



Pepper (*Piper nigrum* L.) harvest and postharvest handling practices used by smallholder farmers in Morogoro district, Tanzania

*¹ CHRISTIAN, A. K., ¹MTUI, H. D., ¹MAJUBWA, R. O.

¹Department of Crop Science and Horticulture, Sokoine University of Agriculture, P. O. Box 3005, Chuo Kikuu, Morogoro, Tanzania

* **Corresponding author:** anitha.christian@sua.ac.tz

Abstract

The purpose of this study was to collect baseline information on the socio-economic factors, harvesting, and postharvest handling practices among smallholder pepper farmers in Morogoro district, Tanzania. Understanding these practices is vital for developing appropriate harvest and postharvest handling techniques, but less is known about the harvesting and postharvest handling practices used by small-scale farmers in the district. The study was carried out in 10 villages of 5 wards in the Mkuyuni and Matombo divisions, using a mix of semi-structured questionnaires, key informant interviews (KI), and focus group discussions (FGD). The gathered data were analyzed using the Statistical Package for Social Sciences Version 25 (SPSS, Inc, USA, IL, USA). The results revealed that a majority (86.6%) of farmers harvested pepper when at least one berry on a spike turned red, indicating that farmers primarily rely on the visual ripeness of the peppercorns for harvesting. Regarding postharvest handling, 86.2% of farmers reported drying their peppercorns under the sun on mats, a common practice for removing moisture. For storage, nearly all respondents (98.6%) stored their dried pepper in polypropylene bags, which is standard practice in the region. However, the study also identified significant postharvest losses due to mould growth, with 95.75% of farmers citing it as the primary cause of deterioration in stored pepper. These findings highlight the need for further studies to optimize drying and storage techniques to reduce mould growth and minimize postharvest losses. Implementing improved postharvest management strategies could enhance the quality and marketability of pepper, eventually benefiting smallholder farmers in Morogoro district. This study underlines the importance of context-specific solutions to improve the postharvest handling of pepper and reduce economic losses.

Key words: *Black pepper drying; piper nigrum; postharvest management; storage of pepper*

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Introduction

Pepper (*Piper nigrum* L.) is among the earliest known, cultivated and used spices in the world. It was famously known as the black gold or king of spices because it is the most important, most popular and most widely used spice in the world (Nair, 2020; Spence, 2024). Pepper is native to the southern-western Ghats of India but now is grown in most tropical areas of the world (Kumar and Swarupa, 2017). The top five largest pepper-producing countries in Africa as of 2020 were Madagascar (2 350 MT year⁻¹), Tanzania (660 MT year⁻¹), Uganda (530 MT year⁻¹), Ethiopia (500 MT year⁻¹), and Ghana (190 MT year⁻¹) (FAO, 2020). Tanzania was ranking the third by exporting 5% of least developed countries' total spice export in 1999 (Maerere and Van Noort, 2014). Tanzania's share in the global whole black peppercorn market has dropped from 0.36% in year 2000 to 0.08% in 2020 (FAOSTAT, 2020). Diseases including stem withering and spike shedding are among causes for the decline in production (Shango *et al.*, 2020). Postharvest losses and tight spice export criteria have also contributed to the drop in export share (Mkojera, 2019). In Tanzania, the crop is widely cultivated in Morogoro, Tanga regions and Zanzibar Islands (Maerere and Van Noort, 2014). In Morogoro region, the crop is grown in the Morogoro district, particularly at Matombo and Mkuyuni divisions (Shango *et al.*, 2021a) where it

serves as cash crop with diverse domestic and industrial uses. Apart from culinary uses, the crop produces essential oils, which are used in pharmaceutical and perfumery industries (Balasubramanian *et al.*, 2016; Takooree *et al.*, 2019).

Pepper products exist in three forms; green, black, and white pepper. Black pepper is, however, the most popularly used name that distinguishes the crop plant from chili pepper (Oyemitan, 2017). In order to decrease drying time and improve colour of black pepper, harvested peppercorns are blanched in hot water at 100°C for 10 minutes before drying (Paul *et al.*, 2021). Blanching ruptures the cell walls and catalyzes the browning enzymes which decreases drying time by 44%. It also cleans the product and reduce microbial activity and load from the black pepper surface (Al-Amrani *et al.*, 2020). Green pepper is prepared from immature pepper fruits blanched at 80°C, for 2 minutes, drained, cooled, and then soaked in Sulphur dioxide solution to fix the green color before drying at 50°C. White pepper is prepared by removing the outer rind of the pepper. White pepper has a mild flavor compared to black pepper due to the absence of certain compounds found in the outer layer of the berry (Oyemitan, 2017).

