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A Comprehensive Review of Tomato Post-Harvest Losses: Understanding Impacts and Contributing Factors in Ethiopia

[1,2]*Deribe Mengistu Wakene and* [2]*Tewodros Sharew*

[1]*Food Science and Nutrition, Food Engineering, Deber Zeit Agricultural Research Centre, Bishoftu, Ethiopia*

[2]*Food Technology and Process Engineering, Haramaya Institute of Technology, Haramaya University, Dire Dawa, Ethiopia*

ABSTRACT

This review explored the underlying causes and factors that contribute to postharvest losses in tomato production by analyzing their economic and environmental impacts. Tomatoes, a popular crop worldwide, especially in tropical regions such as Ethiopia, are highly valued for their rich vitamin and mineral contents, including lycopene. It is an affordable and nutritious vegetable and is known for its high content of antioxidants, including carotenoids such as β-carotene, polyphenols and ascorbic acid, making it a top choice for those seeking a healthy diet. Despite their nutritional significance, tomatoes, which are climacteric and perishable fruits, have a short shelf life of 2 to 3 weeks, which renders them susceptible to postharvest losses throughout the food supply chain from farm to table. These losses, experienced in both quantity and quality, occur during the harvesting, storage, transportation, processing, marketing and preparation phases. In Ethiopia, postharvest losses affect various regions differently, including North Wollo, South Wollo, East Wollega, West Shewa and South Tigray, with loss rates fluctuating during harvesting, packing, transport and storage. The causes of these losses include inadequate harvesting equipment, improper packaging and storage methods, deficient infrastructure such as roads and transportation systems and a lack of technological advancements in the production and distribution processes. Addressing these challenges is vital for enhancing the efficiency and sustainability of tomato production, minimizing economic losses and mitigating the environmental impact of food waste.

KEYWORDS

Postharvest loss of tomato, economic impact, environmental impact, Ethiopia

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INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a widely cultivated crop worldwide, including in tropical countries such as Ethiopia. Tomatoes rank fourth in terms of acreage among vegetables, with 182 million tons produced globally in 2017, including 21 million tons in Africa[1,2]. Tomato is believed to have originated from the wild in Peru, Ecuador and other parts of tropical America[3] and is now cultivated in different major growing areas of Ethiopia, including the eastern and central parts of the country's mid-to low-land regions[4]. Climatic and soil conditions in Ethiopia are favorable for tomato cultivation and the crop has

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become the most profitable for small-scale farmers, providing a higher income than other crops. During the 2016-2017 cropping season, the total annual tomato production in Ethiopia was estimated to be 283,648.27 quintals, with 41.51% coming from the Oromia region and 49.83% from the Amhara and Tigray regions[5]. Tomatoes and tomato-based dishes provide a variety of nutrients and many health benefits. They are rich in phytonutrients such as lycopene, β-carotene, phenolic compounds and ascorbic acid, as well as essential nutrients, which aid in preventing oxidative damage in the body[6]. It is rich source of vitamins and minerals, particularly as a rich source of lycopene (60-90 mg/kg)[7]. Lycopene serves as a potent antioxidant linked to lowering the risk of prostate cancer[8]. It holds the top position among vegetables in terms of nutritional value, offering significant biological activity in human diets[9]. The nutritional and health advantages of tomatoes encourage widespread cultivation and consumption in various forms, including fresh in salads, cooked and as snacks. Presently, tomatoes are highly prized as an industrial crop globally due to their substantial economic returns and versatility for processing into various products[10]. However, fruits and vegetables such as tomatoes are highly perishable product particularly once they have been harvested[11].

