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Effect of harvesting stage on postharvest quality of black pepper (*Piper nigrum* L.) cultivars grown in Morogoro, Tanzania

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Abstract

Optimal harvest maturity stage determines the on-shelf quality of black pepper (Piper nigrum L.). Small-scale farmers in Morogoro harvest black pepper before reaching full maturity to catch up with high market prices offered early in the season. Unfortunately, traders are complaining on the quality of black pepper from the area. This study evaluated the effect of harvesting stages on post-harvest quality of pepper cultivars grown in the Morogoro district. Pepper cultivars; Babu kati, Babu kubwa, and Ismailia at premature and mature stages were dried on coconut leaves mats to suitable drying stage. Treatments in a 2 x 3 factorial experiment following a complete randomized design (CRD) were replicated thrice. Statistical significance of variables was generated by ANOVA and mean separation by Tukey HSD test at $p \leq 0.05$. Results showed a significant ($p<0.001$) difference between harvest stages and cultivars on berry colour, moisture content, berry firmness, dry recover and weight loss percentage. Pepper berries at pre-mature stage across cultivars had higher (79.11%) initial moisture content than mature berries (71.6%). Mature berries had higher dry recovery percentage (28.84%) than pre mature (15.78%). Mature "Ismailia" berries had the highest firmness (10.5kg/mm2) than premature (5.8 kg/mm2). During sun drying, colour values L*(brightness), and b* (yellowness) decreased significantly while greenness decreased as a* values increased from more negative values to zero in both harvesting stages as pepper berries darkened. Colour changes were sharper on mature than pre-mature harvested pepper corns. These findings will help farmers to make right decision on when to harvest for quality black pepper product. Farmers are recommended to harvest black pepper when mature for better firmness and colour development during drying. Further studies are required to determine the sensory quality and volatile oil contents of the cultivars when harvested premature and mature stages.

Keywords: *Piper nigrum; berry fruit quality; postharvest handling; pepper harvesting stage, black pepper drying*

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Introduction

Black pepper (Piper nigrum L.) is one of the oldest and most widely used spices in the world (Salehi et al., 2019). Because of its high demand in the international market, black pepper is also known as the 'King of Spices' or Black gold

(Somashekar *et al.*, 2021). Because of the therapeutic benefits, black pepper has long been used to treat rheumatoid arthritis, dyspepsia, asthma, pain, and respiratory tract infections in many Asian nations (Tran et al., 2019). Also, it has stimulant, digestive, tonic, and antibacterial properties (Takooree et al., 2019). The harvestable part of the crop is the fruit that at various stages of maturity can produce white, green, and black pepper (Oyemitan, 2017). White pepper is extracted when pepper berries are harvested before reaching full maturity, after the outer peel of the berries has been removed. Black pepper is a product prepared from well mature berries with their peel intact and has a stronger flavour. Green pepper is distinguished by its herbal, fresh taste and is developed from unripe berries preserved on brine or vinegar (Khew *et al.,* 2022) or from immature pepper fruits blanched for 2 minutes at 80^{o}C, then drained, chilled, and soaked in Sulphur dioxide solution to fix the green color before drying at 50^{o}C (Oyemitan, 2017). This study focuses on black pepper rather than other types of pepper.

The main producers of *P. nigrum* are; India, Brazil, Indonesia, Malaysia, Vietnam, and Sri Lanka (Dosoky *et al.*, 2019). Tanzania is one of the top five pepper producing countries in Africa, with 450 metric tons produced in 2018 (FAOSTAT, 2020). In Tanzania, the crop is grown in Morogoro, Tanga and Zanzibar (Maerere and Van Noort, 2014) where the main product traded is black pepper.

Black pepper has asynchronous nature of flower development and non-uniform fruit ripening within a spike. The subsequent uneven timing of pepper fruits (berries) maturity needs a considerable labour input for proper harvesting of the black pepper products (Khew *et al.*, 2020). To produce dried black pepper with good appearance and other qualities, pepper berries must be harvested at the correct stage of maturity (Bharathi and Akila, 2021). That is important because, black pepper postharvest performance determined by the maturity or physiological status of the fruit at harvest in combination with postharvest management practices applied. The quality of black pepper is lowered when pepper berries are harvested at pre mature or over ripened stage (Mishra and Gamage, 2020).