Storability and quality of dried spices including black pepper are function of cultivar, harvest maturity, drying, and storage practices (Shango *et al.*, 2021a).

Unfortunately, the effect of the harvesting and postharvest handling practices used by farmers in Morogoro on quality and storability of black pepper are less understood. Improper drying may lead to development of non-uniform colour, loss of pungency and aroma, and encourage growth of mould on stored black pepper (Nelson and Cannon-Eger, 2011). Microbial fermentation and or mould development on black pepper can be reduced through adoption of proper harvest and drying practices (Das and Sharangi, 2018; Mkojera, 2019). It is hypothesized that smallholder farmers in Morogoro district use poor harvest and post-harvest handling practices, resulting in poor black pepper quality. Similarly, presence of mycotoxins and or mycotoxins producing fungi pose a barrier to international trade of food products including black pepper and cause cancer in human (Benkerroum, 2020).

The study's core research questions were: what are the harvesting and postharvest handling practices used by smallholder black pepper farmers in Morogoro district? and how does the practices affect black pepper storage quality?

This study aimed at generating key information on black pepper harvest and postharvest handling practices applied by

smallholder farmers at Matombo and Mkuyuni wards in Morogoro district. The findings from the study will help in devising proper and economically viable harvest and postharvest handling techniques for maintaining black pepper quality and minimize losses along the supply chain. The study is in line with Sustainable Development Goal (SDG) 12.3. which aim at reducing food losses including postharvest losses.

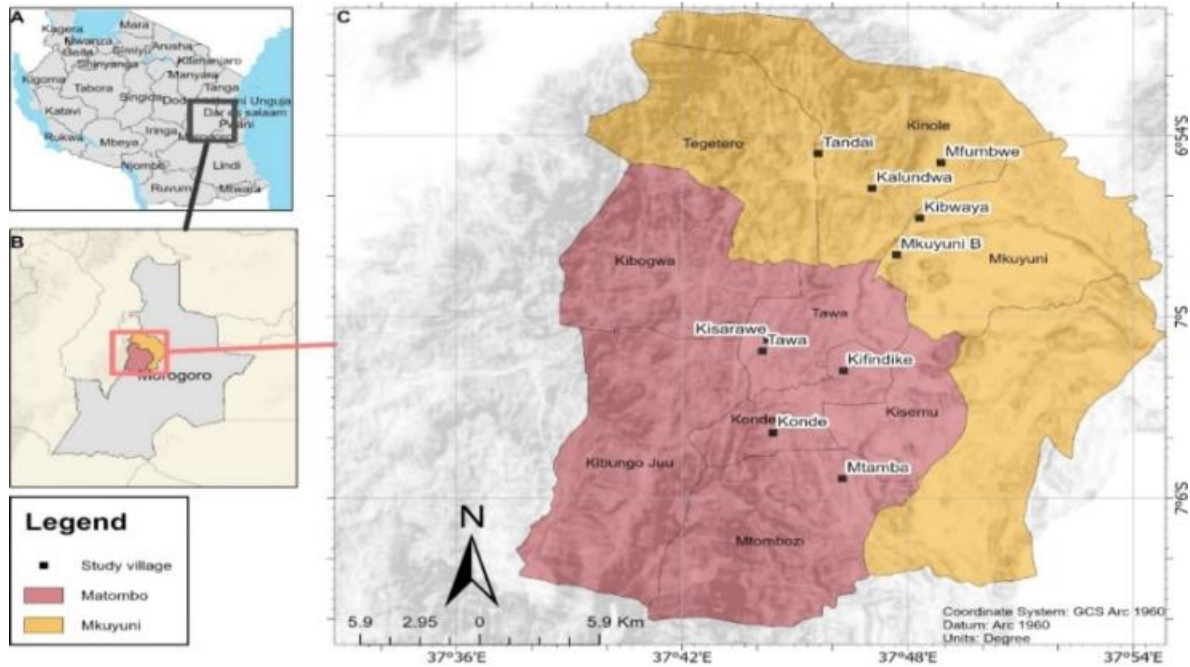
Materials and methods

Description of the study site

The study was conducted in ten villages of Mkuyuni and Matombo divisions in Morogoro district (Figure 1) during the 2021/2022 cropping season. Mkuyuni and Matombo divisions are the main pepper producing areas in the district (ITC, 2014). The area covers an altitude ranging from 250 to 600 meters above sea level (masl). The area receives short rains between November to the end of January, and long rains from February to May followed by a dry season from June to October (Meteoblue, 2021). The area receives mean annual rainfall and temperature of 2000 mm and 22°C, respectively. The mean annual minimum and maximum air temperature ranges from 15 to 17 °C and 26 to 28 °C, respectively (Meteoblue, 2021).