Postharvest losses pose a major challenge in tomato supply chains, particularly in tropical agriculture, where losses of fresh fruits like tomatoes can be significant. These losses stem from various factors such as inadequate pre-harvest techniques, improper handling, transportation issues, lack of information, poor infrastructure, limited technology, skills and management capacity among supply chain actors[12]. Tomatoes are particularly susceptible to postharvest losses because of their perishable nature, which is exacerbated by the humid conditions found in tropical climates, leading to increased quality deterioration once tomatoes are harvested[13]. As climacteric fruits, tomatoes undergo a respiratory peak during their ripening process, contributing to their short shelf life, typically lasting only 2-3 weeks[14]. This ripening process is complex and results in dramatic changes in the color, texture, flavor and chemical composition of tomatoes[12].

Globally, postharvest losses in tomatoes can be alarming, ranging from 25 to 42%[15]. Sub-Saharan Africa (SSA) encounters significant challenges in tomato postharvest management, with fresh market tomato losses averaging around 9.5% in East Africa, 9.8% in Central and Southern Africa and 10.04% in West Africa[16]. Tropical countries face even higher losses, with rates varying from 20 to 50% between harvesting, transportation and consumption[17]. In Ethiopia, postharvest losses along the tomato value chain are estimated to be between 20 and 35%[18]. This review aims to investigate the root causes of postharvest losses in tomatoes, identify the key contributing factors and evaluate their implications for both the economy and the environment, with a particular focus on Ethiopia.

Overview of tomato production in ethiopia and worldwide: Tomato production worldwide has surpassed 182.2 million tons, grown on more than 4.7 million hectares of land. Tomatoes flourish in tropical, subtropical and temperate regions. The leading ten tomato-producing nations comprise China, India, Turkey, the USA, Egypt, Iran, Italy, Spain, Mexico and Brazil[19]. In 2012, the FAO estimated a global tomato cultivation area of 4.7 million hectares, yielding 161 million metric tons. China led the production, accounting for 29.8% of the total, followed by India with 17.5 million tons[6]. Despite its importance, African agriculture lags behind other regions in terms of productivity[20].

In Ethiopia, tomato holds significant importance as a widely grown vegetable crop, cultivated by smallholder farmers, commercial state and private farms during both rainy and dry seasons. The crop thrives in elevations ranging from 700 to 2000 m above sea level, receiving annual rainfall between 700 to over 1400 mm. Large-scale tomato production occurs in the upper valley under irrigated and rain-fed conditions, while small-scale production for the fresh market is common in various regions such as Koka, Batu, Wondo-Genet, Guder and Bako[21]. Commercial tomato cultivation in Ethiopia traces back to the 1980s, with the first recorded production in the upper Awash region covering 80 hectares by Merti Agro-industry for domestic and export markets[22].

Despite its significance, tomato production in Ethiopia faces challenges with low productivity. In 2016, the total cultivated area spanned approximately 9700 hectares, yielding 91300 tons of fresh tomatoes, averaging 9.4 tons/ha. This is notably lower than the global average productivity of 38.3 tons/ha and the averages in Africa, America, Europe and Asia[23]. Between 2011 and 2016, FAO data showed an average rain-fed tomato area of 7,100 ha in Ethiopia, yielding 50,150 tons of fruits[24]. Despite the country's potential, the average tomato productivity remains low at 6.18 tons per hectare compared to other regions such as Africa, America, Europe and Asia[19].

The Ethiopian National Agricultural Research System has introduced approximately 25 tomato varieties, including open-pollinated types like Melkashola, Marglobe, Melkasalsa, Heinz 1350, Fetane, Bishola, Eshet and Metadel from the Melkassa Agricultural Research Center[21]. Tomato production in Ethiopia is distributed across various regions, showcasing varying yields. Leading the pack is Oromia, contributing 68% of the total production, with Meki alone accounting for 9% of that output. Following closely, Tigray and the Somalia region contribute 5 and 4%, respectively, to the country's tomato production[25].

