the farm. However after the project women were taught to clear all the bushes and removing all the stumps using hand hoes, rakes and tractors as part of proper land preparations activities. In addition, when preparing the terraces women were taught to observe measurements of one centimetre from one terrace to the other and apply manure at the same time. Also, when planting cassava sticks, one stick should be one centimetre away from the other stick. These methods increased cassava yields and allowed women to have enough yields for commercial and food purposes. The income generated from selling cassava was used to buy or rent farms. The land bought or rent by women themselves allowed them to make independent decisions on what type of crops to plant and area under production. During FGD one woman said that:

*"I couldn't produce as much as I am now, because my husband was the one controlling the land usage. However, after I cultivated cassava in my own plot I was able to sell them and buy land and rent some. Now as I can buy or rent farms, I can make decisions on what crop to cultivate apart from cassava. For instance last season I was able to cultivate cassava, maize, cotton and sweet potato in different plots"* (Women FGD 23/04/2020 in Guta village).

Furthermore, during FGD another woman said that:

*"It is not easy to conduct any production activity if you are not financially independent. This is because our husbands were the ones providing us with resources like land then it was them making all decisions concerning production matters".* (Women FGD on 15/06/2020 in Miseke village).

The same finding was reported by Fletschner and Kenny (2011) that interventions that enhance women's direct access to and control financial resources were imperative as they improved women's positions against their husbands, strengthening their role as decision-makers, deciding which crop to grow and enhancing their ability to influence how their households allocate resources. Additionally, this finding was as well supported by the finding of George and Themachan (2018) who argued that if women have savings, they can make their decisions and the result is to be economically empowered. Furthermore, Jeckoniah et al. (2012) reported that to women, the important indicator that they are empowered was for them to be in a position to participate in the household decision and to have influence at the household and community in general.

On the other hand, women reported to be empowered to make decisions on which inputs to be used during production. This may be due to the fact that the trainings from the project enlighten them on improved inputs like improved cassava sticks for plantation and use of fertilizers. Additionally, as women were generating income, they were able to purchase improved inputs like fertilizers. During FGD women agreed that agricultural trainings have allowed them to be aware of the improved inputs to be used when cultivating cassava. The improved inputs have increased the yields and the increased yields allowed them to sell and get enough income to buy more improved inputs.

However, these findings were contradicting those of Msamha *et al.* (2017) who argued that at the household level women in Kigoma who participated in cassava value chain were not empowered in making decisions on the inputs to use in production activities.

Generally, during focus group discussions women agreed that:

*"Before the project they were not able to decide on any production matter because they were not financially independent. Their husbands were the ones making decisions as they were resources providers. However, CAVA II project provided them with improved methods of cultivating cassava such that the yields increased enough for home consumption and for business purposes. The income generated from selling cassava gave them freedom to make decisions on production matters"* (Women FGD 23/04/2020 in Guta village).

Additionally, women revealed that if the Government of Tanzania (GoT) wants to eliminate all kinds of gender based violence and reduce poverty among poor and uneducated women and girls in rural areas, then women should be empowered to have independent sources of income. The independent sources of income will empower them to make independent financial decisions. Furthermore, it was reported that women who participated in the project experienced increased cassava yield due to the training on improved methods of cultivating cassava they received. The increased yields were enough for consumption and sale. The income accrued from selling cassava yields allowed them to have independent source of income and thereafter empowered them to make decisions on how the income should be utilized. These findings concur those of Masamha et al. (2017 and Jeckoniah *et al.* (2015) who claim that the income of women in Tanzania increased as the results of participating in the cassava and onion value chain interventions.

The findings also show that women who participated in the project experienced having more income than those who did not. This allows them to provide their family with basic needs. This is due to the fact that the income gained from the production supported by the project has empowered them to make decisions in their households. During FDG women agreed that:

*"For women to make independent financial decision in the household was very hard since they did not have independent source of income. Therefore, the training on improved methods has led to the increased cassava yields far enough for home consumption and for business purposes. The incomes generated from selling cassava allow them to make independent financial decisions"* (Women FGD on 23/04/2020 in Guta village).

Furthermore, women during FGD agreed that:

*"The increased income enabled them to provide basic needs to their families and hence involved in financial decisions at the household and community level.* (Women FGD on 15/05/2020 in Nyamasanda village).

These findings concur with those of Roy *et al.* (2017) who claim that the ability of women to make decisions in the household depends on the contribution of women in the family income.

These findings imply that financial independence is an important indicator of women empowerment. This is because financial independence allows women to make independent choices and decisions on different production matters. Similar findings were reported by Fletschner and Kenny (2011) that interventions that enhance women's direct access to and control over financial resources are imperative as they will improve women's position against their husbands, strengthening their role as decision-makers, decide on production matters and enhancing their ability to influence how their households allocate resources. The same findings were reported by Fisher and Carr (2015) that women who are constrained by lack of financial resources for purchasing inputs like fertilizer and others cannot influence their households in arming decision processes. Also, these findings denote that agricultural trainings are very crucial as they equip women smallholder farmers with new and updated agricultural practices. These findings are in line with those of Tambi (2019) who argues that farm training is equipping farmers with different methods and techniques of agricultural production. These trainings create awareness, expertise, introduce new techniques of production, effective use of inputs, better management of cropping system and thus increased agricultural production.

Furthermore, this study suggested that women's authority to make independent financial decisions is an important indicator that rural women farmers were empowered. The authority is gained when they are engaged in income generating activities that allow them to generate independent income; this income allows women to provide their families with basic needs like food, cloth and shelter. This in turn allows family members to respect women's decisions on financial matters. Including the decisions on how the remaining money should be used for the wellbeing of members of the family. These findings do conform with those of Bernasek and Bajtelsmit (2017) that women are more likely to have an influence on financial decisions when they contribute an income share to the household. Additionally, these findings supports those of Krishnan *et al.* (2017) that levels of income of women who own income generated activities have positive impacts on the decision making authority of women and has contributed significantly to women empowerment.

**Socio-economic status and women empowerment**

The study assesses the relationship between socio-economic status and women empowerment. The results from cross tabulation as shown in table 4 revealed that there is a significant association between levels of women empowerment and socio-economic status. Variables like age, l cassava acreage and economic activities had a significant association with level of women empowerment (P<0.005). However, the exception is for marital status which showed no significant association.

women empowerment. Women aged between 36-55 years were more empowered compared to women aged between 15-35 years. This may be because women with aged between 36-55 years were considered more matured and could make decisions even if the household head is a male. Compared to women aged 15-35 years who could not make decision as they were married when young. Women who were married at a young age in patriarch system cannot make productive decisions. The same was reported by Tareque *et al.* (2007) that generally, marriage at an early age can be a barrier in women empowerment while marriage at a mature age was a strong determinant of women empowerment.