Figure 1

Map showing the location of the study area



Note. Map of Tanzania (A), Morogoro District (B), Villages in the Morogoro district where the baseline survey was conducted (C).

Sampling framework

A baseline survey was conducted among pepper growers in 5 wards of Mkuyuni and Matombo Divisions. Five wards were purposively selected based on their popularity in pepper production. Sample size was determined according to Yamane (1967) following the formula presented in equation 1;

$$n = \frac{N}{1+N(e)^2} \dots\dots\dots(1)$$

Where n = sample size, N = Population size, and e = level of precision (5%).

Based on a population size of 600 black pepper farmers found in the divisions, a total

sample (n) of 209 farmers was established and then sub samples from selected wards were identified using a simple random sampling approach. Random numbers were generated using Microsoft Excel and used to select farmers in each village.

Data collection

Farmers' interview

A semi-structured questionnaire coded on an Open Data Kit (ODK) software (Version V2021.3.3) was used to collect qualitative data from the 209 farmers randomly selected from the 5 wards. Data collected during the survey included; demographic information, social economic information, harvesting (pepper maturity indices and harvesting methods),

post-harvest practices (drying methods, storage methods, and postharvest handling

Key informant interview

Key informant interviews were conducted among black pepper farmers and agriculture extension officers. An interview guide on harvesting and postharvest practices applied by farmers was used for consistency during the interviews. At least two key informers were interviewed in each ward.

Focus Group discussion

Focus group discussions were conducted with groups of at least five farmers. Farmers of mixed gender were selected (Krueger and Cassey, 2000) from farmer groups already established by Sustainable Agriculture Tanzania (SAT). In addition to the checklist, follow-up probing questions were applied when the content was unfamiliar or new. Audio recording and note-taking approaches (Nyumba *et al.*, 2018) were adopted to improve the quality of data collection. Each focus group discussion lasted for approximately thirty minutes.

Data analysis

Collected data were analyzed using Statistical Package for Social Sciences program V25 (SPSS Inc, USA, Chicago, IL, USA). Qualitative data from FGD and KII were transcribed into categories based on the content (Sim and Waterfield, 2019). The statistical significance of relationships among

constraints) applied by black pepper farmers.

variables was determined using the Chi-square test at $p \leq 0.05$.

Results

Socio-demographic information of respondents

The majority of farmers interviewed (79.9%) were male and 20.1% were female, aged 38 to 55 years (Table 1). The majority of pepper farmers had a primary school education (77.5%) and more than ten years of farming experience (50.8%).

The findings show that nearly all farmers (99.5%) in the study area relied on agriculture as their primary source of income (Table 1). Approximately 56% of farming households had 3-5 family members (Table 1). The majority of pepper growers (84.21%) in the study area were part of social economic groups. Agriculture and credit and saving were the most common activity in social groups (44%) through Village Community Banks (VICOBA) (Table 1). Through formed farmer groups, black pepper growers were able to get numerous trainings, including postharvest treatment of various crops (including spices).

Table 1*Social-demographic information of respondents*

Variable	Category	Frequency percentage of respondents) n=209
Gender of respondents	Male	167 (79.9)
	Female	42 (20.1)
Age of respondents (Years)	19 to 37	51 (24.4)
	38 to 55	94 (45)
	56 to 73	53 (25.4)
	>73	11 (5.3)
Level of education	No education	23 (11)
	Primary education	162 (77.5)
	Secondary education	24 (11.5)
Pepper farming experience (Years)	1 to 5	54 (25.8)
	6 to 10	47 (22.5)
	>10	108 (47.8)
Main source of income	Farming (Agriculture)	208 (99.5)
	Self-employment	1 (0.5)
Household size	0 to 2 people	14 (6.7)
	3 to 5 people	117 (56)
	6 to 9 people	74 (35.4)
	>9 people	4 (1.9)
Social group membership	Yes	176 (84.21)
	No	33 (15.78)
Activities performed in social groups	Agriculture only	76 (36.4)
	Credit and saving through VICOBA	8 (3.8)
	Agriculture + Credit and saving through VICOBA	92 (44)