Pepper plant established from cuttings the first harvest is realized in the third year from planting and the maximum production is reached in the fifth to seventh year (Jayashree, 2011; Thangaselvabal *et al.,* 2008). A well-managed crop can produce for up to fifteen years and continue to provide fruit into its 20th to 50th year (Anitha and Hore, 2018). After flowering, the fruits take between eight and nine months to reach maturity (Das and Sharangi, 2018). The optimal harvesting stage for black pepper is at the late hard-dough stage when one or two berries change colour from green to yellow or red (Das and Sharangi, 2018). Typically, in Morogoro district a single bamboo pole is used as ladder support for reaching spikelets at the higher part of the crop plant (Bharathi and Akila, 2021). Because of such inconveniences and desire to catch up with the higher early market price in a season, most farmers at Morogoro pick black pepper fruits at both immature and mature stages (Mkojera, 2019). Such practices are likely to compromise the final quality of pepper products for compliance with local, regional and world markets.

Similarly, in other parts of the world farmers harvest pepper berries earlier to avoid heavy loss due to berry drop and damage by birds (Balasubramanian *et al.*, 2016). Unfortunately, such practice can affect the appearance, sensory and postharvest quality of black pepper (Hu *et al.*, 2019). For instance, piperine content has been reported to be higher on mature than immature harvested pepper cones (Do, 2022). Less is known about the at harvest and postharvest responses of the pepper cultivars grown in Morogoro, Tanzania when harvested at immature and mature stages. This study therefore aimed at evaluating the extents of effects of the harvesting stages on harvest and post-harvest quality of three pepper cultivars grown by smallholder farmers in Morogoro district. The information generated will help to inform farmers and traders for better management of harvest maturity and hence improve quality of their black pepper products.

Materials and Methods

Description of the study site

Field experiments were conducted at Tandai village (6°54´ S, 37°45´ E 779 m.a.s.l), Mkuyuni division in Morogoro district during the 2021-22 cropping season. Drying of pepper was conducted at the Horticulture unit of Sokoine University of Agriculture (SUA). Tandai village experience means annual rainfall range of 1000 - 3000 mm and mean annual temperature ranging from 15°C to 28 °C (Meteoblue, 2022).

Plant materials

Three most common black pepper cultivars; Babu kati, Babu kubwa and Ismailia grown by farmers in the study area were used. Detailed morphological characteristics of the cultivars are detailed by Shango *et al.* (2021). Selection of experimental plants considered consistence on bearing and age of the plants (5 years old).

Experimental design

A 2 x 3 factorial experiment in a complete randomized design (CRD) was used. Three pepper cultivars (Babu kati, Babu kubwa, and Ismailia) were harvested at two different maturity stages (pre mature and mature). Each of the six treatment combinations were replicated three times. For tracking of berry maturity, spikes were tagged during anthesis and measurements taken on monthly basis for nine months. Pre mature harvesting was done when all berries on the spikes were still green, which was 46 days before maturity and mature harvesting was done when at least two berries within a spike changed colour from green to yellow. Drying of pepper was done on mats made of coconut leaves for 8 hours a day from 0800 hours to 1700 hours. Drying was done until when the pepper attained the required moisture content (12%). Two kilograms of fresh pepper berries of each treatment combination was used per replicate. The average temperature, relative humidity, sunshine hours and radiation during drying were 22.48^{O}C, 68.31%, 5.6 Hours and 15.13 MJ/m^2 respectively (TMA, 2022).

Data Collection and Analysis

Moisture content analysis

A sample of 100 g of pepper was measured using a digital kitchen scale (Wheel balancing machine, ADG 2000, Wagtech International Ltd, UK) and put on paper envelopes (10.2 cm * 21.6 cm) then placed on baking sheets of conventional laboratory oven (Memert GmbH+Co.KG, ULM 400, Germany) set at 105±3^{o} C for 24 hours (Danso-Boateng, 2013). Oven dried samples were cooled in a desiccator containing silica gel beads for half an hour to allow the envelopes to cool under dry conditions before taking measurements. The moisture content was calculated as the difference between the initial and oven dry weight divided by the oven dry weight (AOAC, 1975). Percentage moisture content was calculated using equation 1 below;

$$Moisture\ content(\%) = \frac{Initial\ weight - Oven\ dry\ weight}{Initial\ weight} X\ 100 \ldots\ldots\ldots\ldots (1)$$