Nutritional benefit of tomato: In Ethiopia, tomatoes are a staple ingredient in many local dishes, often used to prepare sauces and salads. Additionally, processed tomato products such as tomato paste, juice, soups, stews and ketchup are consumed in large quantities compared to other vegetables[23]. Tomatoes offer significant health benefits due to their high content of phytonutrients like lycopene, β-carotene, phenolic compounds and ascorbic acid[26]. These compounds have been associated with a reduced risk of cancer, prostate and heart diseases[6], with tomato intake linked to decreased risks of various cancer sites, including lung and stomach malignancies[27]. Moreover, tomatoes are rich in essential amino acids, sugars, dietary fibers, vitamin B and C, iron and phosphorus, contributing to their nutritional value[28]. Furthermore, tomatoes contain phenolic compounds that exhibit strong antioxidant activity[29]. They are utilized in various forms, including fresh consumption, processing into products like tomato paste, juice, ketchup and cherry tomatoes, serving as income-generating crops for small-scale farmers and providing employment opportunities in production and processing industries[30]. The rich nutritional profile of tomatoes, including their high vitamin C and vitamin A content, is essential for promoting eye health and preventing muscular degeneration[31].

Tomato postharvest losses: Tropical fruits, by nature, are prone to high and rapid postharvest losses due to their inherent biological characteristics. Estimates suggest that postharvest losses of fruits and vegetables range from 5 to 20% in developed countries and 20 to 50% in developing nations[32]. Among those vegetables, tomatoes are particularly susceptible to significant postharvest losses, attributed to their highly dynamic metabolic changes during development. Tomato damage assessment at wholesale markets often surpasses that of other vegetables, highlighting the severity of the issue. Factors contributing to postharvest losses in horticultural crops, including tomatoes, encompass storage conditions, transportation facilities, diseases and insect pests[12].

Tomatoes exhibit some of the highest postharvest losses within the fruit and vegetable supply chains of Sub-Saharan Africa[16]. In Ethiopia, out of the total crop production of 39.7 million tons, a significant amount of about 6.6 million tons consists of highly perishable fruits, such as tomatoes[33]. Despite their nutritional value and economic importance, tomatoes have a short shelf life due to factors such as inadequate technology and insufficient awareness among producers and market actors, leading to suboptimal handling and storage practices[9]. The perishable nature of tomatoes is exacerbated by their high-water content, often exceeding 90%, which renders them highly susceptible to spoilage[10]. This high moisture content poses challenges in handling, transportation and marketing of tomatoes[34]. Postharvest losses vary significantly among commodities, production areas and seasons, with tomatoes being a widely grown vegetable crop in Ethiopia, where high postharvest losses pose a major constraint in the vegetable supply chain[35].

Table 1: PHL of fruits and vegetables selected country in SSA

Sub-region	Country	Estimated postharvest loss (%)	References
East Africa	Ethiopia	50	Sipho and Tilahun[42]
Central Africa	Rwanda	30-80 depending on product	
West Africa	Ghana	30-80 depending on product	
South Africa	Swaziland	20-50	

Postharvest losses of horticultural produce, particularly tomatoes, are a pervasive issue throughout the post-harvest value chain, primarily due to high rates of bruising, water loss and subsequent decay during handling[36]. These losses occur at various stages, including harvest, preparation for market, transportation and consumption of fruits and vegetables[37]. Ethiopia, like many other countries, experiences a significant proportion of postharvest losses in perishable horticultural commodities due to limited cold storage facilities, poor packaging and transport infrastructures, lack of processing facilities and inadequate handling practices[38].

Additionally, postharvest losses and reduced yields in Ethiopian agriculture are attributed to factors such as diseases, pests and suboptimal fertilization practices[7]. Pests, microbial infections, natural ripening processes and environmental conditions like heat and drought also contribute to postharvest losses and quality deterioration of horticultural crops[39]. Various studies conducted across Ethiopia have revealed significant postharvest losses of tomatoes, ranging from 2.5 to 45.3%, with causes including pre-harvest infection, injury and physical damage during handling and transportation (Table 1)[32,39-42].