Note. Numbers in parenthesis indicate the percentage of respondents in the specified category

Harvest and postharvest handling of pepper

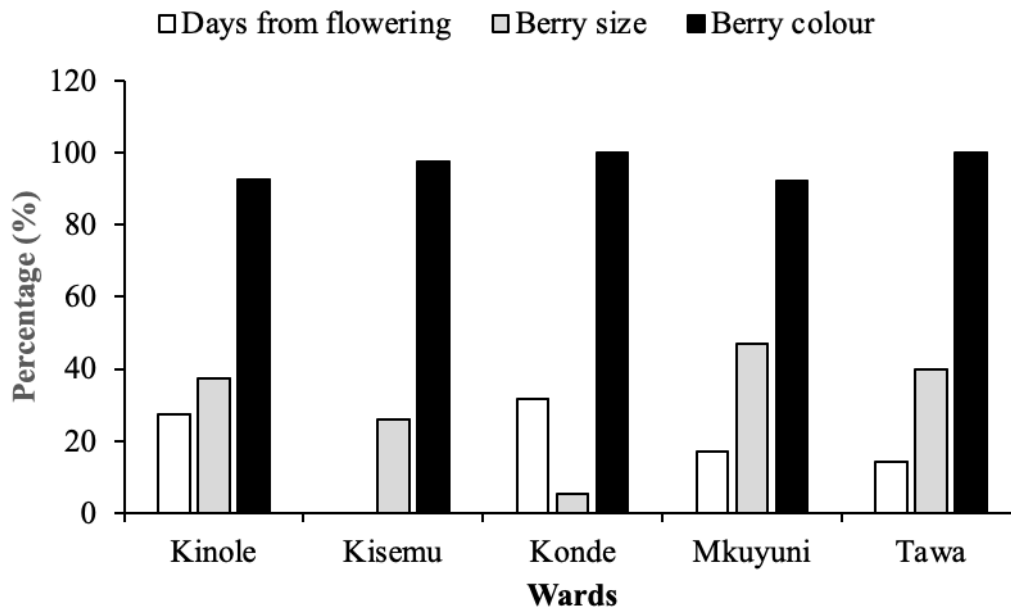
Pepper maturity indices used by farmers

The dominant maturity indicator used by farmers across wards was colour change from green to red (95.75%) (Fig. 2). On the other hand, the proportion of farmers using time (days) from flowering ($\chi^2 = 10.61$, $df = 4$, $p = 0.031$) and berry size ($\chi^2 = 12.281$, $df = 4$, $p = 0.015$) as harvest maturity indices varied

significantly between wards (Fig. 2). Time from flowering (in days) was more used in Konde (31.6%) ward followed by Kinole (27.5%), and Mkuyuni (17.5%) than Tawa (14.3%) wards. However, berry size was much more used at Mkuyuni (46.9%), followed by Tawa (39.7%) and Kinole (37.5%) but less at Kisemu (26.1%) and Konde (5.3%) wards (Figure 2).

Figure 2

Pepper maturity indices used by farmers in Morogoro District



Note. Pepper maturity indices used by farmers in Morogoro District

Harvesting practices of pepper

Most farmers (77.5%) reported to harvest pepper by selecting mature spikes only. About 22.5% farmers reported to harvest all spikes on a pepper plant at once. During FDGs and KII, farmers reported to have two harvesting seasons of pepper in the study

area; the minor season (June-August) and the major season (December-January). During the minor season yields are estimated to be three times less than in the major season. It was further revealed that some farmers were convinced to harvest their pepper crop earlier at pre-mature stage to catch up with the

higher market prices early during the minor harvesting season.

