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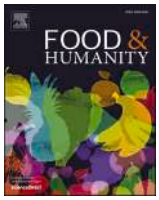

Assessment of current post-harvest handling techniques for mango and avocado in Mbeya region, Tanzania: Challenges and opportunities for improvement

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ABSTRACT

Mango (*Mangifera indica*) and avocado (*Persea americana*) are valuable fruits in Tanzania, known for their nutritional and economic importance. However, their perishability leads to significant post-harvest losses, especially for smallholder farmers in Mbeya. The limited knowledge about post-harvest handling identifies a research gap. This study assessed practices and challenges among mango and avocado farmers to improve handling techniques. A survey of 150 smallholder farmers in Kyela and Rungwe districts (August–September 2024) examined harvesting, storage, transportation, and post-harvest challenges. Data analysis revealed that 64 % of farmers use traditional harvesting methods that lead to mechanical damage. While 68.8 % manually hand-harvest, others rely on tree shaking (8.3 %) and sticks or stones (18.8 %), further increasing fruit damage. Storage at ambient temperature (46 %) fails to extend shelf-life, causing rapid quality deterioration. Transportation by motorcycle (44 %) and head carrying (34 %) exposes fruits to damage. Key challenges included fruit drop (36 %), rotting before harvest (28 %), and insect infestation (24 %). Only 23.4 % of farmers had reliable market access, highlighting a major constraint. Education level influenced challenges, with lower-educated farmers facing more rotting and pest issues. Findings indicate current post-harvest practices are inadequate, leading to major losses. Simple, cost-effective technologies like edible coatings and training on improved harvesting, storage, and transportation are necessary. Investment in affordable cold storage and better transport infrastructure is crucial. This study provides actionable insights for policymakers and stakeholders to enhance mango and avocado value chains in Tanzania.

1. Introduction

Mango (*Mangifera indica*) and avocado (*Persea americana*) are essential fruits in the global horticultural industry, valued for their flavour, nutritional content, and economic significance (Baltazari et al., 2020; Gelaye & Getahun, 2024; Kalle et al., 2007; Kyerematen & Reitz, 2017; Mlengera et al., 2025; Msogoya & Kimaro, 2011; Tarekegn & Kelem, 2022; Tumaini et al., 2024). Originating from South Asia and Central America, these fruits have been widely adopted in tropical and subtropical regions, including Tanzania (Macfru, 2018; Match Maker Associates, 2017). In Tanzania, both mangoes and avocados are vital to the agricultural sector. The country has been recognized for its potential in producing these fruits, with mangoes and avocados being one of the few fruits exported internationally. Avocado production is also increasing, with Tanzania emerging as a notable player in the African market. The country ranks third globally in avocado production, following Mexico and Peru (Juma et al., 2019). Despite this potential, challenges remain in maximizing production efficiency and accessing international markets. Many Tanzanian farmers are small-scale producers who often lack connections to more extensive export networks (Ekka & Mjawa, 2020; Match Maker Associates, 2017). With favorable agro-climatic conditions, the Mbeya region is a significant producer of

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mango and avocado in Tanzania. However, the high perishability of these fruits, coupled with inadequate post-harvest handling practices, results in substantial losses, reducing the economic benefits for smallholder farmers (Ekka & Mjawa, 2020; Manual, 2024; Tumaini et al., 2023).

Post-harvest fruit losses are critical in the agricultural value chain, particularly in developing countries where infrastructure and technology are often limited. For mangoes and avocados, the shelf-life is typically less than two weeks under ambient conditions, leading to rapid deterioration in quality (Abdel Salam, 2021; Rwubatse et al., 2019). In the Mbeya region, where smallholder farming is predominant, the lack of appropriate storage facilities, poor transportation methods, and limited knowledge of post-harvest management exacerbate these losses (Gelaye, 2024; Mlengera et al., 2025). This study assessed farmers' post-harvest handling practices in the Mbeya region (Kyela and Rungwe) to identify key challenges and opportunities for improving mangoes and avocado fruit shelf-life and reducing losses (Msogoya & Kimaro, 2011; Tumaini et al., 2024). Understanding the existing practices and the farmers' constraints will provide actionable recommendations for enhancing the region's post-harvest management of mangoes and avocados. Thus, the present study provides actionable insights that policymakers, extension agents, and stakeholders must adopt to improve the value chain of mangoes and avocados for high-value fruits in Tanzania.

2. Materials and methods

2.1. Study area

The study was conducted in the Mbeya region in the Southern Highlands of Tanzania. The area is characterized by a diverse climate variation that supports cultivating various crops, including mangoes and avocados. The survey targeted farmers from tropical (Kyela district) and subtropical (Rungwe district) areas, the primary production zones for mango and avocado plantations in the Mbeya region.Fig. 1.

2.2. Survey design and data collection

A structured questionnaire was developed to gather detailed information on the post-harvest handling practices of smallholder farmers. The target population included all registered mango and avocado farmers in Kyela and Rungwe districts. Farmer lists were obtained from District Agriculture Offices. The sample size was determined using Yamane's (1967) formula with a 95 % confidence level and 7.5 % precision, resulting in 137, rounded up to 150 farmers to ensure adequate representation and account for non-response.

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

Where n is the sample size, N is the total population (~600), and e is the precision level (0.075).

Proportionate stratified random sampling was employed based on district farmer population distribution (Kyela 60 %, Rungwe 40 %). Within each stratum, farmers were selected randomly using Excel-generated random numbers. Data collection was conducted through face-to-face interviews, field observation, and market visits during August–September 2024. Verbal consent was obtained from all participants.

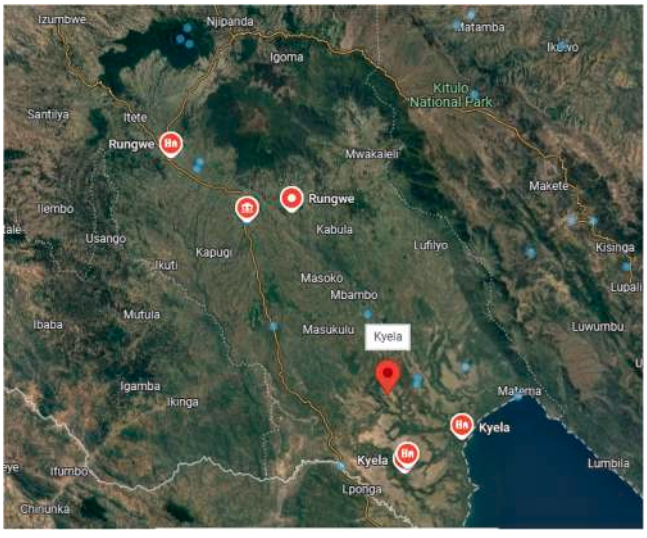

Fig. 1. The Map showing the study area (Rungwe and Kyela) where the farm survey was conducted.

2.3. Data analysis

The collected data was coded and analyzed using descriptive statistics to summarize the frequency and distribution of different post-harvest handling techniques using IBM SPSS 24 as described by Mng'ong'o et al.(2021). The crosstabulations were used to explore relationships between variables such as education level, harvesting methods, and the challenges faced by farmers. The results were presented in tables and figures to provide a clear and comprehensive overview of the findings.

3. Results and discussion

3.1. Social economic factors

The data reveals that a significant proportion of our respondents, approximately 72.91 %, have attained only a primary level of education. This data suggests that primary education is the dominant educational level among the surveyed population. Following this, secondary education is the second most common, with 12.5 % of respondents reaching this level. Fewer respondents have achieved other types of education, including certificates or diploma qualifications, and only a few have obtained a degree (Fig. 2). Most of the respondents have a primary level of education, indicating that most farmers might have limited formal education. This distribution highlights that most respondents have limited formal education beyond the basics (Mabaya, 2017; Meiguran & Basweti, 2016; Zegeye et al., 2022). Consequently, this lack of advanced education could impact their ability to adopt or understand more complex or advanced agricultural practices, particularly post-harvest handling techniques (Luo et al., 2022; Udimal et al., 2017). Since these methods often require a certain level of technical knowledge or training, farmers with only primary education might find it more challenging to implement new practices effectively (Lin, 1991; Mabaya, 2017; Meiguran & Basweti, 2016; Zegeye et al., 2022). This barrier could affect productivity and the quality of harvested goods, potentially impacting their income and economic stability.