Moreover, this paper revealed that

**Table 4: Socio-economic status and women empowerment**

| Socio-economic characteristics | Level of empowerment | | | $\chi^2$ | P |
|---|---|---|---|---|---|
| | **Low** | **Medium** | **High** | | |
| Area under cassava production | Less than one acres | 1-5 acres | More than one five acres | 13.86 | 0.01* |
| Age | 15-35 | 76 and above | 36-55 | 12.87 | 0.05* |
| Economic Activities | Live stocking | Petty trader | Farming and wage labor | 20.31 | 0.03* |
| Marital status | Married | Divorced | Widow | 14.96 | 0.34 |

**Significant at 5%*

This study indicated that women with more than 5 acres planted with cassava were classified in high level of women empowerment because of the cassava value chain intervention compared to women with less than one acre who were categorized in low empowerment level. Women with more than five acres due to the agricultural training were able to produce more cassava yield. More yield means more income, also their families were ensured of food security at all time. This in turn allowed women's decisions to be respected at household and community levels. This result agreed with those of Diiro *et al.* (2018) that an increase in productivity per acre influenced women empowerment in Kenya, and that, increased yields may enhance women's share of farm income, their contribution to household food security, or their status within the community. Additionally, it was found that the age of women also has a significant relationship with level of women who were farmers and employed were categorized in high level of women empowerment. That is, women who were employed benefited more from agricultural training because they had access and control over financial resources and they had more power to make decisions on production matters in their households. This allowed them to purchase huge land for cultivating cassava and also use improved inputs introduced by the project. The same was reported by Dietz *et al.* (2018) that even when salaried women participate in off-farm economic activities even at lower rates than men, they (women) have more autonomy in decision making over tasks and income generated from those activities.

## Conclusion and Recommendation

### Conclusion

This paper tried to assess the contributions of CAVA II project to women empowerment in

Mara Region, Tanzania. The findings show that women were able to increase cassava yields due to the exposure to new, updated, and improved cassava cultivation methods, which allowed them to start a business of selling cassava flour and bits made from cassava flour. From these experiences, women's empowerment is exemplified by their ability to make independent financial decisions after being exposed to project interventions. In addition, women acquired authority when they are engaged in revenue activities that allow them to generate independent revenue. This revenue enables them to meet the basic needs of their family, such as food, clothes, and shelter. As a result, household members are more likely to appreciate women's financial decisions. In addition, the study found that women with more than 5 acres planted with cassava are characterized as having a high level of women empowerment since they are able to produce more cassava and generate more income as a result of the cassava value chain intervention. On the contrary, women who have less than one acre of land and were unable to generate a higher cassava yield resulting in lower income. Furthermore, it was observed that women between the ages of 36 and 55 are more likely than women between the ages of 15 and 35 to benefit from the value chain intervention and to be more empowered. The fundamental reason is that, even if the household's leader is a male, women between the ages of 36 and 55 are considered competent and capable of making independent decisions without much influence from their husbands.

## Recommendations

Based on the key findings from the study, it can be recommended that:

i) Government of Tanzania, NGOs, and Development Partners should design their intervention programs whose approaches should embrace women empowerment in order to ensure that poor women who are cultivating cassava also gain opportunity to participate in these initiatives;
ii) Secondly, such programs should make sure that agricultural trainings are provided to women smallholder farmers so as they can participate fully in agricultural activities compared to men who are shifting to off-farm activities; and
iii) The value chain intervention by GoT, NGOs and Development Partners should increase their efforts to address unfavourable gender norms that reduce women participation in agricultural production which in turn limit them from benefiting in such programmes in terms of participating in decision making and in using household production proceeds.

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# Tanzania Middle Income Country Status and Implications for Future Economic Growth Strategies

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**Abstract**

*Tanzania, having attained a gross national income per capita equivalent to $1,080 graduated from a low-income country to a lower-middle income country, which had a threshold of $1,036 in year 2020. The lower-middle income status is an important milestone for Tanzania and Tanzanians have all the reasons to celebrate, partly because research shows that countries may take many years to move from one category to the other, but having attained the (lower) middle-income country status level, well before year 2025 as envisioned in the Tanzania Development Vision 2025. This paper looks at the trends in some of key macroeconomic data related to this development and draws implications for future economic growth strategies to sustain this achievement and the drive the country towards an upper-middle income country status.*

***Keywords***: gross national income, low-income country, lower-middle income country, upper-middle income country, higher income country

## Introduction

In July 2020, Tanzania was declared to have attained a lower-middle income country by the World Bank, thus graduating from a lower income country category. Tanzania had achieved a gross national income per capita (GNI/capita) of $ 1,080, having crossed a threshold of GNI/capita of $ 1,036 based on 2019 gross national income per capita.

In categorising economies well-being, World Bank has adopted a universally recognised income measure of the gross national income. On this basis, World Bank has assigned countries' economies into four income groups: low income, lower-middle income, upper-middle income, and high income (Table 1).

Countries income categories are updated annually on July 1, whereby the World Bank releases new categories. There are a number of reasons for updating the categories, including changes in macroeconomic factors that can influence the gross national income such as economic growth, inflation, exchange rates and population growth.

Tanzania graduated to a lower middle income country in July 2020, having achieved a gross national income per capita equivalent of $ 1,080, which was above the World Bank threshold of $ 1,036, based on the 2019 GNI per capita. Two other countries, Benin ($ 1,250) and Nepal ($ 1,090) joined Tanzania in moving from low income countries to lower-middle income countries in July 2020 (Table 2).

**Table 1: World Bank Classification by Gross National Income/Capita as on July 2019 and July 2020 (US$)**

| Category | July 2019 | July 2020 |
|---|---|---|
| Low Income | < 1,026 | < 1,036 |
| Lower-Middle Income | 1,026 -3,995 | 1,036 - 4,045 |
| Upper-Middle Income | 3,996 - 12,375 | 4,046 - 12,535 |
| Higher Income | > 12,375 | > 12,535 |

***Source:*** World Bank, 2020

**Table 2: GNI/Capita (US$) for Countries Migrating from Low Income Countries to Lower-Middle Income Countries as of July 2020**

| Category | July 2019 | July 2020 |
|---|---|---|
| Benin | 870 | 1,250 |
| Nepal | 960 | 1,090 |
| Tanzania | 1,020 | 1,080 |

***Source:*** World Bank, 2020

This paper briefly explains the implications of this achievement on Tanzania's future economic growth strategies in sustaining growth and broader well-being of its people. Specifically, the paper attempts to address the question what Tanzania has to do so as to not go back to a lower income country category? This paper is based on experience in working in policy formulation and implementation for economic transformation.

## Can Tanzania Slip Back?

Achieving a lower-middle income status or an upper-middle income status and moving forward is one of the challenges that countries must be concerned with. Experience shows that some countries at higher income status fell back to a lower income status. World Bank (2021) reports that 23 countries that were in lower-middle income category fell back to lower income category during the last 10 years. During the July 2020 categorization, some countries switched to lower categories (Appendix 1). Similarly, there are countries that moved to higher income categories (Appendix 2).

These observations are particularly important to Tanzania as the level of income with which the country crossed to lower-middle income attained is close to the threshold income of US$ 1,036 (Figure 1). The trend in GNI/capita shows that whereas the GNI/capita grew from US$ 970 in 2014 to US$ 980 in 2015, it fell back to US$ 970 in 2016, remained at that level in 2017 before rising to US$ 1,020 in 2018 and reaching US$ 1,080 in 2019, an equivalent increase of about 6% between 2018 and 2019. Compared with compatriots, Benin had an increase of 45% whereas Nepal had an increase of 14%. With, a relatively large proportion of the population still in the basic needs poverty category, especially in rural areas such that slight shocks without meaningful safe guards, may affect their incomes and hence impact on the lower-middle income status of the country.