Drying of pepper

The proportion of farmers using concrete floor ($X^2 = 36.934, df = 4, p = 0.001$) and Canvas ($X^2 = 33.976, df = 4, p = 0.001$) (Fig. 3) varied significantly between wards in the study area. The proportion of farmers using concrete floor was high in Mkuyuni ward (39.5%) and low in Kinole (7.5%) ward but no farmers were found to use concrete floor in Kisemu and Konde wards. Percentage of

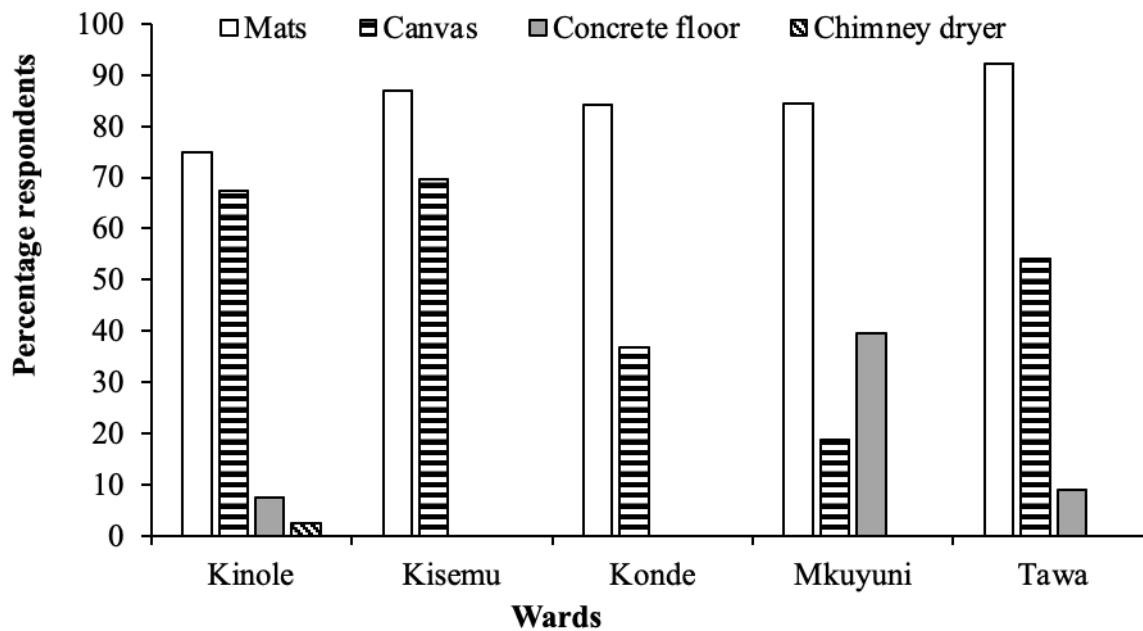
canvas users was higher at Kisemu (69.6%), Kinole (67.5%) and Tawa (54%) wards but least at Mkuyuni ward (18.8%). Chimney drier was less prominent and used only by a few farmers (2.5%) in Kinole (Figure 3).

According to KII, the majority of farmers dry pepper for 2.5 to 3 days before storing it.

However, during FGDs, farmers claimed that they do not monitor pepper moisture when drying since they do not have the means to do so.

Figure 3

Drying facilities used in Morogoro District



Note. Drying facilities used in Morogoro District

Storage of pepper

Generally, most respondents stored pepper on woven polypropylene bags (98.6%). Only 4.8% of respondents used sisal bags followed

by those using buckets (1.9%), and metal pots (0.5%). The time used to store produce varied significantly ($X^2 = 19.113, df = 3, p = 0.001$) with package. According to KII, farmers

utilized woven polypropylene for extended storage and buckets for short-term storage. Through FGDs and KII it was revealed that pepper farmers were aware of sisal bags but were not using them because of scarcity.