3.2. Job title among studied value chain actors

Among 150 respondents assessed for post-harvest handling techniques for mangoes and avocados in the Mbeya region, the majority (77.1 %) were farmers, followed by civil servants and entrepreneurs (each at 8.3 %). Brokers comprise 4.2 % of the population, and private sector employees were the smallest group (2.1 %). This breakdown highlights that farmers constitute the primary stakeholders in the mango and avocado post-harvest sector. It thus suggests that any improvements in post-harvest handling practices must be accessible and practical for this group. The small percentage of civil servants, entrepreneurs, and brokers involved underscores the need for stronger stakeholder

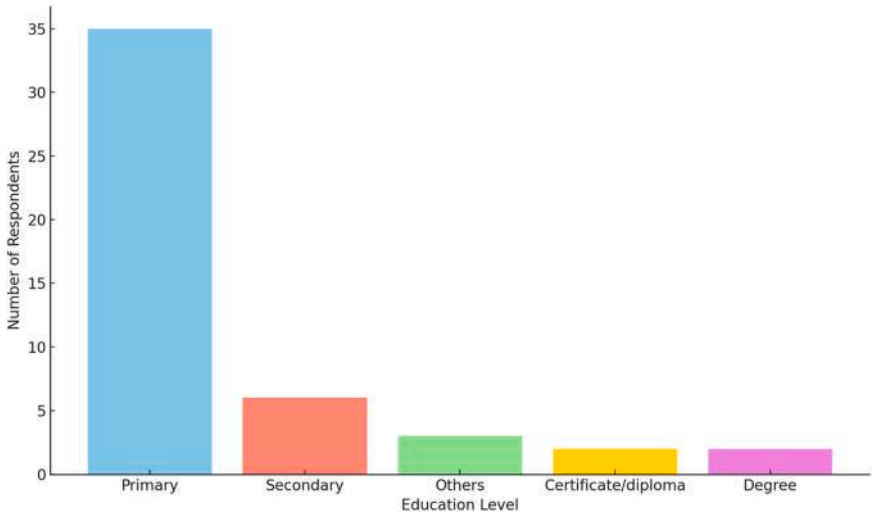

Fig. 2. Education levels among respondents involved in the study provide insights that might affect harvesting practices and postharvest handling of mangoes and avocados among the farmers surveyed.

engagement from these groups, who could support more effective value chain development (Ekka & Mjawa, 2020; Mabaya, 2017; Match Maker Associates, 2017; Tumaini et al., 2023). This distribution presents challenges and opportunities, as the concentration of farmers may limit access to advanced post-harvest technologies. It also presents a unique opportunity to design targeted training and infrastructure improvements that directly benefit the primary handlers of these fruits.Table 1.

3.3. Respondent's working experience on avocado and mango value chain

Among 150 studied respondents on working experience, it was observed that a significant portion (60.4 %) has over 6 years of experience, indicating that most stakeholders involved in post-harvest handling of mangoes and avocados possess extensive hands-on knowledge. This depth of experience provides a solid foundation for implementing improvements, as seasoned individuals are likely familiar with the complexities and challenges of current practices (Mabaya, 2017; Minja, 2024; Nyairo et al., 2022; Okonji & Awolu, 2020; Zegeye et al., 2022). Another 20.8 % have 3–5 years of experience, and 16.7 % have 0–2 years, representing newer participants in the sector who may lack extensive knowledge but offer potential for growth and innovation with appropriate training (Table 2 and Fig. 3). The high proportion of experienced workers could facilitate the adoption of new techniques and technologies to enhance post-harvest practices, while the presence of less experienced individuals suggests an opportunity for targeted capacity-building programs (Meiguran & Basweti, 2016; Nyairo et al., 2022; Okonji & Awolu, 2020). By focusing on skill enhancement, especially for those with fewer years of experience, interventions can improve the overall quality and consistency of post-harvest handling. Leveraging the knowledge of experienced individuals while empowering newer entrants can address current challenges and create opportunities for more efficient and sustainable post-harvest practices.

Table 1
The job distribution among studied respondents reflecting diverse actors in the value chain.

Job title	Frequency	Percent (%)
Farmer	116	77.1
Civil servants	13	8.3
Private sector servant	3	2.1
Entrepreneur	13	8.3
Broker	6	4.2
Total	150	100.0

Table 2
Working experience distribution among avocado and mango value chain actors.

Working experience (Years)	Frequency	Percent (%)
0–2 Years	25	16.7
3–5 Years	34	22.7
6 + Years	91	60.4
Total	150	100.0

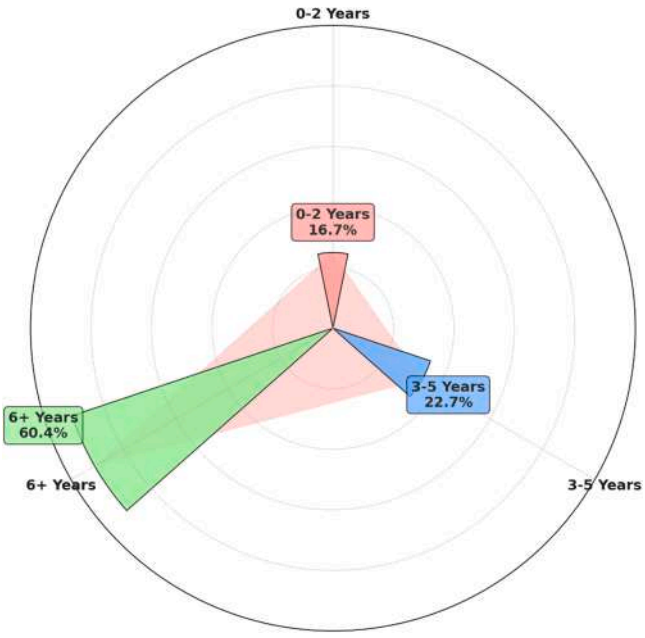

Fig. 3. The distribution of respondent experience in avocado and mango value chain.

3.4. Harvesting stage or maturity

Based on the collected data on the harvesting stages for mangoes and avocados among 150 respondents, it indicates that the majority (58.3 %) of farmers harvest these fruits 4–6 months after flowering, suggesting that they allow sufficient time for the fruits to mature fully before harvest. Meanwhile, 33.3 % of respondents harvest within 2–4

months, and a smaller group (8.3 %) harvest as early as 0–2 months. Studies by Motis and Swartz (2019) and Dorantes et al. (2004) indicate that harvesting mangoes and avocados within this timeframe ensures optimal fruit development, flavour, and shelf-life. Conversely, 41.7 % of farmers harvest earlier than the recommended period, potentially compromising fruit quality and marketability. This variation in harvesting stages highlights a diversity in practices that could affect the quality, shelf life, and marketability of mangoes and avocados in the region (Juma et al., 2019; Macfru, 2018). Harvesting at the appropriate stage is a critical factor in post-harvest handling, as it influences the fruit's physical properties, nutritional quality, and susceptibility to post-harvest spoilage (Dorantes et al., 2004; MOFL, 2004; Motis & Swartz, 2019). The predominance of later-stage harvesting (4–6 months) suggests that a significant portion of the respondents are aware of the importance of allowing fruits to reach an optimal stage of maturity, which typically enhances flavour, texture, and overall quality (Motis & Swartz, 2019). Mature fruits harvested at the right stage are more likely to withstand handling and transport, reducing losses and improving market value. This practice aligns with improved post-harvest handling outcomes, as mature fruits generally have better resistance to bruising and decay than immature ones (Dorantes et al., 2004; MOFL, 2004).

On the other hand, the data shows that 41.6 % of respondents harvest earlier, with 33.3 % harvesting between 2 and 4 months and 8.3 % as early as 0–2 months (Fig. 4). Early harvesting can lead to immature fruits that may not develop their full nutritional and sensory qualities. These fruits are more susceptible to physical damage and have a shorter shelf life, making them less desirable in the marketplace and market rejections (as reported in recent cases in Tanzanian avocados in the South African Market). Immature fruits are also more prone to shriveling, bruising, and pathogen infection, increasing the risk of post-harvest losses (Motis & Swartz, 2019). This practice suggests a potential knowledge gap or market-driven factors, such as the need for early income or pressures from buyers who may demand earlier supplies. The present study finds highlights an opportunity for improvement in post-harvest handling by promoting education on optimal harvesting times. Farmers who harvest earlier might benefit from training programs or workshops that emphasize the advantages of delayed harvesting, both for quality and economic returns. Thus, ensuring that more farmers understand the benefits of harvesting 4–6 months will help to improve the quality and consistency of mangoes and avocados in the region. Thus, local policies or market incentives that reward quality over quantity are needed to encourage farmers to harvest at the ideal stage rather than rushing to market with immature fruits.