Dry recovery rate

A total of 100 pepper seeds were picked randomly from each treatment combination and weighed using a digital kitchen scale (Wheel balancing machine, ADG 2000, Wagtech International Ltd, UK). The seeds were weighed before drying to obtain the fresh weight and after drying (dry weight). Percentage dry recovery (dry matter content) was calculated according to (Somashekar *et al*., 2021) using equation 2;

$$Dry\ recovery\ (\%) = \frac{Dry\ weight}{Fresh\ weight} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Berries colour measurement

Berry colour of fresh and dried berries were determined according to (Keskin *et al*., 2021) using a chroma meter (Konica-Minolta, CR-400, Osaka, Japan) at 24 hours' intervals. The colour was expressed in terms of the International Commission on Illumination (CIE) using the L*, a* and b* values, where L* represent brightness of the colour (0 = dark, 100 = bright), a*; redness-greenness (-60: green, +60: red), b*; yellowness-blueness (-60: blue, +60: yellow). The Chroma meter was set up for illuminant C and adjusted using a standard white reflector plate. Three readings for an individual sample were made and the average recorded.

Percentage Weight Loss during Drying

Percentage weight loss (%) during drying was calculated according to (Hayat, 2020) using equation 3;

$$Weight\ loss\ (\%) = \frac{Initial\ weight - final\ weight}{Initial\ weight} X100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where the initial weight refers to the initial daily weight and final weight refers to the final daily weight recorded at the end of each day of drying.

Berry firmness

Berry firmness in terms of compression force (kg/mm^2) was measured according to Burdon *et al.* (2014) using a hand-held pressure tester (FT 011, USA) mounted on a manual test stand (QA Supplies LLC, USA). Five berries from each treatment combination were compressed separately using a 11mm diameter probe tip. The maximum force (Kg/mm^2) required to compress each berry to cracking was recorded. During the drying period, firmness was measured at 24 hours interval.

Data Analysis

The collected data was subjected to analysis of Variance (ANOVA) using R statistical software version 4.0.4 (R Core Team, 2021**)**. Means separation was done using Turkey's HSD test. In all cases, differences were considered significant ($p<0.05$).

Results

Berries colour measurement

The colour of dried pepper is a key indicator of pepper quality since buyers prefer black pepper with dark/black colouration. Colour change of black pepper during drying was marked by a decrease in L* values (increase in blackness) and b* values (decrease in yellowness) and increase in a* values (increase in redness). The study tracked colour change of immature and mature harvested black pepper of "Ismailia", "Babukubwa", and "Babukati" pepper cultivars prior and during drying. There was a significant interaction between cultivar and harvest stages ($p<0.01$) in terms of L*, b*, and a* values. Pre-mature berries of Ismailia were more blighter (L* =33.63) than Babu kubwa (L* =31.12). The trend is revised at maturity where berries of Babu kubwa were more brighter (L* = 29.99) compared to Babukati (L*=25.04) and Ismailia (L*=22.19) (Figure 1a). These findings suggest that, berry brightness changes are less consistent among cultivars. During drying, all pepper cultivars showed progressive decrease in L* values (darkening) but the rate of decrease was much higher on mature than pre-mature berries. Among mature fruits, rate of darkening during the first four days of drying was higher on Ismailia and Babukati than Babukubwa. For the pre-mture berries, higher rate of darkening was observed on Babukubwa in the first four days of drying.

Similarly, decrease in b* values (yellow colouration) were significantly higher ($p<0.001$) on mature Ismailia and Babukubwa than Babukati cultivars. For pre-mature berries, the rate of decrease was higher on Babukubwa than Ismailia and Babukati. The variation was much vivid on day 2, 3 and 4 of drying (Figure 1c).

The increase in a* values (increase in berry redness) varied significantly between cultivars and harvest stages. In the first two drying days (day 2 and 3) development of red colouration was higher on Ismailia and Babukati than on Babukubwa (Figure 1b). The trend is revised for pre-mature harvested berries where red colouration is higher on Babukubwa than Ismailia and Babukati, particularly from day one to day 4 of drying. It is however fortunate that, at the end of drying all pepper cultivars attained relatively similar colouration (L*, b*, and a* values) (Figure 1 a, b, and c). This study however, noted that, when pepper is harvested mature, the drying time to reach the required colouration and moisture content is reduced from 6-10 to 4-5 days.