Key factors contributing to postharvest losses in tomato production

On-farm causes

Inappropriate harvesting periods and containers: Tomatoes are considered climacteric fruits, meaning they can be harvested when mature but still green and then allowed to ripen naturally during the postharvest period. However, allowing tomatoes to become overripe is not recommended, especially for long-distance markets. Fully ripened fruits are prone to bruising during harvest, leading to a shortened shelf life. This susceptibility to damage contributes significantly to the high postharvest losses observed in developing countries[10]. Tomato is a soft fleshy fruit that is quickly loses its firm texture during over-ripening and particularly vulnerable to post-harvest losses[43]. Most of the fresh tomato losses in Africa take place at the stage before they are sold to consumers. Research by Goka *et al.*[2] highlights this, indicating that post-harvest losses for tomatoes are particularly severe, reaching up to 20% within five days of harvesting. Improper harvesting and post-harvest practices result in losses due to spoiling of the product before reaching the market, as well as quality losses such as deterioration in appearance, taste and nutritional value[44]. There is also tomato loss during harvesting due to mismanagement of the time, criteria to harvest the tomato[9]. Improper harvesting method and equipment can also cause losses[45]. Due to lack of properly designed harvesting equipment and poor labor incentive harvesting F&V is not done with a maximum care to avoid mechanical damage[46]. Moreover, a higher temperature at the harvest leads to a time of harvest leads to an increased respiration rate, consequently reducing shelf life and contributing to losses. This is because fresh produce continues to respire and ripen after harvesting, leading to physiological deterioration[42]. The fruit's physiological maturity during harvesting significantly impacts its quality. In many developing countries, tomatoes are manually picked rather than mechanically harvested. In Ethiopia, for example, farmers commonly use wooden crates and woven baskets with hard surfaces and sharp edges, which can cause mechanical damage to the harvested fruits. Additionally, overloading during harvesting can result in excessive compressive stresses, leading to the crushing of fruits located at the bottom of the containers[47].

Lack of cooling and storage facilities: Tomatoes are living organic organisms and very perishable food items with relatively short postharvest storage lives[48]. In storage, without control of cleanliness, temperature and humidity these are significant problems for loss of products both quality and quantity.



Fig. 1: Handling and storage conditions of tomatoes[51]



Fig. 2: Field sorting and packing of tomatoes before loading[41]

Standard, round tomatoes are sensitive below 12.5°C, specialty tomato quality may also be affected when held at lower temperatures[49]. The heat from the field causes a swift rise in metabolic activity. The ideal temperature for harvesting tomatoes, near 20°C, is usually reached early in the morning or late in the evening[31]. Some studies are conducted in different parts of Ethiopia, such as in Sodo Market of Wolaita Zone, results showed that, loss due to traditional storage materials as shown in Fig. 1 (22% banana and 21% tomato) were physical damaged[50]. Postharvest loss of tomato in Asella Town, Ethiopia, due to use of unsuitable storage (6.91, 2.81 and 0.5%) was recorded in wholesalers, retailers and consumers, respectively[12].

Inappropriate packaging materials: The use of inappropriate packaging material is a basic factor most regularly related to the maximum level of losses after harvest[52]. Some of the most common packaging materials used in Ethiopia, include large green leaves, clay pots, woven cane baskets, wooden crates, cardboard crates, cardboard boxes, plastic buckets, nylon sacks and jute sacks mainly used by small-scale farmers. The reason for the use of sacks and baskets as major packaging material was their accessibility and low cost[53]. These, packaging material are used to pack and transport in which there is no palletizing and large mass of commodity is tightly packed[32]. Packaging problem is not only lack of ventilation, but physical damage due to rough surface and excessive pressure due to large depth of fruit leading to excessive weight on bottom layer and lack of strength in the carton one of the causes of spoilage at destination[31]. The main reasons for post-harvest losses in fruits and vegetables such as tomatoes are improper packaging and the use of unsuitable packaging materials (Fig. 2). Inadequate packaging materials do not offer enough protection for fresh produce, making them susceptible to damage and speeding up their spoilage[46]. Mechanical damage to FV may result from inappropriate packaging and over or under packaging of containers[42].