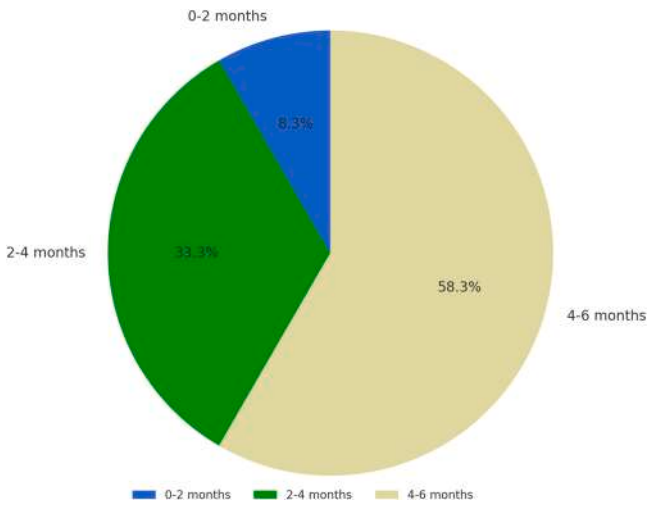

Fig. 4. Harvesting stages for avocados and mangoes among studied farmers in Kyela and Rungwe districts could reflect the potential post-harvest losses.

Standardizing the harvesting stage could lead to more uniform product quality across the region, making it easier for processors, distributors, and exporters to rely on a consistent supply of high-quality fruits. This approach would help reduce post-harvest losses, improve shelf life, and increase the market competitiveness of mangoes and avocados produce.

3.5. Harvesting methods

Reliance on traditional harvesting methods significantly reduces post-harvest losses (Dorantes et al., 2004). Mechanical damage during harvesting can lead to bruise, which accelerates the ripening process and reduces the marketable life of the fruits. Training farmers to use improved harvesting techniques, such as fruit pickers or padded containers, could significantly reduce mechanical damage and extend the shelf-life of mangoes and avocados. Most respondents (68.8 %) reported that they harvest fruits by hand, indicating a preference for manual and possibly careful handling methods (Fig. 5, Table 3, Plate 1). This practice is likely chosen to minimize damage to the fruits, as hand harvesting allows for a more controlled and careful approach, preserving fruit quality. A smaller percentage (4.2 %) of respondents use bending the tree to harvest, which may be specific to certain tree structures or fruit types, especially for young trees or trees with short heights.

Additionally, 8.3 % of respondents harvest by shaking the tree, which is less labor-intensive but may result in bruised or damaged fruits, mainly if they fall directly to the ground. Lastly, 18.8 % of the respondents use stones or sticks to knock the fruits off the trees, which is likely less selective and could result in more significant damage to the fruit. While it may be practical for quickly reaching higher branches, this approach reduces the quality and marketability of the fruits. These findings suggest that hand-picking is the preferred and likely most effective harvesting method in preserving fruit quality. However, many farmers rely on less controlled methods, such as shaking the tree or using stones/sticks, which may compromise fruit quality. This fact indicates an opportunity for improvement in post-harvest handling by encouraging the adoption of gentler, more efficient harvesting practices that can enhance the produce quality and market value.

3.6. Containers used during harvesting

Among 150 studied avocado and mango actors, various materials were observed to be used during harvesting. The data on containers used for post-harvest handling of mangoes and avocados shows a diverse range of practices and materials used. Over half of the respondents (52.1 %) use buckets or plastic containers for storage and transport (Fig. 6 and Plate 2). This choice of containers likely offers some protection to the fruits, as plastic containers can reduce bruise and damage during handling and transportation. The high percentage of respondents using buckets or plastic containers suggests a preference for relatively durable and reusable materials, which may contribute positively to post-harvest outcomes. However, 35.42 % of respondents use grounds (locally called *matenga)* for post-harvest handling, meaning fruits are often placed directly on the ground or simple grass surfaces. This practice could lead to increased damage, contamination, and post-harvest losses, as direct contact with the ground exposes fruits to dirt, pests, and physical harm. The use of grounds reflects traditional or resource-limited handling methods, and it points to a need for improved infrastructure or access to affordable containers that can better protect the fruits. We observed other respondents (6.25 %) use nylon sacks, which are not ideal for handling delicate produce like mangoes and avocados. Nylon sacks do not provide adequate support and ventilation, leading to compression and bruising, compromising the fruits' quality and shelf life.

This practice indicates a potential lack of awareness about appropriate post-harvest containers or limited access to better alternatives. Conversely, 6.25 % of respondents reported using other types of

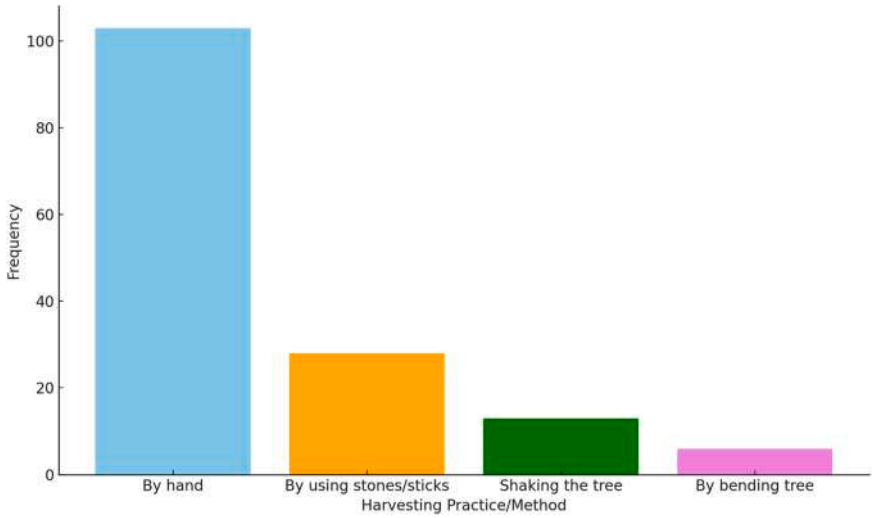

Fig. 5. Harvesting practices among study participants.

Table 3
Common harvesting practices/methods based on avocados and mangoes valued by actors.

Code	Harvesting practice/method	Frequency	Per cent
1	By hand	103	68.8
2	By bending tree	6	4.2
3	Shaking the tree	13	8.3
4	By using stones/sticks	28	18.8
	Total	150	100.0

containers, which might vary in their effectiveness in protecting the fruits. This category suggests a degree of flexibility or improvisation in post-harvest practices, which could result from economic constraints or limited availability of standardized containers (Minja, 2024; MOFL, 2004). The findings suggest an opportunity to improve post-harvest handling practices in the region by encouraging the use of protective, standardized containers. Educational initiatives could raise awareness of the importance of using standard containers to minimize physical damage. Access to affordable, appropriate containers, i.e., stackable plastic crates and ventilated boxes, will help farmers transition from traditional methods to more effective handling techniques to increase fruit shelf life and market value.

3.7. Transportation of avocados and mangoes

Motorcycles are the predominant means of transportation (44 %) used by farmers to transport their produce from the farm to the market. This method, while convenient, poses significant risks to fruit quality due to the lack of cushioning and protection during transit, suggesting that this is the primary means of transport for many farmers and traders. Motorcycles are likely chosen for their accessibility and efficiency in reaching various locations, mainly rural or off-road areas. However, they inadequately protect delicate produce, leading to potential bruising and damage. Head carrying (34 %) further exacerbates the risk of physical harm, as fruits are often exposed to rough handling and environmental stress (Fig. 7). This traditional form of transport is likely used for short distances, such as from farms to local markets. While it may be practical, carrying buckets on the head could contribute to physical stress and offer limited protection for the fruits, potentially impacting their quality by the time they reach the market. Lorries and canters, which offer fast and better fruit protection, are used by a smaller proportion of farmers (12 %). A few respondents use lorries or canters, which are more suitable for bulk transportation and provide excellent fruit stability and protection. This method is likely more effective for reducing post-harvest losses and ensuring the fruit arrives in good condition. Still, they are less accessible due to higher costs or limited availability in some areas. The limited use of these vehicles is likely due to their higher cost and restricted access, particularly for smallholder farmers with limited financial resources. Improving access to more

Plate 1. A mango with cracks as a result of impacts of bad harvesting practices like shaking of the trees.