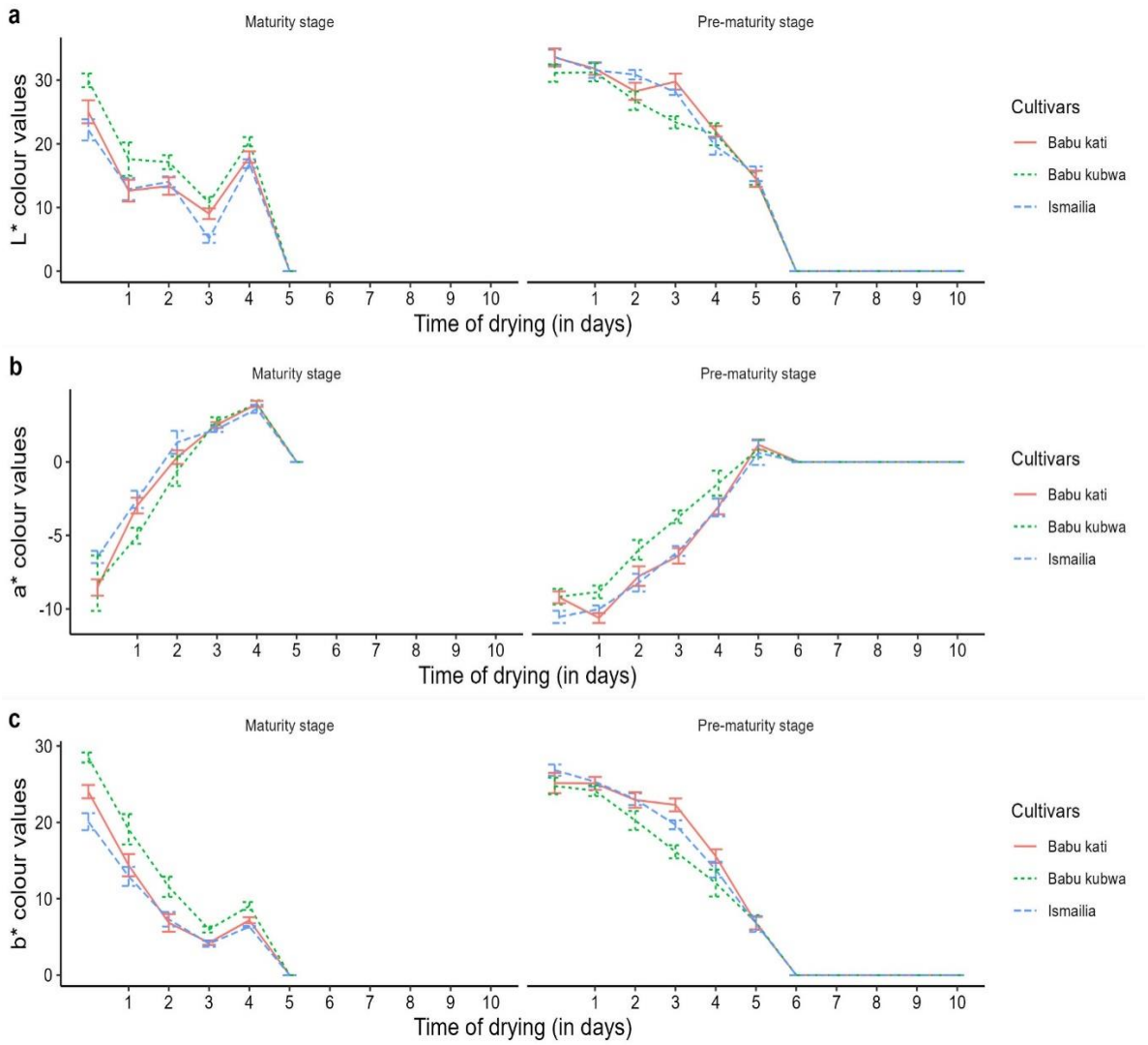

*Figure 1a, 1b,1c. Change in (L*a*b*) colour values of pepper berries harvested at pre-mature and mature stages during sun drying*

Moisture content

Maturity stage had significanf effect on initial moisture content of pepper berries at harvest ($p=1.21\times10^{-5}$). The average moisture content of pepper berries harvested at pre-mature stage was higher (79.11%) compared to that recorded in mature pepper beries (71.61%). There was significant interaction ($p<0.001$) between pepper cultivars and harvesting stages in terms of moisture content. At mature harvesting stage, Babukati (75.8%) demonstrated to have significantly higher moisture content than Babukubwa (70.1%) and Ismailia (68.86%), On day 0, day 2 and day 3 of drying, pre-mature harvested berries of Ismailia (80.33%) and Babukati (80%) had higher moisture content than Babukubwa (77.00%) (Figure 2). Regardless of the cultivar premature and mature harvested pepper berries required nine and four days respectively to dry to optimal moisture conent of <12% moisture content (Figure 2).