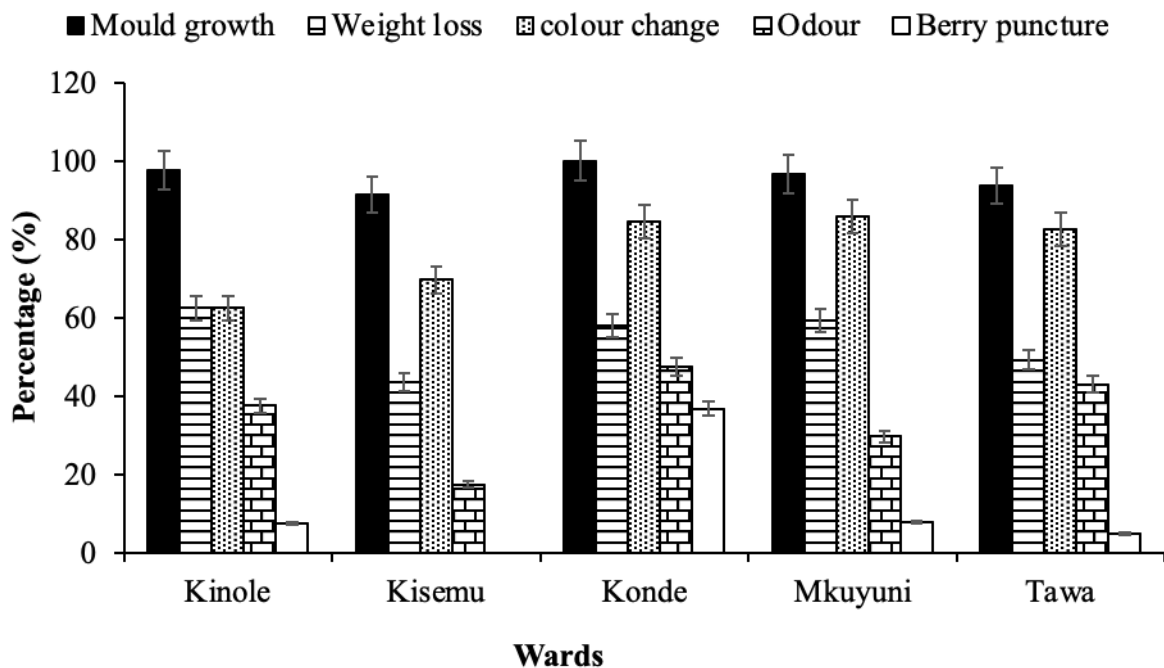
Causes of pepper spoilage

Overall, most of the pepper spoilage in the study area was due to mould growth (95.75%), followed by colour change (development of whitish materials on berries) (79%), weight loss (55%), odour (off flavour) (35.4%), and berry cracking (8.6%) (Fig. 4).

However, farmers' response on causes of pepper spoilage in terms of colour change ($\chi^2 = 10.21, df = 4, p = 0.037$) and berry cracking ($\chi^2 = 27.707, df = 4, p < 0.001$) varied significantly between wards (Fig. 4). Deteriorations of pepper due to colour change was highly reported in Mkuyuni (85.9%), Konde (84.4%), and Tawa (82.5%) wards compared to Kisemu (69.6%) and Kinole (62.5%) wards. Berry cracking was mostly reported at Konde ward (36.8%) compared to Mkuyuni (7.8%), Kinole (7.5%) and Tawa (4.8%) wards (Figure 4).

Figure 4

Causes of pepper spoilage in Morogoro District



Note. Causes of pepper spoilage in Morogoro District

Post-harvest handling constraints

The most postharvest handling challenge experienced by farmers was mould growth (45.5%) followed by low price and lack of potential customers (36.4%) (Table 2). There were high incidences of mould infestation in peppers harvested during the main season (73.7%) compared to low (lean) season (1.9%) (Table 2). FGDs and KII revealed that all pepper cultivars

were similarly infested by mould. Farmers used different strategies to prevent mould growth including drying pepper under the shade place during rainy season (35.4%), washing mouldy berries with warm water and re-drying (27.3%), as well as rubbing mouldy berries with cooking oil (12.4%) (Table 2).

Table 2

Postharvest handling constraints of pepper in Morogoro District

Variable	Category	Frequency percentage of respondents) n=209
	Mould growth	95 (45.5)
Postharvest handling challenges	Others (lack of potential buyers, low price)	11 (36.4)
	Others (climate change, high production costs)	24 (11.5)
Incidence of mould infestation	High season (December-January)	154 (73.7)
	Low season (June-August)	4(1.9)
Techniques used to prevent/remove mould growth on pepper berries	Washing with warm water and re-drying	57 (27.3)
	Rubbing with cooking oil	26 (12.4)
	Drying under the shade place during the rainy season	74 (35.4)

Note. Numbers in parenthesis indicate the percentage of respondents in the specified category; where % totals add up to more than 100% there were multiple categories selected by respondent.

Discussion

This study has indicated that there is low involvement of female and youth in black pepper farming in Morogoro district. The same trend has been reported among farmers of food crops and most high value crops grown in Africa and Asia (Elias *et al.*, 2018). The fact that males tend to work on crops with high value, could account for their predominance in the production of black pepper. According to Ingabire *et al.* (2018), men are more engaged in high-value ventures than female. As a value chain becomes more commercialized, males will tend to outnumber women. This suggests that pepper is a high value crop in the study area.