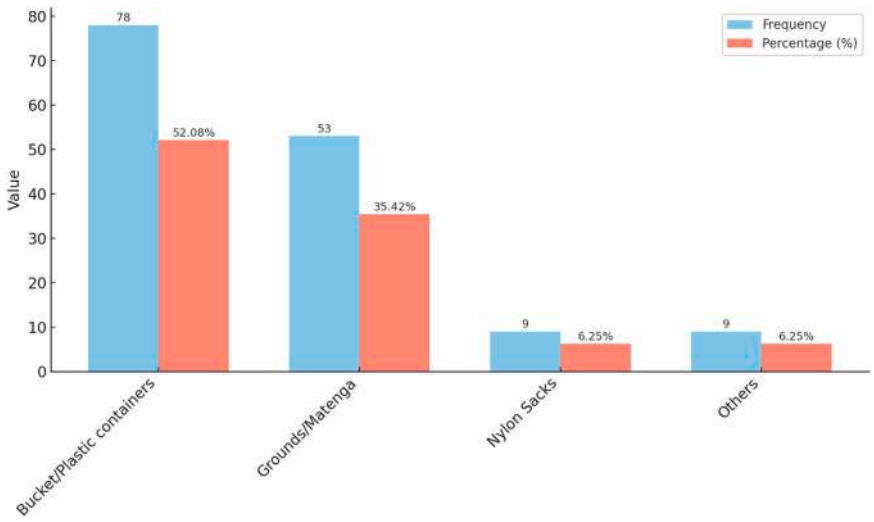

Fig. 6. The common materials or equipment used for storing avocados and mangoes during harvesting and transportation.

Plate 2. Mangoes packeted in plastic containers along the road posing them to potential quality loss stresses.

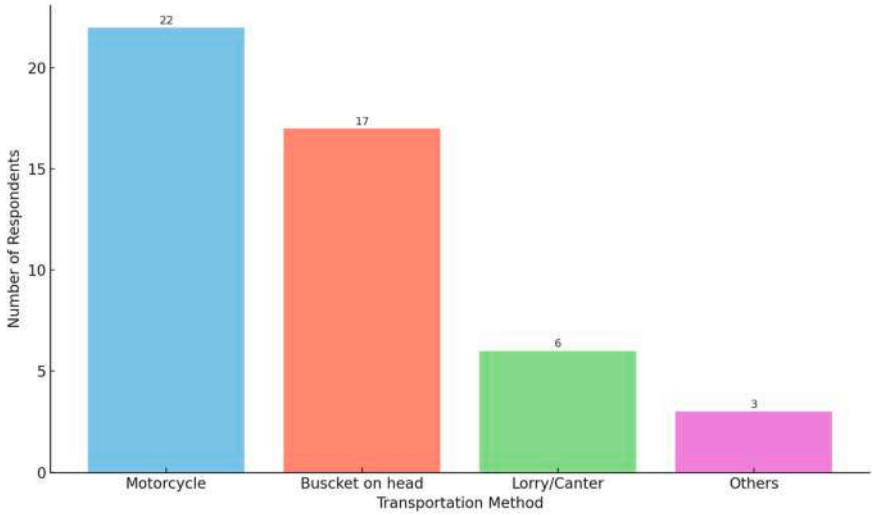

Fig. 7. The most common means of transportation used by the farmers are motorcycles and lorries/canters, as they have limited access to more advanced or larger-scale transportation options.

suitable transportation options, such as padded containers or insulated vehicles, could help reduce mechanical damage and maintain fruit quality during transit.

Among studied respondents, other transportation means were highlighted as possible used methods, which could encompass any alternative or improvised forms of transportation. These methods vary in their effectiveness and reliability for transporting fruits. This distribution of transportation methods highlights an area for potential

improvement in post-harvest handling practices in the region. Providing access to or supporting the use of more suitable transportation options, such as covered and ventilated vehicles, will help to reduce fruit damage during transit. Furthermore, raising awareness on possible transportation methods that maintain fruit quality will enhance the shelf life and market value of mangoes and avocados.

3.8. Time is taken to transport fruit to the market

The transport duration could have significant implications for the freshness and quality of the produce by the time it reaches the market (Tumaini et al., 2023). The time taken to transport fruit from the farm to the market shows significant variation among 150 respondents studied, which has implications for the quality of fruits reaching the markets. Most respondents (53.2 %) reported that it takes 6–24 h to transport their produce to the market, indicating that long transport times are common, likely due to distance, infrastructure challenges, or the availability of transport options. Such lengthy transit periods can affect fruit quality, leading to potential spoilage, bruising, or weight loss, all of which reduce market value and shelf life (Ekka & Mjawa, 2020; Match Maker Associates, 2017; Tumaini et al., 2023). About 29.8 % of respondents take only 0–1 h to reach the market (Fig. 8), suggesting that a segment of farmers is close to their markets. This short transit time is beneficial for maintaining fruit quality, as it minimizes handling stress and reduces the chance of physical or microbial damage. A smaller group (14.9 %) takes 1–6 h for transportation. While this is longer than the 0–1-hour group, it is still manageable to maintain fruit quality, especially if adequate post-harvest handling practices are in place (Etefa et al., 2022; Le et al., 2022).

On the other hand, 2.1 % of respondents take 1–7 days to transport their produce, a significant delay that could severely compromise fruit quality. This group likely faces logistical challenges, such as remote locations, limited transportation options, or inadequate infrastructure, making it difficult for farmers to get their produce to market promptly (Etefa et al., 2022; Le et al., 2022). Extended transport times increase the risk of spoilage and loss of marketability, especially for perishable fruits like mangoes and avocados (Knowledge Center, 2023; Poland-Transport.eu, 2024). The current study data highlights an opportunity for improvement in transportation logistics for post-harvest handling of fruits in the Mbeya region. Supporting infrastructure development, such as road improvements and more reliable transportation options, could help reduce transit times, improving mangoes and avocados' quality and shelf life. Additionally, training in packaging and handling techniques for longer transit times may help mitigate some of the negative effects associated with extended transport to enhance produce quality and value.

3.9. Storage practices

The current study revealed that ambient temperature storage is a common method for storing fruits after harvesting. Almost half of the respondents (47.9 %) store their fruits at ambient temperature, which is the simplest and least resource-intensive method (Fig. 9). However, this practice exposes fruits to fluctuations in temperature and humidity, which can accelerate ripening and spoilage and reduce shelf life (Dorantes et al., 2004; Etefa et al., 2022; Manual, 2024). Ambient temperature storage may suffice for short-term holding, but it is not ideal for preserving fruit quality over extended periods. This method is inadequate for prolonging mangoes and avocadoes' shelf-life, as it does not provide the controlled conditions necessary to slow down the ripening process. However, 14.6 % of respondents use sacks to cover the fruits. While this approach offers protection from dust and pests, it does not effectively regulate temperature or humidity, which are critical for maintaining fruit freshness. Storing fruits in sacks can also lead to compression and bruising, particularly with delicate produce like mangoes and avocados, further diminishing quality (Abdel Salam, 2021; Etefa et al., 2022; Minja, 2024; Zegeye et al., 2022). The remaining 37.5 % of respondents reported using "other" methods, which could encompass various traditional or improvised storage practices i.e., Storage under shade trees (15 %), providing cooler conditions than direct ambient storage by reducing sunlight exposure, Grass-lined pits or holes (12.5 %), which moderate temperatures and humidity, extending shelf-life compared to open-air storage, hanging fruits in nets inside houses (10 %), preventing pest damage and bruising while maintaining ventilation. Compared to ambient storage or sacks, these "other" methods offer partial improvements by reducing temperature fluctuations and physical damage. However, they remain less effective than cold storage or evaporative cooling chambers for extending shelf-life significantly. These alternative methods vary widely in effectiveness, with some possibly offering better protection than ambient storage or sacks (Abdel Salam, 2021). However, without more specific data, it is challenging to assess the efficacy of these methods in preserving fruit quality.