Apart from the threat of slipping back to a lower income category, aa body of research also shows that many countries are stuck in the middle

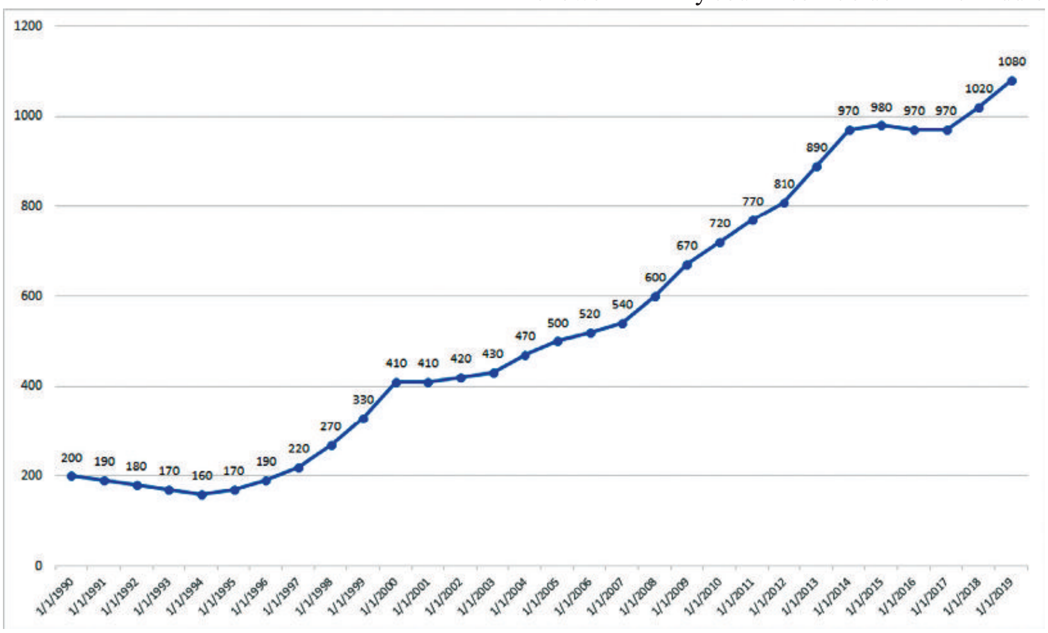


**Figure 1: Trend of GNI/Capita (US$) in Tanzania 1990-2019**

***Source:*** World Bank, 2021

income level (commonly known as middle income trap) for many years failing to move to a higher income level (Agenor and Canuto, 2012; Bulman, *et al.* 2017; Kharas and Kohli, 2011). Several reasons have been advanced for staying in the middle including failure of the economy to develop adequate knowledge base, capital and innovations that could help in breaking through to higher income level having exhausted opportunities provided by resources that enabled the economy to move from a low income status to middle income status. Countries fail to adopt new growth strategies needed to develop new products, processes, and markets once they reach middle income country status Kapotwe 2021). Agenor (2016) showed that diminishing returns on capital, exhaustion of cheap labour and imitations gains, insufficient quality of capital and inadequate contract enforcement and intellectual property protection as some of the reasons for slowed down growth. Others are distorted incentives and misallocation of talents, inadequate access to better infrastructure and finance.

The middle-income country status is one of the aspirations of the Tanzania Development Vision 2025 (TDV 2025) inaugurated in 1999. Tanzania Development Vision 2025, envisaged Tanzania to become a middle income economy by year 2025, accompanied by high quality of livelihoods; peace, stability, and unity; good governance; a well-educated and ready to learn society; and a competitive economy that can sustain growth and shared prosperity. These aspirations are well beyond the gross national income per capita. They reflect a higher level welfare and well-being of the people requiring more investment in sectors that have impact to many people such as crops, livestock and fisheries and macroeconomic policies changes among other things. These changes may lead to stable economic gain at household level.

It is important to note that whereas income per capita is a good indicator of economic well-being of the country and indirectly a proxy for the well-being of the people, as it can enhance production, consumption, investment through savings, it generally falls short in capturing non-income attributes as those espoused in TDV 2025. Also, it is not easy to deduce on the qualitative aspects of livelihoods of the people, competitiveness and ability to sustain growth as envisaged in the TDV 2025. Therefore, more work is ahead of Tanzanians if the country is to meet the TDV 2025 aspirations. In addition, for Tanzania to remain in the lower-middle income country category and move up to a higher middle income category strategies should be designed and sustainably operationalised in the implementation of the TDV 2025.

In general, a key implication of this development is for country to do more for two reasons:

(i) Safeguard and sustain the achievement and transition to upper middle income,

(ii) Complement the income success achievement with strategies that will improve the broader well-being of the people.

**Tanzania Development Vision 2025 and the Five Years Development Plan Implementation Journey**

Tanzania Development Vision 2025 was inaugurated in 1999, aimed at undertaking socioeconomic transformation of the country's economy and its people. TDV 2025 was launched following unimpressive macroeconomic policies reforms performance carried out in 1980s and 1990s that required Tanzania to embrace privatization, free market economy and deregulations. Launching of the TDV 2025 was necessary after a period of slow economic growth that was accompanied by a serious shortage of basic goods and services, high inflation, falling export revenues, rising and unsustainable debt obligations, poor revenue collections compared to relatively high government expenditure that resulted in large budgetary deficits among others.

In an attempt to redress the situation, the government implemented structural and economic adjustment programmes in 1980s and 1990s, with support from international organizations. Implementation of these programmes came along with a number of public sector reforms including Public Sector Reform Programme (PSRP), Local Government Reform Programme (LGRP), Public Finance Reform Programme (PFRP) and Legal Sector

Reform Programme (LSRP) (World Bank 2021). Among other things, these reforms required the government to refrain from carrying out commercial activities which also saw a significant number of commercial public companies being divested and privatized. To a large extent, the government was required to create good business climate for private sector to thrive and at best the government was to perform a referee role where market could not work well. To achieve the goals of creating good business ground for all, regulatory authorities were established including SUMATRA (now LATRA and TASAC), EWURA, TCRA, TCAA, TRA, TPA, TANROADS among others.

The unveiling of the TDV 2025 in 1999 was done in the wake of unbearable external debt crisis. However, TDV 2025 was overshadowed by two initiatives such as the Multilateral Debt Relief Initiative (MDRI) and Highly Indebted Poor Countries (HIPC). These initiatives were financed by international financial institutions and development partners aimed at addressing debt crisis and poverty in the medium term with the implementation of Poverty Reduction Strategy Paper (PRSP). Out of the PRSP, the National Strategy for Growth and Reduction of Poverty (NSGRP I) (2005/06-2009/10) and National Strategy for Growth and Reduction of Poverty (NSGRP II) (2010/11 – 2014/15+1) were developed and implemented.

Recognizing the slow pace of implementation of TDV 2025, prompted the government to come up with a Long Term Perspective Plan (LTPP) in 2011. The LTPP refocused efforts to implement TDV 2025, emphasising on economic growth with poverty reduction and human development. LTPP was to be implemented in 15 years, but broken down into three five years planning frameworks.

To date, three five years development plans, linked to one another, have been developed.

(i) *Five Year Development Plan (FYDP I)* implemented during 2011/12–2015/16, focusing on *Unleashing Tanzania's Latent Growth Potentials*. This was meant to address infrastructure challenges inhibiting growth, especially energy, ports, roads, railways and social services infrastructure.
(ii) *Second Five Year Development Plan (FYDP II)* has been implemented during 2016/17-2020/21, paying attention to *Nurturing Industrialization for Economic Transformation and Human Development.* This Plan put more emphasis on human centred growth as aspired by the TDV 2025.
(iii) *Third Five Year Development Plan (FYDP III)* to be implemented during 2021/22–2025/26, focusing on *Realising Competitiveness and Industrialization for Human Development.* Again, this buttressed the TDV 2025 ambition of building a strong, middle income, semi-industrialised and internationally competitive economy while serving human development goal. Attention is paid on equitable sharing of productive resources and benefits of economic growth.