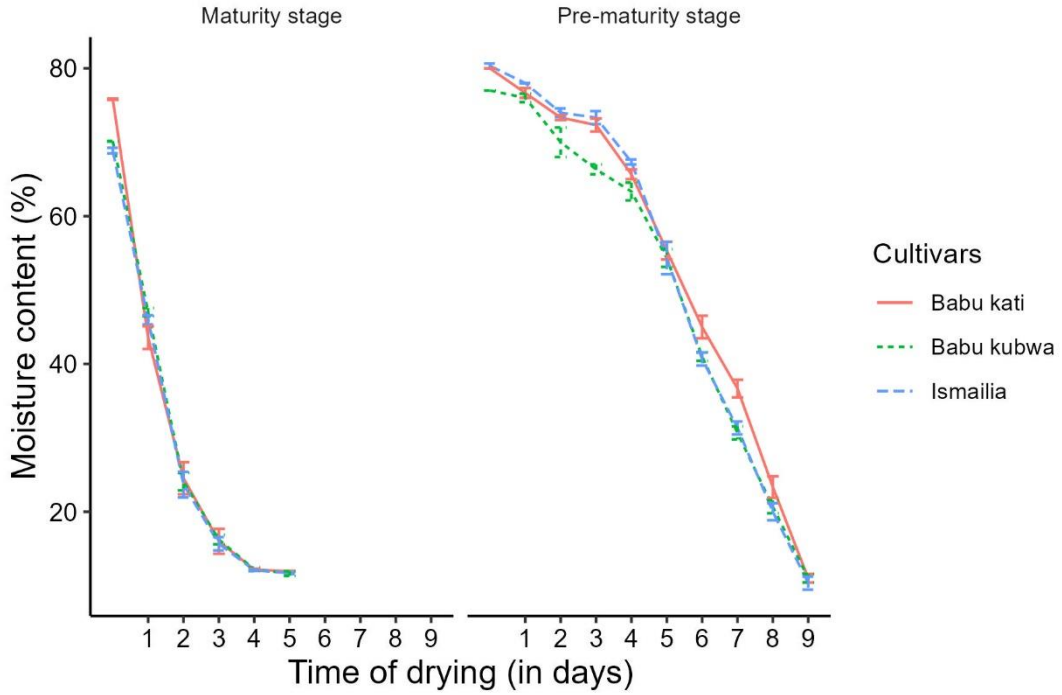

Figure 2. Moisture content loss in black pepper cultivars harvested at pre mature and mature stages during sun drying

Dry matter recovery percentage

Results on dry matter recovery percentage as affected by harvesting stage is presented in figure 3. There was significant interaction ($p=3.86\times10^{-5}$) between cultivars and pepper maturity stage in terms of dry matter recovery percentage. Pepper berries harvested at mature stage had higher dry matter recovery (28.84%) compared to pre-mature harvesting stage (15.78%). Cultivars harvested at pre-mature stage varied significantly on dry recovery percentage ($p=2x10^{-8}$). Babu kati harvested at pre-mature stage had significantly higher dry matter recovery (23.07%) compared to Ismailia (14.20%) and Babu kubwa (10.08%) (Fig. 3). However, at mature harvesting stage all cultivars did not vary significantly on dry matter recovery percentage ($p=0.2$) (Fig. 3).