The high temperature and humidity typical of the Kyela and Rungwe districts accelerate the respiration rate of the fruits, resulting in faster ripening and spoilage (Macfru, 2018). The predominant use of ambient storage and sacks and limited use of cold storage facilities, due to their high cost and limited availability, highlight a potential area for

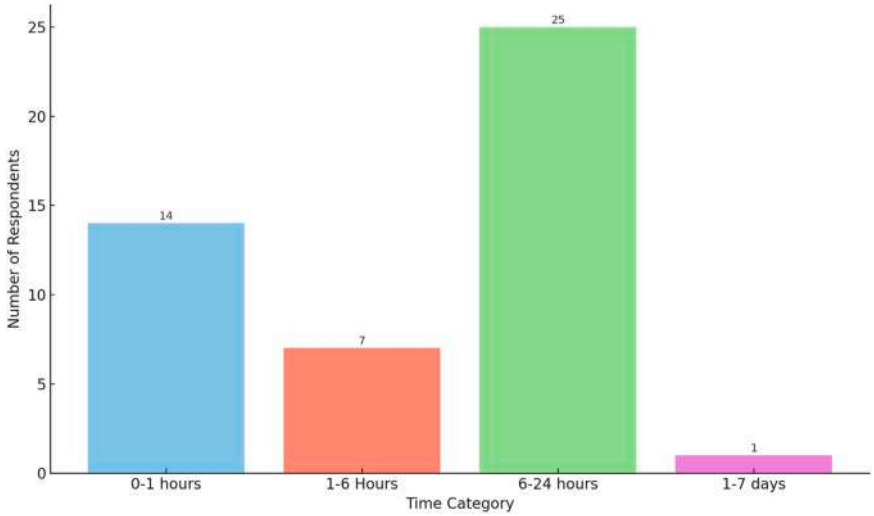

Fig. 8. Transportation time from harvesting to markets taken by farmers in the study area as of September 2024.

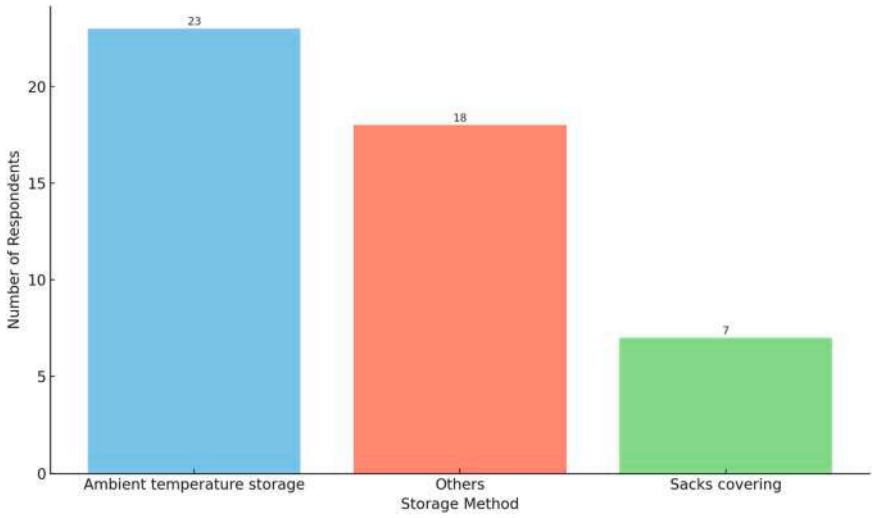

Fig. 9. Common storage methods reported in the study area.

improvement in post-harvest handling practices and the need for alternative storage solutions accessible to smallholder farmers. Introducing more effective storage options, such as cool storage facilities or evaporative cooling chambers, could significantly enhance fruit preservation, extend shelf life and reduce post-harvest losses. Education on simple, affordable storage innovations could also help farmers and traders minimize spoilage, maintain fruit quality, and improve profitability in the mango and avocado supply chain (Dorantes et al., 2004). Edible coatings and other low-cost preservation methods offer promising solutions for extending the shelf-life of mangoes and avocados. These techniques involve applying a thin layer of edible material to the surface of the fruit, which acts as a barrier to moisture loss and oxygen exchange, thereby slowing down the ripening process. Thus, the present study project will develop and promote such technologies among farmers that could help reduce post-harvest losses and increase the availability of fresh fruits in the market.

3.10. Awareness of other storage techniques

The collected data on awareness of alternative storage techniques for mangoes and avocados in the Mbeya region reveals an overwhelming lack of knowledge. Out of 150 respondents, only 8.3 % reported awareness of other storage techniques. In contrast, 91.7 % indicated they were unfamiliar with options beyond the traditional methods commonly used, such as ambient storage (Fig. 10). This high percentage of unawareness reflects a substantial knowledge gap that could contribute to significant post-harvest losses and reduced fruit quality. In assessing post-harvest handling techniques for mangoes and avocados, this lack of awareness presents a critical challenge. Limited knowledge of improved storage practices, such as evaporative cooling chambers, solar-powered coolers, or other cost-effective methods, likely restricts farmers and traders from adopting more effective solutions that could help preserve fruit quality (Rwubatse et al., 2019). Without understanding these techniques, many producers rely on practices that expose produce to high temperatures and humidity fluctuations, accelerating ripening and spoilage. Thus, there is a need to address this knowledge gap by introducing targeted interventions focused on education and the demonstration of practical, affordable storage solutions. Training programs and workshops on awareness creation about alternative post-harvest handling techniques associated with low-cost are vital to improve fruit shelf life and quality. Such initiatives would empower farmers and traders' knowledge to make informed choices in post-harvest handling, hence reducing postharvest losses, increasing profitability, and enhancing fruit supply chain sustainability.

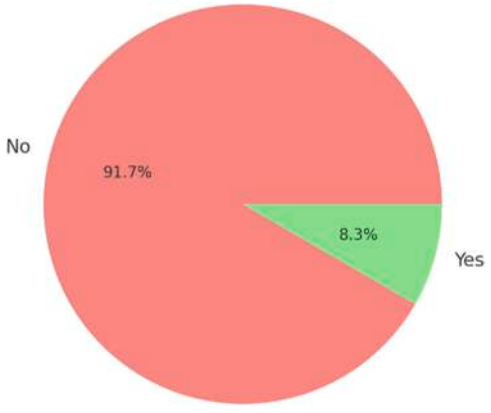

Fig. 10. The awareness of participants on the existence of other alternative storage methods or techniques.

3.11. The use of treatment during storage and treatment used

The data reveals that respondents in the Mbeya region rarely employ treatment during storage. Only 2.1 % of respondents reported using any form of treatment to preserve fruit quality during storage, Among those who reported using treatments, methods included Blanching (33.3 %), where fruits are dipped briefly in hot water to reduce surface microbial load., Drying (16.7 %), particularly slicing and sun-drying mangoes for preservation, Ash dusting or herbal smoke treatment (50 %), where fruits are either dusted with wood ash or stored in huts exposed to herbal smoke to repel pests and slow ripening. Although these treatments offer some preservation benefits, their effectiveness is limited compared to modern post-harvest technologies such as controlled atmosphere storage or edible coatings.

While a significant majority, 91.7 %, indicated they do not use any treatments (Fig. 11). On the other hand, 2.1 % of respondents mentioned the use of an unspecified category. In the context of mango and avocado post-harvest handling, this lack of treatment use highlights another potential area for improvement. Treatments such as controlled atmosphere storage, natural preservatives, or wax coatings can significantly reduce spoilage rates and extend shelf life by limiting moisture loss, pest damage, and microbial growth (Gelaye, 2024; Rwubatse et al., 2019). However, the low usage rate suggests that farmers and traders may lack awareness of or access to these options, potentially due to cost constraints, limited knowledge, or lack of locally available resources.