Results suggests that majority of the farmers in the study area had low level of education which could lead to low adoption of improved postharvest handling practices of pepper. Farmers with low level of education struggle to understand written information and combine technical skills with implicit local understanding of post-harvest management practices. A study conducted by Abate *et al.* (2019) reported that increase in education level improve ability of farmers to utilize existing technologies. Given the long-term involvement of the farmers in pepper farming, it suggests that farmers had enough experience in pepper production which could also favour good postharvest handling practices of pepper in the study area. Ng'atigwa *et al.* (2020) noted that farmers with more experience in

farming tend to develop some technical knowledge in farming including harvest and postharvest management compared to those with little or no experience. However, such experience seems to increase when coupled with additional formal trainings (Otekunrin *et al.*, 2021).

The family size of 3 to 5 people (56%) suggests unavailability of enough family work force for agricultural activities among the pepper-farming households in the study area. Household members serve as family labour against shortfall of hired labour (Otekunrin *et al.*, 2021). The majority of post-harvest tasks such as timely harvesting, drying, winnowing, packaging is labour-intensive and require a large number of people. It has been reported that a 1% rise in adult family size in households would result in a 0.77% decrease in the probability of crop post-harvest losses (Bachewe *et al.*, 2020; Stathers *et al.*, 2020). Involvement of farmers in social groups such as VICOBA helps to increase farmers' access to financial supports that are difficult to acquire through commercial banks and access to agricultural services and information. It also improves their voices in making agricultural decisions (Ainembambazi *et al.*, 2017; Abdul-Rahaman and Abdulai, 2018).

The use of colour change as harvest maturity index was common because allowing berries to over ripen leads to berry drop and damage by birds (FGDs). Commercial harvest maturity of pepper is judged based on colour, when one or two berries on a spike change from green to yellow (Ganapathi *et al.*, 2018; Roslan and Yodin, 2020) the whole spike can be harvested. Despite of colour being used as a standard indicator for harvest maturity of pepper, timing of colour change on berries (at least one berry per spikelet) was still a challenge. Through FGDs, it was explained that some farmers picked berries when they turned from green to yellow and some from green to red. The use of berry size as harvest maturity indicator suggests that, less precise maturity indicators are used to judge readiness of berries for harvest. This could potentially increase the chances of harvesting pepper at immature stage because berry size varies with cultivar (Shango *et al.*, 2021b). Such practice could lead to poor quality of the pepper produce in terms of pungency, pepper colour, and storability (Balasubramanian *et al.*, 2016).

Harvesting was done by climbing on tall pepper plants with bamboo sticks or ladders, as pepper plants might reach heights of more than 40m. Bharathi and Akila (2021) also have reported similar practice in India. The harvest practices could lead to poor spike selection during picking. Farmers could opt to harvest all spikes to avoid the risks of repeated climbing. Swarnapriya (2020) reported that harvesting of pepper berries from tall trees requires experienced and skilled labourers. It also takes time to climbing and do the selective harvesting.

Harvesting of pepper at pre-mature stage leads to product with low saleable weight, less flavor quality and storability (Balasubramanian *et al.*, 2016). Variations in drying facilities used by farmers across wards was partly attributed to their availability and accessibility. For instance, the availability of concrete floor in Mkuyuni facilitated by Sustainable Agriculture Tanzania (SAT) led to increased use of the facility compared other wards (39.5%) (KII). Prominence and repeated use of mats by majority of farmers across wards suggest the possibility of cross contamination of produce among farmers (if lend each other) and between seasons. Mats can harbor fungal spores, bacteria, and other microorganisms from the previous season which can contaminate pepper berries during the drying process. Use of mats also suggests potential contamination by extraneous materials such as dust and animal droppings if they are placed on the ground. The results are supported by Sitorus *et al.* (2020) who reported that farmers in India dried pepper traditionally using bamboo mats.

Open sun drying method results in poor quality produce since the food material is easily polluted by dirt, dust, damage from animals, birds, or insects and their droppings. Similarly, direct exposure of pepper to sun radiation degrades some produce quality and render it susceptible to fungi, bacteria, and other microorganism attack (Lingayat *et al.*, 2020).

Through FGDs and KII it was reported that berries were considered dry when it gave sound similar to that of poured rice. This suggests deficits in measure of dryness and that pepper may have over or under dried. Mkojera, (2019) found that the moisture content of pepper dried

using such practice was 12.3% which is higher than the safer limit of 10-11% for black pepper. Also, pepper drying was done for an average of 2 to 3 days, contrary, Roslan and Yodin, (2020) reported that pepper take up to seven days to dry under the open sun depending on weather condition. De vera *et al.* (2017) speculate that difficulty encountered under open sun drying is the drying time since there is no proper evaluation of the moisture released with respect to time. Such practices are likely to encourage mould growth on pepper. Das and Sharangi, (2018) explained that drying is an important process to reduce mould growth. Moisture content higher than 12% was potentially the main cause of mould growth on pepper (Mkojera, 2019).