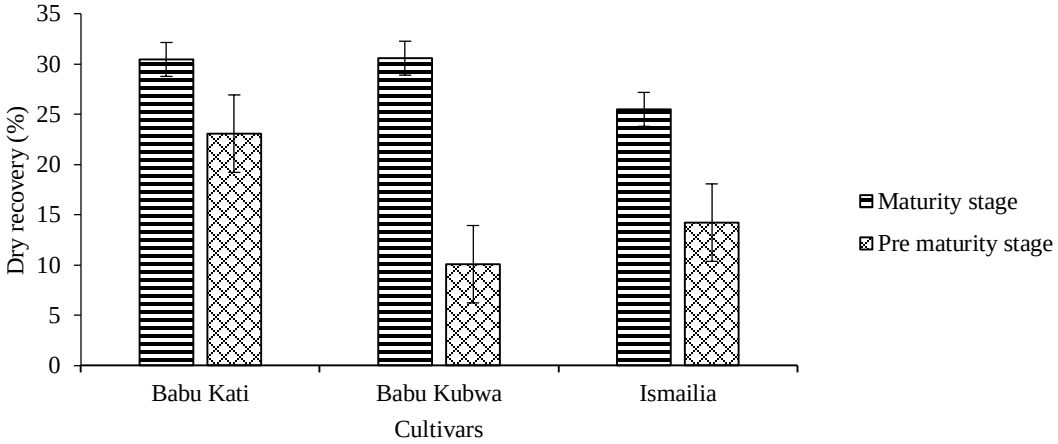

Figure 3. Dry matter recovery percentage of pepper berries harvested at pre mature and mature stages after sun drying

Percentage Weight Loss during Drying

The current study revealed a significant ($p=3.66\times10\text{-}5$) interaction between cultivars and harvest stages in terms of weight loss percentage. Regardless of the cultivar, pepper berry harvested at pre-mature stage had higher percentage weight loss (74.21%) than those harvested at mature stage (71.26%). However, pre-mature harvested berries of Babukubwa (89.92%) and Ismailia (85.79%) cultivars had significantly higher percentage weight loss than pre-mature harvested Babukati (76.92%) (Fig. 4). Similarly, Mature harvested berries of Ismailia had significantly higher percentage weight loss than Babukati and Babukubwa.

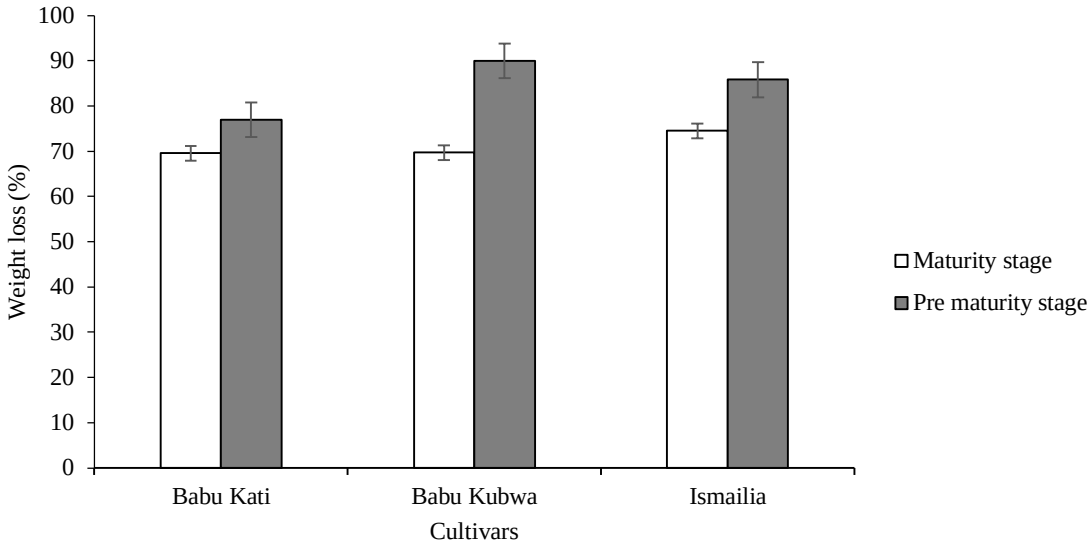

Figure 4. Percentage weight loss of pepper berries harvested pre-mature and mature stages after drying

Berry firmness

The force required to compress and crack pepper berries harvested at pre-mature and mature stages was recorded. Results indicate a significant interaction ($p=2\times10^{-16}$) between harvesting stages and cultivar in terms of berry firmness. At mature harvesting stage high firmness was recorded in Babukubwa (10.66 kg/mm^2) while Babukati (9.84 kg/mm^2) had low firmness after drying. At pre mature harvseting stage Babukubwa expressed high firmness (5.986kg/mm^2) compared to Ismailia (5.393 kg/mm^2) after sun drying (Fig. 5). However, the average fruit firmness gradually increased with increase in drying time.