With a proper base developed from FYDP I and FYDP II, it is expected that FYDP III will be implemented with a greater momentum, building on and consolidating successes so far achieved (URT, 2021). The FYDP III has five (5) objectives:

(i) Increase the annual GDP growth rate from 6% in 2021 to an average of 8% by 2026;
(ii) Increase internal (domestic) revenues from 15.9% of GDP in 2021/22 to 16.8% of GDP in 2025/26;
(iii) Inflation kept low between 3.0% and 5.0% over the medium term;
(iv) Foreign reserves to meet imports requirements of at least four months;
(v) Eight million jobs created in the private sector between 2021 and 2026.

It is on the basis of this background, FYDP III implementation strategies must ensure that they will uphold or sustain the middle income status that has been attained. Tanzania can achieve much in FYDP III and drive the country to an upper-middle income status if attention is paid on sustaining good macroeconomic targets among other things.

**A Select of Basis for Our Success?**

A discussion on what Tanzania should do to sustain and build on the attained middle income status needs to be done from a wider economy (macroeconomic) perspective. This is partly because macroeconomic policy decisions and their impacts may take time to be realised (due to lags) and may have far reaching impacts (multiplier effects). Although, instantaneous changes may occur under some circumstances, macroeconomic performance in a given year normally reflects decisions made some years back. Therefore, stable and predictable macroeconomic policies that will have an in impact in an economy are very important. In this regard, the country requires coherent policies in almost every sectors that will increase the confidence of international and domestic (indigenous) investors in the country. Recently, reports have indicated that Tanzania is doing well in some indicators and some need improvement (World Bank, 2021).

On average, *the annual GDP growth rate* has been between 6-7% over a decade, falling short of 8% annual growth rate envisaged in the TDV 2025. In recent years, annual GDP growth rate has been largely accounted for growth in investment in infrastructure in the energy, transport, and mining and quarrying sectors. Average annual GDP growth rates for the different sectors have been as follows: construction (14.4%), manufacturing (8.3%), transport and storage (8.2%), mining and quarrying (8.0%), ICT (6.2%) and agriculture (5.1%). Agricultural GDP share has declined from 29.0% in 2016 to 26.6% in 2019, possibly an indication of structural transformation as well as trade related challenges facing farmers. Since, agriculture is the mainstay of the economy and still is major employer (65% of the population), strategies to stimulate meaningful agricultural growth are needed.

*Inflation* has averaged to 4.4%, with headline inflation declining from 5.3% in 2016 to 3.3% in 2020. Decline in inflation has been partly due to adequate food supply, stability and at some stage falling oil prices that occurred in 2020 amid COVID-19 and good fiscal and monetary policies. By December 2020, foreign exchange reserves were sufficient to cover 5.6 months imports of goods and services, well above the East African Community (EAC) target of 4.5 months imports. This is a good signal to potential investors and creditors, cushions against external crisis; and possibly curb erratic movement in the local foreign exchange markets.

*Fiscal performance* shows that domestic revenue collection has been increasing overtime, albeit below the annual targets. Domestic revenue as percent of the GDP has increased from 13.4% in 2016/17 to 14.7% in 2019/20. Development expenditure as a percentage of GDP has increased to 31.4% in 2019/2020 from 22.5% in 2015/16. Fiscal deficit as a share of GDP has fallen from 3.4% 2015/16 to 1.4% in 2019/2020, well below the EAC and Southern Africa Development Community (SADC) convergence target of 3% and financed largely by borrowing from both domestic and foreign sources.

*National debt* is sustainable, with low risk of distress and all relevant ratios are below the risk thresholds. For example, present value of national debt as a share of GDP (debt/GDP ratio) is 16.4%, lower than the threshold of 55%. Present value for external debt to export is 103.9% (2019/20), which is expected to decrease after the completion of major development projects under implementation. Credit Reference Bureau is working well as almost all banks (55 out of 56 banks) submit data to the Bank of Tanzania to facilitate credit referencing. With the growing deployment of Internet, the number of banking agents has equally grown from 591 in December 2013 to 28,358 in December 2019. Similarly, microfinance institutions are required to share creditor's information with the Central Bank.

*Agricultural sector* average annual growth rate is estimated to be 5.1% over 5 years, accounting for about 26.6% of the GDP, 24.1% of exports earnings and 65% of employment and a significant supplier of food, with food sufficiency ratio averaging to 118% in the last five years; and an important source of raw materials for agro-industries. However, agriculture sector is facing low productivity and in dire need for further commercialization. *Manufacturing* accounted for 8.5% of the GDP in 2019, up from 7.9% of the GDP contribution during 2015/16. Annual growth rate is 8.3% in 2019, up from 6.5% in 2015. Manufactured exports include cotton yarn, coffee and tobacco, sisal products (yarn and twine), plastic items, textile apparels. Trade share in SADC has increased from 12%

in 2015 to 14% in 2019, whereas the share has declined in the EAC from 16% in 2015 to 13% in 2019. Manufactured exports have increased in both regional markets. Construction share of the GDP 14.4% (2019), with an annual growth rate of 14.4% (largest) precipitated by the government infrastructure construction projects which has included roads, bridges, railways, mining, airports, seaports, government buildings in Dodoma water and health facilities, schools; and procurement transport equipment, and building of motor vessels in Lake Victoria, Lake Tanganyika and Lake Nyasa among others. Similarly, construction in the informal sector has been rising.

*Poverty* is relatively high, especially in rural areas. Basic needs poverty has declined from 28.2% in 2011/12 to 26.4% in 2017/2018. Food poverty has also declined from 9.7% in 2011/12 to 8.0% in 2017/18. Improvement in access to basic services and productive assets is noteworthy as exemplified by improved lighting (rural electrification), improved road transport, access to education, health, markets, water and sanitation. Multi-dimension poverty index (MDPI) is being developed and is expected to be used during the implementation of FYDP III. *Human Development Index* (HDI) is 0.528 well above 0.507 for countries with low human development indices. Life expectancy has increased to 66 years in 2019 from 63 years in 2015. Expected schooling years is 8.0 years (2019) compared to 5.3 years in 2010.

**Some Strategies to Support Future Economic Growth**

Over 20 year period, Tanzania's GDP growth rate has been estimated to average at 6.5% per annum and the annual per capita growth rate has been at an average of 3.6% per annum. Aspirations of the FYDP III is for the GDP to reach at least 8% by 2026 to align with the middle income status. Given the small margin with which Tanzania transitioned to lower-middle income status, a key question to be addressed is what *Tanzania has to do to prevent from slipping back to the lower income country list.* The following are some of the strategies which can not only promote and accelerate economic growth to sustain the lower-middle income country status, but also take the country to an upper-middle income country status.

a. *Maintaining macroeconomic stability,* which include increasing resource mobilization and public expenditure efficiency so as to keep fiscal deficit low and to achieve an annual GDP growth rate target of 8%. Furthermore, sustaining debts at the lowest levels possible and with low risk of distress will be essential. Recent data show that the national debt as a share of GDP (debt/GDP ratio) is about 16.4%, lower than the threshold of 55%. With the completion of huge development projects under implementation, the ratio is expected to improve, thus increasing investors and financial institutions confidence. Low rates of inflation within 3%-5% as envisaged in the FYDP III will be important to support internal consumption. However, it will be important to revisit the level of disposable income in relation to taxes. Low disposable income coupled with high taxes on key consumer goods and services, chances of stimulating internal demand will be low and hence undermining economic growth in the long run.