The use of hermetic bags to store pepper was not common among pepper farmers in the study area although could potentially reduce moisture loss or gain and hence lower mould growth on produce. Susceptibility of dried spices to spoilage and toxin-producing microorganisms increases with water activity above safe limits, and storage temperature suitable for their growth (Duncan *et al.*, 2017). Through FGDs and KII it was explained that farmers have no knowledge of safe limit of moisture levels for black pepper storage. Field observation indicated that farmers in the study area stored packaged pepper on the floor in rooms without enough air circulation. Such storage conditions favour contamination by decay microbes, insects and rodents, thus increasing postharvest losses. Similar results on storage were reported by different scholars in other crops in developing countries (Díaz-Valderrama, 2020; Manandhar, 2018; Mkojera, 2019 and Njoroge, 2019). For instance, Mkojera (2019) reported that pepper was stored in living and bed rooms on the floor thereby favouring contamination.

Difference in pepper spoilage causes among wards may be due to variations in physical factors such as moisture, temperature and relative humidity. The high percentage of pepper spoilage due to mould growth could be due to improper drying of pepper, poor storage facilities, and or storage environment. According to Manandhar *et al.* (2018) mould proliferation is higher at temperature ranging between 25°C-30°C and relative humidity of 70%. The temperature range in the study area is 15-28°C (Meteoblu, 2022)

which is within the range favouring mould growth. Also, a study by Das and Sharangi (2018) reported that pepper tends to deteriorate very rapidly, so the storage facility should be very adequate. Before pepper storage moisture levels should be reduced to safer limits (12%). Moisture content above 12% encourage microbial infestation (Nair, 2020).

Findings on postharvest constraints facing black pepper farmers such as low price and lack of potential customers (36.4%) are consistent with that of Wulandari (2022), who reported that pepper is a commodity with comparatively high price volatility because of higher production risk involved in pepper production.

The high incidence of mould growth during the high season could be attributed to rainfall and high relative humidity. The intensity and amount of sunshine tend to decrease during the rainy season. Roslan and Yudin, (2020) reported that pepper quality is further degraded by the delays in drying during rainy days. During rainy days the drying process takes long time and moisture removal off the product is not uniform which favour mould growth.

Different techniques were used to prevent and or remove mould growth on black pepper such as washing mouldy pepper with warm water and re-drying (27.3%). In addition to mould control, such treatment also is known to preserve black pepper's colour. This may drive sales because local consumers care about the product's appearance. Similar findings were reported by Mkojera (2019) who indicated that farmers masked the effects of mould growth on pepper by rubbing degraded pepper with cooking oil.

Conclusion and Recommendation

Our research has provided insight into how pepper is harvested and handled after harvest in Tanzania's Morogoro district. Berry colour change from green to red was the most used maturity indicator. Stage of harvesting was mainly influenced by market demand. Pre-mature berries are harvested when market demand and prices are high. Despite the smaller proportion of farmers who harvested all spikes on a pepper plant at once, its impact on degrading the quality of pepper cannot be under estimated. The under

open sun pepper drying methods as the most used approach suggest difficult drying of the crop harvested during rainy season. Introduction of alternative drying technologies may help to reduce postharvest loss of the crop. The commonly used measure of pepper dryness, poured rice sound, is an inaccurate moisture content determinant to allow farmers to store well dried product. Alternative moisture content determination techniques are required to allow proper and long storage of pepper. Woven polypropylene bags were the most popular pepper storage packages as farmers lack knowledge and access to alternatives improved storage packaging. Introduction and side by side evaluation of alternative storage packages is required to enhance their adoptions in the study area. Occurrence of mould on pepper was favoured by storage conditions. Tailor made training on proper harvest maturity, harvesting, drying and storage are potential to enhance quality of pepper among farmers in the study area. This become essential because of the inherent socio-economics and climatic conditions of the study area.

Acknowledgement

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Conflicts of Interest

The authors declare no conflict of interest.

Ethical approval

Ethical clearance was obtained from the Directorate of Research, Technology Transfer and Consultancy of Sokoine University of Agriculture

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