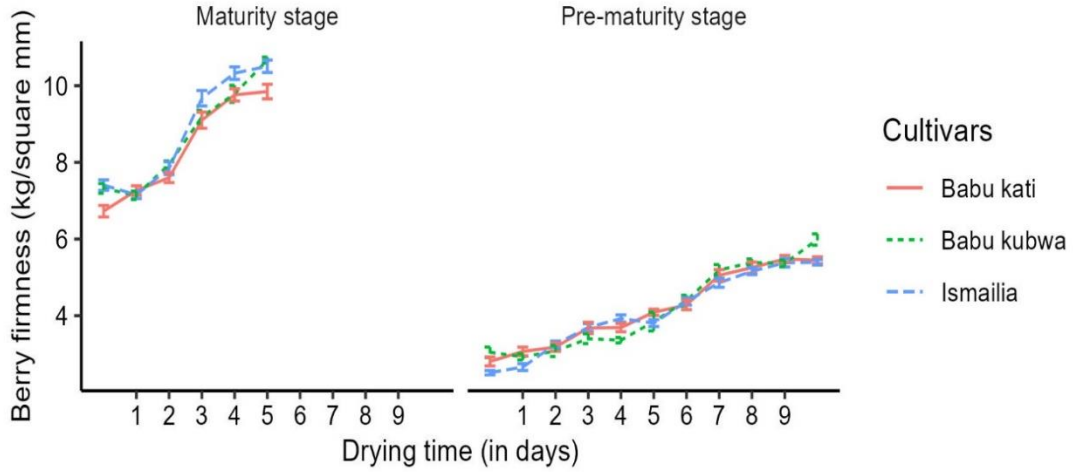

Figure 5. Firmness of pepper berries harvested at pre mature and mature stages during drying

Discussion

Relevant effects of harvest stage on the at-harvest and postharvest qualities of three black pepper cultivars grown in Morogoro district have been revealed in this study. Indicative parameters including moisture content, berry colour, dry matter recovery/content, percentage weight loss, and berry firmness were studied. Moisture content of pepper berries across cultivars decreased to the desired level (<12%) with increase of drying time. However, harvest at mature stage minimized the drying time from nine days to five (5) days. These findings suggest that, harvesting of pepper berries at mature stage increase efficiency of sunny drying. This phenomenon was probably attributed to the lower moisture content observed in mature berries than on pre-mature berries that required a few days to be removed during sun drying. Drying time of mature pepper berries reported in this study was lower compared to 7 days reported by Roslan and Yudin, (2020). This variation could be caused by differences in weather conditions experienced during drying as sun drying is weather dependent (Shreelavaniya and Kamaraj, 2017). The mean berry moisture content of fresh mature berries (71.61%) reported in this study was consistent with other previous research findings reported moisture content of mature pepper berries to be 65-77% depending on the variety (Azman *et al.*, 2021; Shreelavaniya and Kamaraj, 2017; Paul *et al.*, 2021).

The weight of pepper berries harvested at both maturity stages decreased continuously during the sun drying process. However, the observed higher weight loss percentage on pre-mature harvested pepper berries could be attributed to high water and low dry matter contents in pre-mature pepper berries than in mature. These findings were consistent with the previous studies by Dargie *et al.* (2013) and Moneruzzaman *et al.* (2009) who observed a higher weight loss percentage in other berry fruits (tomato fruits) harvested at pre-mature stage. The higher weight loss percentage on mature Ismailia and pre-mature Babukubwa than other cultivars at same maturity stages, respectively suggest genetical and developmental difference among the cultivars. Late maturing fruit/berry crops are likely to have higher water content and hence more weight loss on drying (Lufu *et al.*, 2020).