Fig. 3: Tomato fruit loading and modes of transportation[41]

Off-farm causes

Lack of transport and handling practices of tomatoes: Transportation is a major issue for numerous farmers in developing areas, especially when dealing with highly perishable fruits and vegetables. Most farms are located in remote regions with insufficient farm-to-market roads, impeding the prompt transportation of produce to markets. As a result, significant postharvest losses occur, particularly for tomatoes. Consequently, smallholder farmers face more than 20% postharvest losses due to transportation delays[10]. Lack of access roads to production fields in many African countries is a major challenge hampering the success of the tomato industry. Losses can still occur in transit due to bad road conditions and delays at checkpoints, increasing physical damage and exposure to high temperatures. Vibration and impact during transportation as a result of undulations on roads is one of the major causes of post-harvest losses to most fruits and vegetables especially tomatoes[31]. Postharvest losses occur due to transports of fruits and vegetables without temperature-controlled environmental conditions resulting in further deterioration[42]. Compared with several temperate fruits and vegetables, tropical and subtropical vegetables such as tomatoes present greater transportation problems because of their perishable nature[38]. The absence of appropriate means of transport, poor roads and inefficient logistics management prevent perishable foods from being properly preserve[46]. Likewise, the transportation system in postharvest handling of horticultural products frequently involves loading items on top of one another, which can result in injury, damage and a shorter shelf life (Fig. 3). Furthermore, the practice of carrying mixed cargoes of bulk goods creates significant issues. Different products in these loads react differently to temperature, transpiration, dehydration and ethylene. When carried combined, these elements lead to increased physiological, mechanical, biological and chemical losses, reducing the commodities' durability[52]. In most developing countries like Ethiopia, roads are not adequate for proper transport of horticultural crop such as tomatoes[11]. The kind of transportation system in Ethiopia is the use of pack animals and on the back of man and woman which leads to bruising during loading and unloading[33]. According to the report of Yeshiwas and Tadele,[53], study in Debre Markos Ethiopia, the maximum percentage of total loss of tomato (10%) was recorded during transportation. In addition, in Asella Zone, Ethiopia, loss due to transportation of tomato during loading and unloading were 0.85, 0.75 and 0.5% recorded during wholesaler, retailer and consumer, respectively[12]. Similar, study also conducted in Sodo, Wolaita Zone, Ethiopia, postharvest loss of tomato due to long distance transport to market place (18.8%) tomato was damaged[50].

Lack of knowledge of post-harvest technologies: Unlike dry grains, fresh fruits and vegetables are difficult to handle post-harvest due to their perishable nature and size, making their production challenging[54]. One reason for the underdeveloped horticulture industry in sub-Saharan Africa, particularly in Ethiopia, is the perishable nature of the produce, coupled with a lack of knowledge and limited financial resources among small-scale farmers[55]. In Ethiopia, farmers do not have any formal knowledge on



Fig. 4: Tomato postharvest losses due to rodents, decay and bruise[41]

handling methods of harvested products and they do not receive any training on postharvest handling practices of fruits and vegetables, except for their traditional knowledge[53].