   An aspiration of increasing domestic revenue mobilization from 15.8% of the GDP in 2021/22 to 16.9% of the GDP by 2025/26 aim at ensuring that fiscal deficit shares of the GDP are kept at low levels. Efficiency in domestic revenue (tax and non-tax) collection including the application of digital technologies will be important. Whereas public expenditure is necessary for many reasons, efficiency in public expenditure will help keep fiscal deficits at the optimal levels. Generally, prudent fiscal and monetary policies will be key in enhancing macroeconomic stability.

b. *Improved business and investment environment* will increase confidence in doing business and investment. This may include a revisit of remaining businesses and investors' stumbling blocks including legal as well as administrative barriers. Examples include, the further expedition of VAT refunds to bring relief to claiming entities, initiative to review and abolish inefficient taxes and levies in various sectors should be continued. Whereas, a number of actions have been taken including the abolition of various fees and duplication of roles among public institutions, continuing the implementation of the Blue Print for Regulatory Reforms will provide a good business environment and confidence to the private sector investment and hence contribute to economic growth.

c. *Public investment* apart from increasing the physical capital and thus reducing the infrastructure short falls, sustainable public investment in infrastructure should provide a good platform and incentivize private sector investment and participation, especially in areas where private sector finds unprofitable to venture or limited resources to pursue.

d. Attracting *foreign direct investment* to complement domestic (private and public) investment should be pursued as this may bring along experience as well as technology transfer. Lessons from the past on foreign direct investment in the extractive industries should help in rigorously assessing such investment.

e. *Promoting foreign trade* through reduction of export tax and levies for agricultural commodities will be necessary in reducing trade deficit especially when the economy encounters shocks such as Covid-19 and other disasters. Whereas as much of the exports revenue are from non-traditional exports, with gold generating a large share of export revenue in recent years, deliberate efforts be directed in promoting exports diversity. Value addition in agribusiness and manufactured exports not only will enhance inclusiveness and participation of the rural sector but also help reduce uncertainties in the world commodity markets. Potentials of harnessing cross border and regional trade should be prioritised, with adjacent neighbouring countries given top priority. One stop border points (OSBPs) should promote more trade between neighbouring countries. Predictable trade policies will be vital.

f. *Investing in human capital development* is important in enhancing capital and labour productivity as well as gaining employment in exclusive fields in the market. This entails investment in education, skills, skills upgrading and health among others. Both quality and quantity are important, but with technological progress more investment in quality will be required. The recent announcement by the government to enrol those interested in vocational skills and technical training is a move in the right direction and quality of training should be emphasized.

g. *Promote and support investments that enhance inclusive growth.* Labour intensive value addition activities in agriculture and agribusiness value chains, light manufacturing and non-farm activities will promote inclusive growth. Supporting the development of secure middle c[7]lass in the economy, is bound to create better linkages with the low income groups apart from distribution of incomes and ultimately alleviating poverty. Middle class has been instrumental in the establishment of SMEs and jobs creation and thus can immensely contribute to the 8 million jobs[8] target of FYDP III. Similarly, supporting SMEs in all fronts including finance will go a long way in creating jobs and addressing poverty.

h. Being the largest employer and provider of livelihoods for majority of the poor, *agricultural sector transformation* should be at the centre stage. Although transformation of agriculture is going on, deliberate measures to increase investment in relevant infrastructure[9] that will support agricultural transformation and productivity are necessary. Similarly, supporting the

[7] *According to African Development Bank, this is a category spends between US$ 2-15 per day, constitute about 34% of the population in Africa and account for a large share of employment and tax payments (PAYE, property tax and income tax). Similarly, medium size enterprises have also been found to be instrumental in supporting industrialization and contributing to inclusive growth. They have been found to have better linkages with the rural, and thus more effective in rural poverty alleviation. Also they can absorb shocks better.*

[8] *Estimates show that about 800,000 new workers enter the job market each year.*

[9] *Includes production, storage, institutions and distribution networks.*

adoption and utilization or upscaling of (research) innovations is required in addition to properly funding public agricultural services (research and development, extension, market information) to generate meaningful outcomes. Further actions are required in revisiting and ultimate removing unnecessary trade barriers; completing the review of regulatory frameworks for both inputs and outputs; investing in public agricultural and agribusiness supporting infrastructure and markets.

i. Develop *safety nets* and *resilience to shocks* such as *pest and disease outbreaks*, droughts, floods as well as other disasters. Shocks may result in jobs and income losses, culminating in increasing poverty. Agricultural insurance scheme can be one of the available options.

j. Harnessing *digital technology* is necessary to capitalize on digital based technologies that enhances productivity and efficiency. Examples where digital technologies have increased efficiency include education, health, finance, public administration, judicial services, markets and trade, among others.

## Conclusion

Tanzania has good reasons to cherish the achievement of a lower-middle income status. Significant efforts, in terms of policy consistency and opportunity costs (small budgetary allocations to institutions), have gone into this. Whereas, gross national income per capita alone is not enough given the aspirations of TDV 2025, the gross national income per capita with which Tanzania has crossed to the lower-middle income status is likely to be sensitive to shocks. Thus, Tanzanians should not be complacent. FYDP III, as an implementing arm of TDV 2025, has charted ways to consolidate and transition to the next income per capita category. It will certainly take time to move to the next category, but what is important for the country is to persist in maintaining macroeconomic fundamentals, support agricultural transformation, improve business and investment environment, increase public strategic investment that will facilitate private sector investment, attract foreign direct investment, and promote and support foreign trade. Other areas of attention will be to invest meaningfully in human capital development, promote and support investment that enhance inclusive growth, harnessing the powers of digital technology as well as developing safety nets and resilience to shocks. Tanzanians should rally behind the FYDP III so as to safeguard this achievement and transition to the upper-middle income status.

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## Appendices

**Appendix 1: Countries Transitioning to Lower Income Categories Based on GNI/capita (US$) as of July 2020**

| Country | New Group | Old Group | GNI/Capita July 2019 | GNI/capita July 2020 |
|---|---|---|---|---|
| Algeria | Lower-Middle Income | Upper-middle income | 4,060 | 3,970 |
| Sri Lanka | Lower-middle income | Upper-middle income | 4,060 | 4,020 |
| Sudan | Low income | Lower-middle income | 1,560 | 590 |

***Source:*** World Bank, 2021

**Appendix 2: Countries Migrating from other Lower to Higher Income Categories Based on GNI/Capita (US$) as of July 2020**

| Country | New Group | Old Group | GNI/Capita July 2019 | GNI/capita July 2020 |
|---|---|---|---|---|
| Indonesia | Upper-middle income | Lower-middle income | 3,840 | 4,050 |
| Mauritius | High income | Upper-middle income | 12,050 | 12,740 |
| Nauru | High income | Upper-middle income | 11,240 | 14,230 |
| Romania | High income | Upper-middle income | 11,290 | 12,630 |