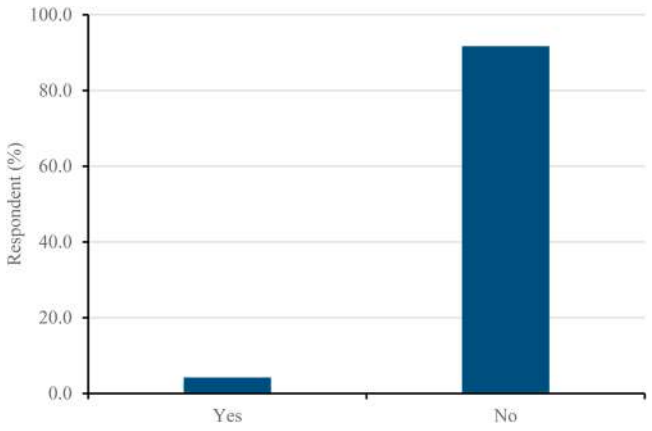

Fig. 11. Respondent awareness and practicing of other storage treatments during storage.

Furthermore, the analysis of specific types of treatments used during storage in the Mbeya region varied significantly, with 12.5 % reporting using storage treatment. Among these, blanching was the most mentioned (33.3 %), followed by drying (16.7 %), with the remaining 50 % grouped under unspecified "other" methods (Fig. 12). These results underscore a broader trend in the Mbeya region mangoes and avocado post-harvest handling practices and limited use of preservation treatments, potentially due to a lack of awareness, access, or perceived cost-effectiveness. Blanching and drying, though somewhat effective, are generally more suitable for specific storage or preparation needs rather than for the long-term preservation of fresh fruit quality. For example, blanching can reduce microbial load but may not be ideal for fresh market sales due to its impact on texture. Addressing this gap needs educational outreach programs on affordable and accessible storage treatments, as well as demonstrating the cost-benefit advantages of basic treatments for extending fruit quality, where even minimal interventions (such as sanitizing treatments or natural coatings) could have a significant impact on spoilage reduction and quality see reductions in spoilage and improvements.

3.12. Waiting time for fruits to stay before selling

The present study found that waiting time before fruits are sold indicates that nearly half (46.81 %) of the respondents store their fruits for 6–24 h before selling (Fig. 13). This moderate waiting period is likely due to logistical or market-related delays, allowing the fruits to reach potential buyers or for market prices to adjust. However, while a short waiting period is generally beneficial for maintaining fruit freshness, this timeframe still exposes fruits to ambient conditions that can impact quality if proper storage methods are not used. On the other hand, approximately 23.40 % of respondents sell their fruit within 1–6 h. This quick turnaround time is ideal for preserving fruit quality, as it minimizes exposure to temperature and humidity fluctuations, reducing the risk of spoilage. Farmers or traders in this group may have direct access to buyers or markets, allowing them to sell produce shortly after harvest.

Furthermore, 14.89 % of respondents wait 1–7 days before selling their fruit. This extended waiting period can negatively affect fruit quality, especially for perishable produce like mangoes and avocados, due to ripening and spoilage over longer durations. The "others" category, also comprising 14.89 %, may include various waiting times that are not explicitly defined, potentially indicating unique circumstances, such as unpredictable market demand or storage limitations. Thus, the distribution of waiting times before selling highlights the need for improved storage solutions to maintain fruit quality during these holding periods. For fruits held beyond 6 h, particularly those waiting 1–7 days, investment in proper storage infrastructure, such as cool storage units or shaded, ventilated areas, could help mitigate post-harvest losses. Developing better market linkages and timely transportation options could help farmers and traders reduce waiting times, ensuring that fruits reach consumers in optimal condition, thereby enhancing profitability and reducing waste in the supply chain.

3.13. Challenges during and before harvesting

Based on the collected survey data on challenges faced by farmers during and before harvesting fruits in the Mbeya region highlights several issues that impact fruit quality and yield. The most common challenge, reported by 37.5 % of respondents, is a fruit drop (Fig. 14). Fruit drops are likely caused by various factors, including weather conditions, nutrient deficiencies, or pest and disease pressure. This issue reduces the quantity of marketable fruits and increases the likelihood of post-harvest losses, as dropped fruits are more susceptible to bruising and spoilage. Rotting before harvesting is the second most prevalent issue, affecting 29.2 % of respondents. Pre-harvest rotting can result from poor handling practices, excessive rainfall, or fungal infections. This challenge diminishes fruit quality and marketability, leading to economic losses for farmers. Addressing these challenges requires improved disease management and better handling practices to reduce fruit exposure to moisture and pathogens.

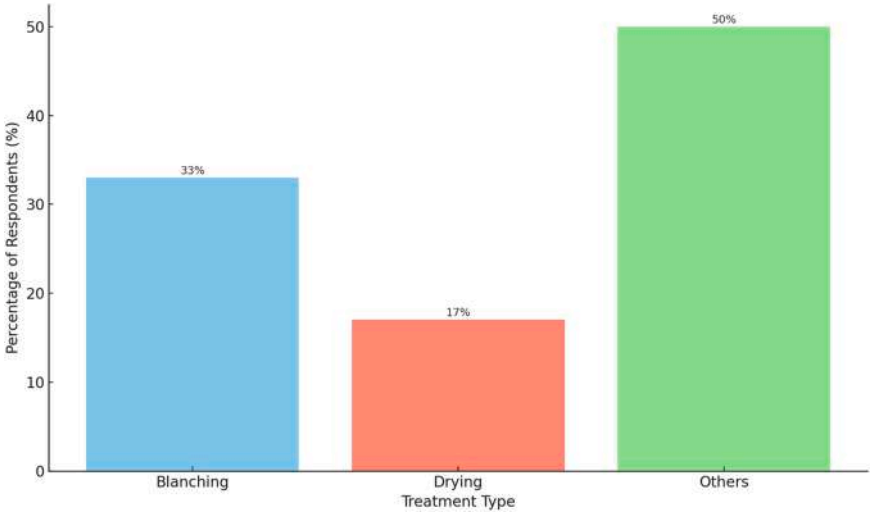

Fig. 12. The common treatment methods used in the study area based on the 150 respondents.

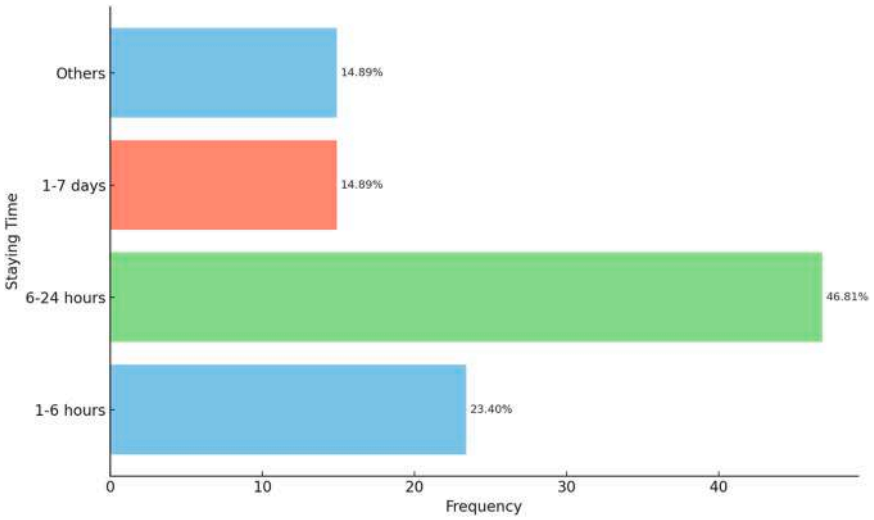

Fig. 13. Waiting time for fruits to stay before selling reported among respondents.