Dry recovery percent is the amount of marketable dry berries from fresh berries. Dry recovery is an important determinant of black pepper yield for producers. The higher dry recovery percent of pepper berries harvested at mature than at pre-mature stage was partly attributed to high and low dry matter accumulation, respectively. Higher berry firmness and low weight loss percentage on berries harvested at mature stage observed in this study suggest high dry matter contents. The significant variation in dry recovery recorded between cultivars at premature harvesting stage could be due to

varietal effects such as pericarp thickness. According to Somashekar *et al.* (2021) cultivars with thin pericarp recorded high dry recovery percentage than with thicker pericarp. So, Babu kati variety harvested at pre mature stage could have a thin pericarp compared to other cultivars at same maturity stage. The findings of this study are in line with Ravindran *et al.*, (2000) and Shivakumar and Saji, (2019) who reported dry recovery of mature pepper berries of 28–38 %

Variation in fruit firmness among cultivars at same harvesting stages observed in this study could be associated with genetic differences including dry matter content, pericarp thickness, fibrousness and waxiness. Ilic *et al.* (2012) reported that the higher pericarp thickness of a variety, the higher the firmness of fruit. The increase in firmness of mature harvested berries could be attributed to low moisture content and high dry matter content (as indicated by low weight loss) which make the inner core of berry harder to crash. Similar findings have been reported on several berry fruits including; pepper (Beckles, 2012), cumin (Saiedirad *et al.*, 2008), tomato (Lahay *et al.*,2013) and sweet pepper (Dargie *et al.*, 2013).

Stage of development determines the biochemical composition and the quality defining parameters of fruit crops. Fruit colour is a result of accumulation of some pigments on the fruit pericarp (Yahia, 2019). Produce colour make the first impression for consumers' purchases. The observed variation in the degree of yellowness (b*), redness (a*), and lightness (L*) among mature and pre-mature pepper berries associated with genetical and developmental differences. The findings of this study revealed colour mark point of Babukubwa, Babukati and Ismailia cultivars at mature and pre-mature harvest stage and their colour change trends during drying. The decrease in L* and b* values and increases in a* values during berry drying was consistent with Fratian *et al.* (2018) who reported decreasing values of L* and b* and increasing values of a* during drying of Goji berries.

The colour variation trend which was much vivid on mature than pre-mature berries suggest that the three peeper cultivars can rarely be distinguished by colour at sub-optimal maturity. Findings also suggest that, colour variation among berries of different cultivars can only be distinguished prior reaching the final moisture content (≤ 12) of drying and that is between day 4 for mature and day 5 for pre-mature. The higher drop in yellowing, increase in redness, and darkness in Ismailia, followed by Babukati and least on Babukubwa was genetical related to physiological development. The rapid darkening of the mature than pre-mature pepper berries associated with accumulation of some compounds including dry matter, piperine, enzymes, and antioxidants which are less on pre-mature berries (Nouck *et al.*, 2021).

Blackenning in pepper berries during drying is the result of enzymatic browning and oxidation of phenolic compounds present in pepper berries (Megat *et al.*, 2019). According to Gu *et al.* (2013) type and amount of major browning phenolics varies with maturity stage. Our findings are consistent with Paul *et al.*, (2021) who reported that black pepper colour change from green-yellowish to black during drying.

Conclusion

Harvest maturity has greatest effect on the at-harvest and postharvest quality of black pepper. Pepper berries harvested at the mature stage had low initial moisture content, lower weight loss percentage, higher firmness, and higher dry recovery. Mature pepper berries could also be differentiated easily by cultivar due to their colour vividness. The low weight loss percentage, higher firmness, and dry recovery on mature pepper berries suggested high dry matter accumulation. Harvest of mature berries also minimized the drying time to optimal moisture content from 9 days (when harvested pre-mature) to 5 days. Reduction in drying time may also help to minimize loss of some heat sensitive compound over long time heat exposure. Improvement of such quality parameters, reduce the risk for produce attack by quality deteriorating microbes including mould and storage insects. On the contrary, harvesting of pepper at pre-mature stage is likely to lower quality and monetary value of black pepper as it accounts for lowering dry recovery, extend the

drying time and improve the storage quality of black pepper

Recommendation

Farmers are advised to harvest pepper berries at mature stage. Berry firmness, colour, and or moisture content percentage are suggested as objective measure for harvest maturity of pepper. Based on the current study we recommend further studies on the evaluation of volatile compounds of the pepper cultivars harvested at different maturity stages.

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Conflicts of Interest

The authors declare no conflict of interest.

Ethical approval

This article did not include any studies on humans or vertebrate animals. However, the research procedure was reviewed by the Institutional Review Board (IRB) through an ethical clearance committee of Sokoine University of Agriculture (SUA).

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