***Source:*** World Bank, 2021

# Scientific Evidence for Policy Making: a Missing Link inHigher Learning institutions in Tanzania

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**Abstract**

*Higher learning institutions are well known for their capacity to produce scientific evidence that can guide development initiatives in developing countries. Despite this acknowledgment, transferring research findings into policy and practice has remained to be a long-time challenge in Tanzania. An action research was conducted to assess the use of research findings generated from higher learning institutions in decision making. Specifically, the study aimed at establishing the level of awareness on the concept of scientific evidence for decision making among researchers; assessing the capacity of researchers in disseminating research findings to policymakers and examining the coordination of higher learning institutions in contributing to evidence informed decision making (EIDM). A survey was conducted on a total of 29 researchers from 9 higher learning institutions and 7 key informants from selected ministries and regulatory authorities. Descriptive statistics and content analysis were used for data analysis. Findings indicate that higher learning institutions are academic oriented as such the research findings generated are not synthesized, and not repackaged and presented in a user-friendly language for easy uptake by policymakers and implementers. Limited awareness of EIDM among researchers; and weak coordinated efforts for evidence generated from higher learning institutions to influence policy change were also reported. The study suggests capacity building among researchers on research findings synthesis and dissemination for EIDM. This will be coupled with the establishment of a research findings synthesis unit to facilitate the contribution of higher learning institutions in EIDM for the country's socio-economic transformation.*

***Keywords***: Evidence informed policy making, synthesis unit, higher learning institutions, Tanzania

## Introduction

The use of evidence in policy-making is an issue of concern to both policymakers and researchers in bringing developmental changes and improving the world (Sanderson, 2003). Evidence informed decision making is a cornerstone for relevant solutions to societal problems because the quality of the decision made depends on quality information and evidence (Sanderson, 2003; HakemZadeh, 2013; Head, 2015; Aryeetey *et al.,* 2017; Stewart *et al.,* 2018). To attain the desired development, African countries have put in place various policies and development strategies however, the efforts have registered very limited success. Among other factors, the limited linkages between research findings and decision making for policy formulation constrains achievement of the intended developmental objectives (Aryeetey *et al.,* 2017). Generally, evidence derived from research is expected to help in framing and understanding problems that demand policy interventions, and in evaluating the ultimate impact of any measures put into effect.

Taking an example of Tanzania, its development path is guided by Tanzania Development Vision (TDV) 2025 that is customized in the country's Five-Year Development Plans (FYDP). The ending FYDP

(2016/17 – 2020/21) which feeds into TDV 2025 and the sustainable development goals as well focused on nurturing industrialization for economic transformation and human development to attain the middle-income status and to move into higher levels of income status in the future. Therefore, linking the agriculture sector and industrial sector has been given priority. To achieve this, embracing Evidence Informed Decision Making (EIDM) in formulating the strategies is inevitable.

Higher learning institutions for a long time have been among the active actors in evidence generation across the World (Jessani *et al.,* 2017). However, the level of uptake of the evidence generated into decisions making differs across the regions. These institutions are placed in a better position to contribute to the process because they have the facilities and manpower to generate evidence. Constantly, these institutions undertake various researches that generate a lot of scientific evidence that can be used to solve various societal problems. Nonetheless, this important opportunity is not well utilized by the decision/policymakers hence, the limited contribution of the higher learning institutions into policy making process (Aryeetey *et al.,* 2017; Stewart *et al.,* 2018). Tanzania has more than 50 universities and university colleges and other higher learning institutions (HLIs) operating under the Ministry of Education and Vocational Training (MoEVT). The above-mentioned HLIs are involved in researching scientific disciplines agriculture and industrial technologies included in order to generate information to inform the policymakers for proper development propositions. Despite the appreciable efforts to increase the number of qualified researchers in the country, Tanzania like many other developing countries suffers a weak link between Academia, Research and Policy making.

Furthermore, literature (Head, 2015; Cairney and Oliver, 2017; Stewart *et al.,* 2018) shows that policymakers do not gather and consider all evidence relevant to policy problems. And that government official and political leaders are often motivated by socio-political factors other than research evidence. Instead, they prioritize certain sources of information and draw on emotions, gut feelings, beliefs, and habits to make decisions quickly (Head, 2015; Cairney and Oliver, 2017; Stewart *et al.,* 2018). On the one hand, the scientists' weak link to decision/policy making is influenced by factors such as lack of time, support, resources, and incentives to engage in dissemination. Therefore, scientific evidence is often not presented at the correct time and scientists are unable to anticipate a demand for information to solve a very specific problem quickly. On the other hand, policymakers lack the research skills to understand/generate scientific evidence. Moreover, policy makers are faced with uncertainties about "what works for whom" and under what conditions. This situation forces them to use the "best available" evidence rather than waiting for the rigorous findings from research (Head, 2015). Therefore, the study on which the paper is based assessed the existing state on the use of research findings generated from HLIs in decision making. Specifically, the study aimed to establish the level of awareness on the concept of scientific evidence for decision making among researchers; assess the capacity of researchers in disseminating research findings to policy makers and examined the coordination of HLIs in contributing to evidence informed decision making (EIDM).

## Methodology

### Study approach

This study was conducted in Tanzania using the action research approach whereby 29 researchers from 9 public universities and 7 key informants from selected ministries were involved in the study. Two days' meetings were conducted. The first day meeting in form of a training workshop on awareness creation on EIDM was conducted with researchers only. The meeting aimed at allowing researchers to reflect and comment on their perceived position in the policy making process. The second day meeting in form of a policy dialogue on the evidence-policy interface was conducted with a mix of researchers and key informants from the selected ministries to find solutions to the missing link on EIDM and higher learning institutions. The study's methodology was also used by Stewart *et al.* (2018) in their study on building capacity for evidence-informed decision making in South Africa. Stewart *et al.* involved the identified stakeholders in evidence informed decision making so as to come up with appropriate capacity building approaches for better linkages between researchers and policymakers.

**Study respondents**

The study involved 29 researchers who were purposively selected. They comprised the universities' directors of research and publications, principal investigators of research projects, and PhD students. These were considered as generators of research findings as well as the potential actors for synthesizing research findings for evidence informed decision making (supply-side). The study also involved 7 key informants from selected ministries in the department of policy and planning who were considered as potential users of research findings in informing their decision/policy making processes.

**Data collection and analysis**

Data from the above-mentioned 29 respondents were collected using a questionnaire prior to the meeting to establish the level of their awareness of EIDM. During the meeting, data was collected through visual recordings of the event; two sets of researcher transcriptions and notes; a flipchart and poster records of the group activities, and consensus-building exercises. Thereafter, quantitative data was analyzed using SPSS to determine descriptive statistics and thematic analysis was used for the qualitative data.

**Results**

**Level of awareness on the concept of scientific evidence for decision making among researchers**

Assessment of the generation and use of evidence in making decisions in the respondents' institutions indicated mixed findings. The findings revealed the use of less scientific ways of generating evidence for decision making coupled with limited awareness of the concept itself. The most cited ways of generating information that can support various decisions at various levels within their institutions to ensure evidence in decision making revealed the use of task forces, research, situational, and stakeholders' analyses. However, when asked further on the sources of evidence used in decision making, 58% of the respondents indicated online publications/journal articles.

The findings on the sources of evidence justify the limited understanding of the EIDM concept and the source of evidence. The major sources of evidence mentioned are also justified by the background of the respondents because most of the workshop participants (86%) were from university/academic institutions. The key responsibilities of academia include teaching, consultancy, and research. Since respondents indicated using evidence from scientific publications to inform their work while the focus of EIDM is on how the findings generated from research works can inform policy/decision making processes the findings justify limited understanding of the concept of EIDM among researchers.

After awareness creation on EIDM, researchers' indicated a need for awareness creation among all stakeholders in the EIDM chain for its uptake in Tanzania. Awareness creation on EIDM should extend to policy makers as well. EIDM need a close working relationship between policy makers and researchers. A common understanding between the two communities is highly needed as contended by one of the workshop participants

*"…this needs a long-time discussion rather than a single day workshop...we need to think as researchers on how to create a database especially for our local context. Where and how to get research done in other universities…we need to synchronize that type of information as such we need a longer time to get this. Policy makers should also be included as participants to get a common understanding and set a common goal towards improving the situation for the development of our country"* (A Female Senior Lecturer, SUA, 4th September 2020).