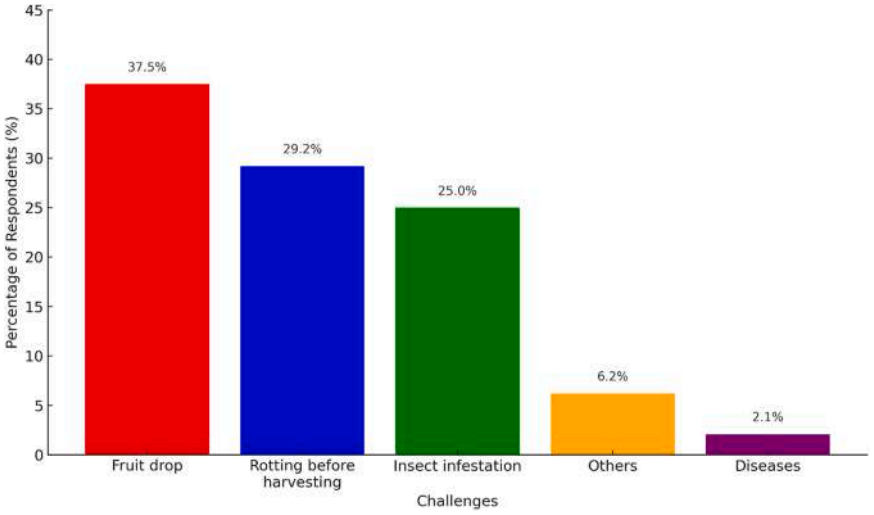

Fig. 14. Various mangoes and avocados challenges reported by participants in the study areas as of September 2024.

On the other hand, insect infestation is another significant challenge, affecting 25.0 % of respondents. Insect infestation, a common problem in tropical and subtropical regions, affects both the quality and quantity of the harvest (Etefa et al., 2022; Kalle et al., 2007; Hirvonen et al. 2024; Le et al., 2022; Mulungu et al., 2023) Pests can damage fruits directly by feeding them or indirectly by introducing diseases. A small proportion (2.1 %) of respondents face issues with diseases other than rot, which may impact fruit quality and yield depending on the outbreak's severity. This infestation can lead to blemished, unmarketable fruits (especially for export markets) and contribute to pre- and post-harvest losses. Farmers reported difficulties controlling pests due to the lack of access to effective pesticides and the high cost of available options. Integrated pest management (IPM) strategies, which combine biological, cultural, and chemical controls, could offer a more sustainable solution for managing insect pests and reducing post-harvest losses. Implementing integrated pest management (IPM) strategies could help mitigate insect damage, preserving fruit quality and yield. Addressing these diseases requires targeted interventions, such as disease-resistant varieties, fungicides, and good agricultural practices. The remaining 6.3 % of respondents reported other unspecified challenges, including labour shortages, adverse weather, or lack of access to harvesting equipment. These additional challenges may vary in impact but highlight the region's complex and multifaceted nature of pre-harvest issues. Thus, there is a need for comprehensive pre-harvest interventions, including improved pest and disease management, better fruit handling practices, and access to resources that reduce fruit drop and rotting as the strategy to help farmers improve their yield and the quality of fruits harvested, ultimately enhancing their profitability and reducing losses in the mango and avocado supply chain.

3.14. *Relationship between education levels and challenges*

The relationship between education levels and farmers' challenges in the Mbeya region during and before harvesting shows that farmers with only primary education tend to face more challenges, such as fruit drop and rotting before harvesting. Fig. 15 shows the high frequency of these issues among primary-educated individuals. This pattern suggests that limited education may influence farmers' capacity to manage or prevent these challenges, potentially due to a lack of knowledge on improved agricultural practices or access to resources. On the other hand, farmers with higher levels of education (certificate/diploma, degree) appear to face fewer of these issues, likely due to greater exposure to best practices and possibly a higher capacity to adopt effective pre- and post-harvest handling techniques. This relationship indicates that improving

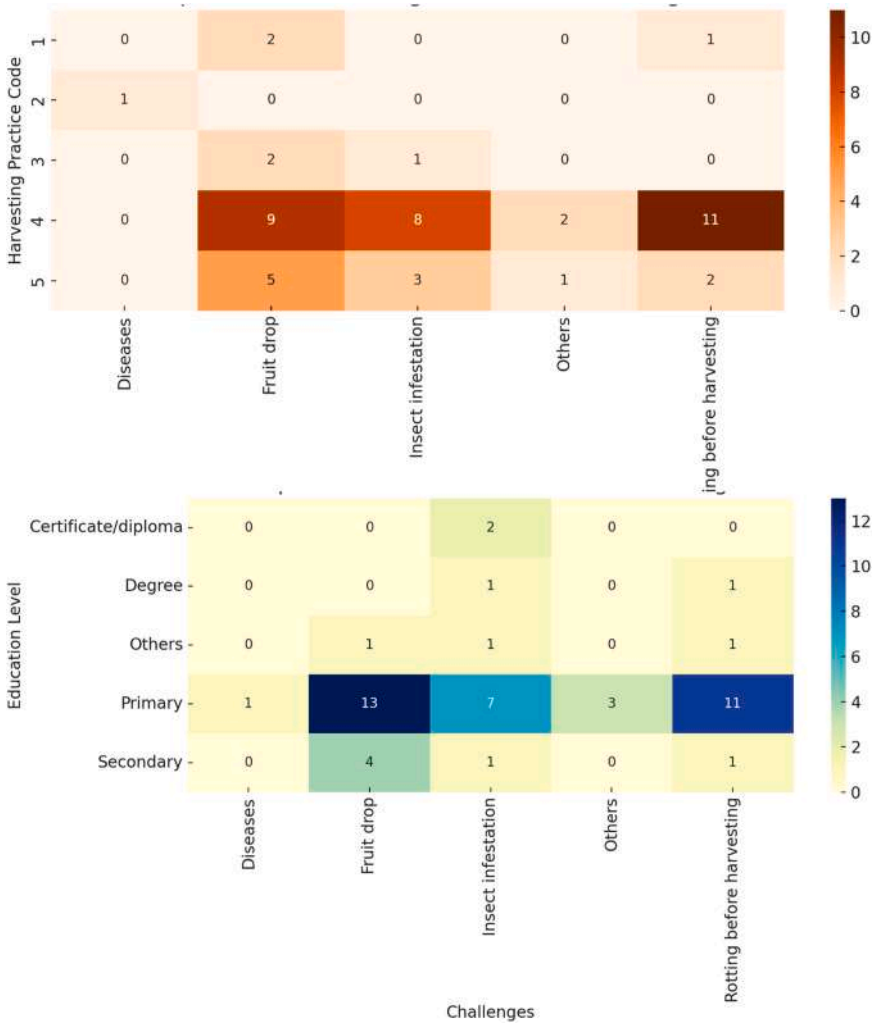

Fig. 15. The correlation between various studied variables in the Mbeya region's avocado and mango value chain.

educational access or providing targeted training could help mitigate challenges associated with fruit drops, rotting, and insect infestation, as higher education seems correlated with fewer challenges. The study observed that quantitative data on market reliability and prices lacks sufficient variability to yield meaningful correlations, so qualitative methods like interviews or focus groups with farmers could offer a more nuanced understanding of market challenges. This approach might reveal insights into the impacts of education on market outcomes, potentially guiding interventions for improved market reliability and price stabilization. Thus, the findings highlight both the challenges farmers face in managing pre-harvest issues and the role that education might play in alleviating these challenges, emphasizing the value of knowledge transfer and best practice adoption in enhancing the resilience of mango and avocado production in Mbeya.

In Kenya, studies found that introducing plastic crates reduced mango post-harvest losses by 40–50 %, aligning with our recommendation to replace sacks and ground storage with protective containers. Similarly, Etefa et al. (2022) reported Ethiopian fruit losses of 25–35 % due to lack of cold storage, comparable to the ambient storage challenges observed in Mbeya. Within Tanzania, mango fruit drop losses found to be 20–30 % in Morogoro, slightly lower than the 37.5 % reported in this study, while Tumaini et al. (2023) reported avocado transport-related rejection rates up to 50 %, consistent with risks posed by motorcycles and head carrying in Mbeya. These benchmarks demonstrate that Mbeya's post-harvest handling issues mirror regional patterns but exhibit unique severity levels that necessitate locally tailored interventions such as edible coatings, infrastructure investments, and IPM training.