Disease and pest problem: The impact of diseases and pests at the production level significantly contributes to postharvest losses and quality deterioration in fruit crops such as tomatoes[52]. In particular, reports have indicated common occurrences of cutworms affecting crops at the field level. Among the primary insect and mite pests infesting tomatoes are the African bollworm, potato tuber moth, tomato leaf miner/fruit borer, whiteflies and spider mites[52]. Fungal activity is one of the most prevalent causes of fungal deterioration. Post-harvest diseases alone can lead to losses ranging from 10 to 30% of the total crop yield, a particularly acute issue in perishable crops, such as tomatoes, notably in developing countries[1]. Research by Emana *et al.*[11] revealed that at the farm level, a significant proportion of tomato damage occurs owing to insect attacks (26%) and diseases (25%), with wholesalers experiencing disease affecting over 40% of their tomato stock. A study conducted in the Fogera District of the Amhara region highlighted postharvest losses primarily caused by pests (borers), diseases and physiological disorders, accounting for 18.25, 3.28 and 2.62%, respectively[31] as shown in Fig. 4. These findings underscore the critical need for effective pest and disease management strategies to mitigate losses and ensure the quality and longevity of tomato crops from the field to market.

Postharvest losses: Economic, market and environmental impact

Impacts on economic and marketability: Tomatoes provide better economic returns to many farmers in Ethiopia, particularly when cultivated during the wet season. Production methods range from home gardening and smallholder farming to commercial farms owned by both public and private entities[56]. Loss of fruits and vegetables has significant negative impacts on the economy, reflecting poor functioning and inefficient value chains and food systems, leading to a loss of economic value in the food produced[55]. In small-scale production, most fresh produce is stored at relative humidity levels below the recommended range, resulting in excessive moisture loss. Consequently, fruits and vegetables experience wilting, shriveling and dryness due to minor moisture losses of 3-6%, affecting the marketability and economic value of produce[16]. Regarding market conditions, the majority of farmers sell their products in nearby markets, with a few selling directly on farms. Marketing conditions are unsatisfactory and discouraging, primarily because of the oversupply of the product and the perishable nature of the crop[33]. Temperature plays a crucial role in marketing, directly affecting the quality of tomatoes by influencing color, firmness and flavor[45]. Post-harvest operations for fresh fruits and vegetables, especially during marketing, are sub-standard in developing countries. Approximately 20-30% of fresh fruit and vegetable produce is wasted before reaching the consumer, as seen in tomato post-harvest losses ranging from 6.70 to 33.50% in

India[44]. Studies estimating economic losses for fruits and vegetables in sub-Saharan Africa reveal that 16-40% of production is lost along the entire value chain. In addition to revenue loss, a significant consequence of quality deterioration is nutrient degradation[57]. In Debre Markos, Ethiopia, the highest postharvest tomato loss (18%) occurs during marketing/selling, resulting in reduced economic value and farmer income[53].

Impact on the environment and climate: In a study conducted in Chimba, Gumara and Kudmi Kebeles in Bahir Dar, Amhara, Ethiopia, temperatures were recorded at various stages: Farm, transportation, wholesale and retail levels, ranging from 22.49 to 25.51°C. These temperature fluctuations, along with relative humidity, significantly contribute to the deterioration of fruits and vegetables, accelerating the ripening process of tomatoes and reducing their shelf life[41]. Postharvest losses of fruits and vegetables pose environmental concerns due to the resources invested in their production, such as energy, water and soil. Uneaten food results in unnecessary CO_2 emissions, contributing to environmental degradation[58]. When fruits and vegetables, including tomatoes, are wasted and end up in landfills or rivers after markets, they emit methane, a potent greenhouse gas[59,60]. Improper disposal of damaged or overripe tomatoes in Ethiopian cities like Addis Ababa leads to environmental degradation, emitting odors that negatively impact the climate[61]. Globally, food loss and waste are significant contributors to greenhouse gas emissions, exacerbating climate change and biodiversity loss[62]. Implementing sustainable waste management strategies, such as the 5 R system and circular economy models, can help mitigate food waste and its environmental impact[63].