**Capacity of researchers in disseminating research findings to policy makers**

Results from the in-depth interviews with key informants suggest limited capacity among researchers in relation to how to communicate their research findings to policy makers/ stakeholders as pointed out by some of the respondents

*"…Policy making process in the country is a big issue,…research findings are not translated into practices"* (A Male PhD Student from SUA, 4th September 2020).

*"… We are not considering EIDM in our research projects,… Academicians undertake research for their academic career there is limited capacity to translate research findings into a more understandable language to policy makers…"* (A Female Senior Lecturer, SUA, 4th September 2020).

*"…we are doing a lot of research, however, .repackaging our research findings to inform the government's policy making process is still a big challenge"* (A Male Senior Lecturer, Mzumbe University, Tanzania, 4th September 2020).

Generally, researchers acknowledged the need to inform the policy making process with quality evidence from researches however, a low priority is given by researchers on translating the findings into usable evidence. Also, limited capacity to synthesis the findings affect the goodwill to do so. Results during small group discussions revealed limited capacity on how to synthesize research findings. These include skills to sort, synthesize and repackage the findings for policy makers. EIDM cannot be realized without synthesizing the research findings from various sources. Results further revealed limited skills by researchers in communicating science to inform decision/ policy making. Similar findings were also reported by Head (2016) that, the language used by researchers in scientific publications is different from the language used by policy makers. Researchers have low capacity to locate, interpret and systematically review evidence in the process of policy development (URT, 2008). The study further revealed presence of structures and mechanisms supporting research communication, research use, and overall EIDM practices in various academic institutions. Only 11.1% of the respondents reported availability of evidence synthesis centers or units charged with synthesizing the research done by the institution for ease of uptake by policy makers (Table 1). Most of the structures and mechanisms identified by respondents do not directly involve synthesis of research findings into evidence

**Table 1: Structures and mechanisms for supporting EIDM practices in the HLIs**

| EIDM structure present in institutions | Responses | Percent |
|---|---|---|
| A communications department/Unit charged with translating and communicating research to non-technical audiences | 15 | 55.6 |
| An evidence synthesis centre or unit charged with synthesizing the research done by the institution for ease of uptake by policymakers | 3 | 11.1 |
| A requirement that all research proposals developed by the institution include a budget for research communication, dissemination and policy engagement | 13 | 48.2 |
| Require your active participation in government decision-making platforms such as technical working groups, taskforces, etc. | 9 | 33.3 |
| A training programme to build your skills in research communications (e.g. writing policy briefs) and policy engagement | 11 | 40.7 |
| A training programme to build your skills in systematic reviews and/ or rapid reviews of the evidence | 7 | 25.9 |
| A formal requirement for your career progression (promotion) on research translation and engagement with policymakers to facilitate the use of your research | 6 | 22.2 |
| **Total** | **64** | **100.0** |

*Results are based on multiple responses* **Source:** Research data, 2021 to be used in policy making. For example, 55.6% of respondents indicated the presence of communications department/unit charged with translating and communicating research to non-technical audience. This kind of structure may support the use of translated evidence in policy making only if the efforts will be done to reach the target group. Likewise, 48.2% of the respondents identified a requirement that all research proposals developed by the institution include a budget for research communication, dissemination, and policy engagement. While the inclusion in the proposal serves as a good starting point to share the evidence for decision making, the practice might be different during the actual implementation of the project.

Apart from the capacity of researchers in synthesis the evidence and presence of supporting structures and centers within the institutions; the lack of a common platform to share findings was also reported. Universities work in isolation as such there is limited networking among researchers from various institutions. Research findings from various universities have limited opportunities of being pooled together, synthesized, and used as evidence for decision making. This connotes poor coordination among researchers in academic and research institutions in Tanzania.

Furthermore, limited funding was also reported to be among the factors limiting the dissemination of research findings to policymakers. For a long time, research funds from the government have been decreasing leaving the role of supporting research activities to donors. Generally, observations from group discussions showed that the government's allocation of research funds to universities is very limited. Therefore, most research projects done by universities are donor funded with limited budget allocations on findings dissemination. Findings by Aryeetey *et al.* (2017) also indicated that much of the existing research in Africa is supported by ad hoc funding and collaborations with non-African researchers and donors. Once the research is supported by donors in most cases it does not address the pressing need of the respective national government hence, the evidence generated might not support the ongoing policy decisions. Additionally, dependence on donor support to the research affects the systematic establishment of the evidence on pressing policy problems of the respective country. While EIDM requires systematic evidence, researchers' responses to the call for research from donors do not guarantee the possibility to continue with the same research idea for a long time.

**Coordination of higher learning institutions in contributing to evidence informed decision making**

***Strengthening Institutions for Evidence Use:*** Generally, results from the survey suggest a lack of adequate structures that could be used to facilitate EIDM practices. When respondents were asked on the availability of structures and mechanisms to support access and use of evidence at the universities; 61.5% indicated access to online research databases and reliable internet connection that facilitated ease access to research and other information. The databases in universities are mainly on journal articles and other scholarly publications that are mostly used for the search of reference materials in research works rather than synthesized research findings for decision making. It was further revealed that 34.6% of respondents mentioned the availability of research agenda that outlines the priority research. Furthermore, 11.5% reported the annual funding/budget for commissioning research and/or systematic reviews needed to inform the institution's decision-making processes. The availability of an evidence synthesis ercenter or unit charged with synthesizing existing research to inform the decisions of their institutions was reported by 7.7% (Table 2).

***Generation of official statistics:*** Results from the key informants involved in the study revealed an increased need for evidence informed policy making than it was before. The National Bureau of Statistics (NBS) as the nation overall in charge of the country's statistics collects limited information to inform policy/decision making. Traditionally, the three sources of data which are surveys; censuses, and administrative sources generate data of limited use. Surveys are done after every 5 years whereas censuses are done after 10 years. Administrative

**Table 2: Structure and Mechanism to support access and use of evidence in the institutions**

| Structure present | Responses | Percent |
|---|---|---|
| Access to online research databases that enable ease access to evidence in decision making | 16 | 61.5 |
| An evidence synthesis centre or unit charged with synthesizing existing research to inform the decisions making | 2 | 7.7 |
| A training programme to build skills of staff in evidence-informed decision-making (EIDM) | 7 | 26.9 |
| Active technical working groups that prioritize regular presentation and discussion of research to inform the decisions the institution makes | 6 | 23.1 |
| Reliable internet connectivity that facilitates ease access of research materials and other information | 16 | 61.5 |
| A guidelines document that promotes and supports research use by staff | 7 | 26.9 |
| Annual funding/budget for commissioning research and/or systematic reviews needed to inform the institution's decision-making processes | 3 | 11.5 |
| A research agenda that outlines the priority research that the institution needs to make decisions in its priority areas | 11 | 42.3 |
| **Total** | **68** | **100.0** |

*Results are based on multiple responses* ***Source:*** *Research data, 2021*

data are produced by NBS in collaboration with other institutions to generate evidence to inform decision making in between the surveys and census. It was further reported that some of the development indicators are not captured in the traditional sources of data. NBS is therefore looking at how it can use the statistics generated by agencies (including universities) to fill the gap to enhance EIDM.