3.15. Reliability of the market for fruits

The survey data on market reliability for mangoes and avocados in the Mbeya region revealed that a significant majority (75.1 %) of respondents reported an unreliable market for their fruits. In comparison, only 22.9 % of respondents indicated they have access to a reliable market (Fig. 16). This figure suggests that the availability of a stable and dependable market is a major challenge for mango and avocado producers in the region, potentially contributing to post-harvest losses and reduced income for farmers. With limited market reliability, producers may struggle to find buyers promptly, leading to prolonged storage times, fruit deterioration, and possible financial losses. An unreliable market exacerbates the difficulties in post-harvest handling, as farmers may be forced to store fruits for extended periods, which can result in quality degradation (Juma et al., 2019). This issue, coupled with challenges like a fruit drop, rotting, and insect infestation, as noted in other findings (Abdel Salam, 2021; Badii et al., 2015; Dorantes et al., 2004; Ekka & Mjawa, 2020; Etefa et al., 2022; Gelaye, 2024; Juma et al., 2019; Hirvonen et al. 2024; Knowledge Center, 2023; Le et al., 2022; Lin, 1991; Luo et al., 2022; Mabaya, 2017; Macfru, 2018; Manual, 2024; Match Maker Associates, 2017; Meiguran & Basweti, 2016; Minja, 2024; MOFL, 2004; Mulungu et al., 2023; Nyairo et al., 2022; Okonji & Awolu, 2020; Poland-Transport.eu, 2024; Rwubatse et al., 2019; Motis &

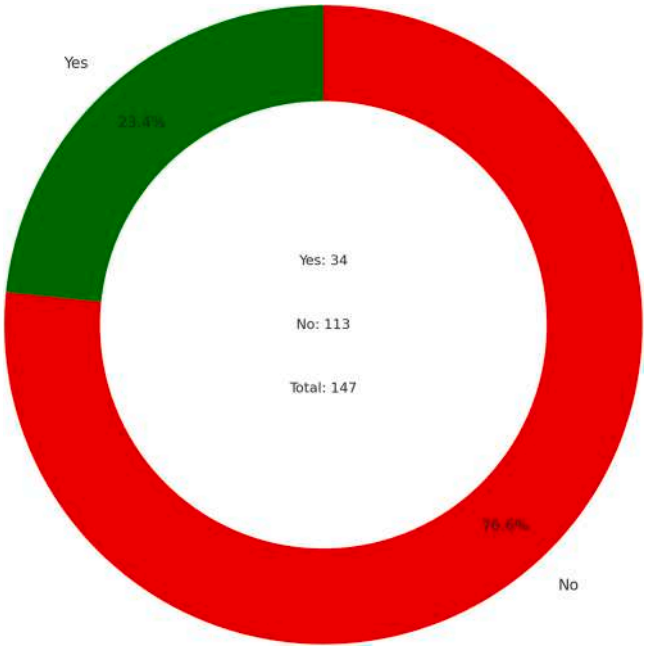

Fig. 16. Bar plots showing the mango and avocado reliability of the fruit market based on respondents' answers, highlighting the significant challenge in market access for fruit farmers in the region.

Swartz, 2019; Tumaini et al., 2023; Udimal et al., 2017; Zegeye et al., 2022), creates significant obstacles for farmers aiming to maintain the quality and profitability of their produce The lack of reliable markets may discourage investment in improved harvesting and storage practices, as farmers perceive limited economic returns from their efforts. The following strategies are recommended to ensure a dependable market for avocados and mangoes:

(i) **Market development initiatives**

Creating and promoting structured and accessible markets for mangoes and avocados could improve reliability and help farmers secure steady buyers. This creation can be achieved by establishing connections with more prominent distributors, export companies, or value-added processing facilities, which could reduce the impact of market fluctuations.

(ii) **Strengthening farmer cooperatives**

Supporting the formation of cooperatives that could provide collective bargaining power, enabling farmers to negotiate better prices and access more reliable markets. This collective approach could also attract buyers interested in bulk purchasing, enhancing market stability.

(iii) **Promotion of value-addition enterprises**

Encouraging farmers or local entrepreneurs to engage in value-addition activities like fruit drying, juice production, or jam-making could reduce reliance on fresh fruit markets. This approach would allow farmers to preserve fruits longer and expand their market options.

(iv) **Exploring alternative marketing channels**

Using digital platforms or mobile apps to sell produce could open new marketing avenues for farmers and provide greater access to potential buyers, thus enhancing market reliability and reducing the risk of fruit spoilage.

3.16. Farm gate prices for mangoes and avocados in the study area

The data on avocado and mango prices provides valuable insights into the pricing trends and variability within the local agricultural market. Avocado and mango prices vary among locations and market dynamics. For avocados, the average price is 452.27 TZS, which suggests that, on average, avocados are relatively affordable in the market. The price range, however, spans from a low of 250 TZS to a high of 1600 TZS per kg, indicating some variability. This range suggests that avocado prices fluctuate, likely due to seasonal changes, regional availability, and the quality of the fruit. The narrowness of the price range, when compared to mangoes, indicates that the avocado market may be relatively stable with fewer extreme price swings. While the prices may fluctuate within this range, the consistency could be attributed to uniformity in avocado quality or the nature of the supply chain, where prices are generally kept within a predictable range. In addition, factors like consumer demand, harvest periods, and local production cycles could all contribute to this moderate price variation.

In contrast, mango prices show far greater variability. The average price of mangoes is substantially higher, at 204 TZS (per kg), suggesting that, on average, mangoes are priced significantly lower than avocados in the market. However, the price range for mangoes is extensive, varying from as low as 200 TZS to as high as 2000 TZS. This wide range signals high price fluctuation and suggests that mango prices are subject to various unpredictable market forces. The extreme variation in prices could be attributed to several potential factors. First, mangoes have significant price differences based on quality, with high-end varieties or large bulk purchases commanding premium prices. In contrast, smaller or lower-quality mangoes are sold at much lower prices. Additionally, mangoes, being more perishable than avocados, might experience more drastic price changes based on supply dynamics and demand, particularly in markets where supply is irregular, or production is affected by seasonal or environmental factors. But also, large standard deviation associated with mango prices further emphasizes mango market segment variability due to seasonality, regional price differences, and quality variations.

4. Conclusion and recommendation

The present study comprehensively assesses the post-harvest handling practices for mango and avocado in the Mbeya region of Tanzania. The findings highlight the significant challenges smallholder farmers face, including the reliance on traditional methods, inadequate storage and transportation facilities, and the prevalence of pests and diseases. These factors contribute to substantial post-harvest losses, reducing the economic returns for farmers and limiting the availability of fresh fruits in the market. It is essential to develop and promote improved post-harvest handling techniques accessible to smallholder farmers to address these challenges. Introducing simple, cost-effective technologies, such as edible coatings and low-cost cold storage solutions, could significantly extend the shelf-life of mango and avocados, reduce losses, and enhance farmers' livelihoods in the Mbeya region. This study recommends targeted interventions that address local realities and national priorities. Firstly, the development and validation of simple, low-cost edible coating technologies using locally available materials such as cassava starch or Aloe vera should be prioritized to extend the shelf-life of mango and avocado under ambient conditions, supporting ASDP II goals to reduce post-harvest losses. Secondly, training and capacity-building programs must be gender-sensitive, ensuring that both men and women farmers are equally included in modules covering improved harvesting, storage, and transportation techniques to enhance equitable access to knowledge and technologies. Additionally, investment in affordable, community-managed cold storage facilities within key producing wards is crucial to improve smallholder farmers' access to preservation infrastructure, aligning with the Tanzania Horticulture Development Strategy's market infrastructure

development component. Moreover, there is a need for policy support by integrating these interventions into district agricultural development plans and extension programs to ensure scalability and sustainability. The promotion of gender-responsive Integrated Pest Management (IPM) strategies through demonstration plots and farmer field schools is essential, ensuring that both male and female farmers are trained in biological control, cultural practices, and safe pesticide use to effectively manage insect pests. These recommendations, by incorporating national policy frameworks and gender considerations, will enhance their practicality, acceptance, and impact, ultimately improving fruit quality, farmer income, and food security in the Mbeya region.

CRediT authorship contribution statement

Mng'ong'o Marco E.: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Absalom Komanya:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation. **Hadija Matimbwa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Lilian Maro:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Abubakar M. Mshora:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Ethics approval

The research approval was obtained before implementation of the project from Local Government Authorities in the study area

Consent to participate

Verbal consent was obtained from all participating members in the current study

Code availability

All data coding is included in the SPSS uploaded file as supplementary materials

Ethics

No procedures involving humans or animals have been done in this study. All authors comply with all advised ethical standards.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The datasets supporting this article have been uploaded as part of the electronic supplementary material. All entry data for all samples are uploaded as SPSS Spreadsheet files.

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