The study also found that generation of official statistics is guided by the National Statistics Act Cap 351 of 2019 (URT, 2019). The statistics (research findings) produced by agencies need to meet criteria and standards set by NBS for the same to be recognized as official statistics. It was further revealed that every person has the right to produce and disseminate statistical information provided that it meets international and national standards. The study results indicate a dilemma on whether Universities generate official statistics or not. However, it was reported that policy decisions are time sensitive, policy makers do not get timely research findings from higher learning institutions to inform decision making. Research from higher learning institutions lack continuity, moreover, one time research might not be desirable to inform policy that has a longtime impact.

***Linking Evidence to Policy:*** Results from key informants indicated three pertinent questions to be considered before undertaking any research: Who wants it? Who is going to use it? Who is going to pay for it? However, results from the research participants indicated that stakeholders are invited during research findings dissemination which has been of little or no impact in influencing decision/policy making processes. It was reported that decision makers who are going to use the results need to be involved from the conception of research; once the decision makers are aware of the research problem, they are more likely to use its findings. In addition, results indicate limited communication between policy makers and researchers during policy formulation and research designing. Limited well-defined fora that can bringing together researchers and policy makers was also identified as a challenge. Moreover, many institutions (agencies) that generate research findings are also not well coordinated, and sometimes there is a lot of duplication of efforts due to limited sharing of research findings among the agencies.

***Pushing the Universities Research for Policy and Development:*** Assessment on how the existing policy environment support universities to undertake research for policy development indicated the presence of institutions aimed at strengthening Science, Technology and Innovation. The key informant from MoEVT pointed out the drawbacks to the achievements as limited coordination on the formulation and implementation of policies on Science, Technology and Innovation; limited contribution of stakeholders (Parliament, Academia and Civil Societies) and regulations to guide the Science, Technology and Innovation do not meet requirements. The existing policy environment also does not stipulate the use of research findings from universities in EIDM. Researches done in the universities are meant for academic purposes such as career advancement and not in decision/policy making. Additionally, lack of a comprehensive and integrated system of national priorities and long-term technology for sighting; limited government funding on research; limited use of research findings were also mentioned. However, universities were pointed out to play important role in Science, Technology and Innovation for social and economic change. Aryeetey *et al.* (2017) also highlighted the role of academia in championing evidence for decision making due to their capacity in undertaking various research programs.

## Discussion

The findings have indicated limited use of empirical evidence in decision/policy making. Moreover, researchers and policymakers are viewed as two separate communities with their systems and language. In addition, the two communities have different priorities, time scales, goals and challenges in the use of research findings generated in HLIs in policy making (Lugo-Gil *et al.,* 2019). Researchers particularly those in universities undertake research projects for academic purposes such as writing publications for career advancement. The publications are written in a scientific language not easily understood by policymakers (Aryeetey *et al.,* 2017). On the other hand, policymakers expect researchers to translate the research findings into simple language for easy uptake (Jessani, *et al.,* 2019), a task which researchers think to be out of their mandate. This indicates an institutional divide that needs a bridge for research findings from universities to be useful in EIDM in Tanzania.

Research institutions are working in isolation with decision making organs and the gap between researchers and policymakers is anticipated to increase due to limited government funding into research and development. Although there are representations of researchers or professionals in various technical working groups, this is not enough for the research findings generated from the research institutions to be used in various decision-making processes. Research findings by Howard and Hugh (2012) indicated the importance of a forum for interpreting/ systematic reviewing and channeling existing and future research findings that have an impact on the large population. The forum helps in providing relevant and reliable information to communicate to policy-makers. Nevertheless, the forum for research findings synthesis cannot be effective if researchers' capacity to undertake the synthesis is still limited. The study findings indicated the uptake of EIDM to be hindered by limited skills in synthesizing and repackaging information for policy makers. Deliberate integrated efforts for EIDM awareness and capacity building for both researchers and policymakers are needed for the formulation of relevant development strategies.

Findings also show that many researches undertaken are supply driven rather than demand driven. Researches conducted do not consider policy requirements during research formulation as such the research findings generated are not in the policy priority areas. It is high time for researchers to consider the national research priorities so that the findings can be used to inform decision/policy making (Stewart *et al.,* 2018). If stakeholders are not well informed on the research hence the uptake of the research findings for decision making will be limited. Nevertheless, the current focus of donors on the influence of research on national policies provides a good opportunity for research findings from donor funded research projects to also inform policy decisions more than it was before. Therefore, the contribution of research findings from higher learning institutions in EIDM will no longer be affected much by who pays for the research projects.

**Conclusions and recommendations**

The findings have indicated limited awareness amongf researchers on the concept of scientific evidence for decision making. The researcher's understanding of the concept reflected their key responsibilities of the academia which are teaching, consultancy, and research with little or no contribution to EIDM. The Limited understanding of the concept among researchers is coupled withinglimited capacity to communicate science to policymakers due to limited capacity for systematic reviewing, translating, and repackaging evidence for policymakers. Although researchers can contribute to EIDM, thispercieved to be an additional work to researchers with limited incentive hence making a task to be less priority among researchers. Despite the generation of scientific evidence in higher learning institutions, there is a lack of coordinated efforts to tap its use for informing the policymaking process.

The study concludes that limited use of research findings from higher learning institutions in EIDM in Tanzania is caused by several factors ranging from the enabling policy environment, research agenda, funding and evidence synthesis capacity of researchers. The policy environment does not stipulate the use of research findings from universities in decision and policy making. The research activities done in the universities are meant for academic purposes such as career advancement. Policy makers need research findings that are communicated in a way different from the way academia need. However, the call by NBS on the involvement of other agencies in generating evidence for decision making provides the higher learning institutions (universities) a better chance to be involved in the process. This will be realized if the following recommendations are considered:

- The government and other development partners should raise awareness of EIDM among researchers and policymakers. This should also go together with capacity building on how to synthesize, pack and disseminate research findings.
- Establishment of a research findings synthesis unit which will serve as a one stop center to access scientific evidence packaged in a simple language. The unit will be responsible for the collection of research findings from different actors and improving interaction between policy makers and researchers by bringing the actors together. The unit should bring in people with different skills and expertise in the research findings synthesis process.. The synthesis unit will make use of various experts from various institutions and government departments.
- Academicians in higher learning institutions should take the proactive role to push for use of the empirical evidence they generate by policy makers through debates, dialogues, and conferences for enhancing the interaction between policy makers and researchers.
- EIDM should be institutionalized from the university level to the national level. Rules and regulations should be in place at the university level that demand the research projects to have findings dissemination plan. At the national level, a policy should be in place that needs all decisions to be evidence based.
- The government funding for research should be increased to reduce donor dependency. The government will invest funds in areas that need research findings to inform decision/policy making. By so doing, research findings will be demand driven hence sound decisions will be made.

**Acknowledgments**

The authors acknowledge the African Institute for Development Policy (AFIDEP) for the financial support for the study through Capacity Building and Promotion of EIDM Among Researchers and Policy Makers for

Enhanced Evidence Use in Tanzania (CREPEE) Project. We are thanksful to the Sokoine University of Agriculture for its support on the overall implementation of the project. We also wish to thank all participants involved in the study; the participation of researchers from the universities in Tanzania and postgraduate students and lecturers is highly appreciated. The authors are also grateful to the anonymous reviewers and editors for their constructive comments that have significantly improved the quality of the paper.

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**Contents**

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**Proceedings of the 2nd SUA Scientific Conference on Research and Technological Innovations Towards Transformation of Lower Middle Income Countries held at the SUA Edward Moringe Campus, Morogoro-Tanzania from 25th to 26th May 2021**

**ISSN 0856-664X**