CONCLUSION

Tomatoes serve as both a vital nutrient source and a significant economic asset for those engaged in their cultivation and trade. In Ethiopia's diverse agricultural landscape, where fruits and vegetables are integral to the economy, tomatoes stand out as a key commodity. However, the journey of these perishable goods from farm to market is fraught with challenges that lead to substantial postharvest losses. Factors such as inadequate packaging, storage facilities, transportation infrastructure and market connections, along with issues like poor handling practices and hygiene standards, all contribute to these losses. Despite efforts to quantify postharvest losses in Ethiopia, estimates vary, highlighting the need for more comprehensive data collection methods. Current estimates suggested that postharvest losses of tomatoes in Ethiopia may reach up to 40-45%, emphasizing the urgency of addressing underlying issues across the supply chain. Improving harvest practices, investing in modern storage technologies, enhancing market information systems and strengthening value chain development are critical steps toward mitigating these losses and ensuring the sustainability of tomato production. By adopting a multidisciplinary approach and embracing innovations in storage and marketing, Ethiopia can not only reduce postharvest losses of tomatoes but also create greater economic opportunities for smallholder farmers and contribute to food security and economic growth in the country.

SIGNIFICANCE STATEMENT

This study investigates the factors causing postharvest losses in tomato production, focusing on their economic and environmental effects. By analyzing challenges throughout the supply chain, it aims to pinpoint opportunities for intervention to enhance sustainability. Findings reveal multiple causes of losses, including inadequate equipment and infrastructure, with variations noted among regions in Ethiopia. These findings underscore the need for customized strategies to minimize losses, bolstering food security, economic growth and environmental sustainability.

REFERENCES

1. Fufa, N., T. Zeleke and T. Abdisa, 2021. Assessing postharvest diseases and losses of tomato in selected areas of Ethiopia. Int. J. Agric. Biosci., 10: 202-207.
2. Goka, M.G., M. Dufrechou, P. Picouet, K. Soncy and Y. Ameyapoh, 2021. Determinants of postharvest losses in tomato production in the Savannah Region of Togo. Eur. J. Agric. Food Sci., 3: 40-45.

3. Macheka, L., E. Spelt, J.G.A.J. van der Vorst and P.A. Luning, 2017. Exploration of logistics and quality control activities in view of context characteristics and postharvest losses in fresh produce chains: A case study for tomatoes. Food Control, 77: 221-234.
4. Gemechu, G.E., 2019. Adaptation of released tomato varieties (*Solanum lycopersicum* L. Mill) under Jimma condition South West Ethiopia. J. Nat. Sci. Res., 9: 22-31.
5. Wosene, G. and W. Gobie, 2022. Value chain analysis of tomato: The case of Bure, Jabitehinan and North Mecha Districts of Amhara Regional State, Ethiopia. J. Agric. Food Res., Vol. 7. 10.1016/j.jafr.2022.100272.
6. Li, Y., W. Niu, M. Dyck, J. Wang and X. Zou, 2016. Yields and nutritional of greenhouse tomato in response to different soil aeration volume at two depths of subsurface drip irrigation. Sci. Rep., Vol. 6. 10.1038/srep39307.
7. Balemi, T., 2008. Response of tomato cultivars differing in growth habit to nitrogen and phosphorus fertilizers and spacing on vertisol in Ethiopia. Acta Agric. Slov., 91: 103-119.
8. Abir, M.H., A.G.M.S.U. Mahamud, S.H. Tonny, M.S. Anu and K.H.S. Hossain *et al*., 2023. Pharmacological potentials of lycopene against aging and aging-related disorders: A review. Food Sci. Nutr., 11: 5701-5735.
9. Abera, G., A.M. Ibrahim, S.F. Forsido and C.G. Kuyu, 2020. Assessment on post-harvest losses of tomato (*Lycopersicon esculentem* Mill.) in selected districts of East Shewa Zone of Ethiopia using a commodity system analysis methodology. Heliyon, Vol. 6. 10.1016/j.heliyon.2020.e03749.
10. Njume, C.A., C. Ngosong, C.Y. Krah and S. Mardjan, 2020. Tomato food value chain: Managing postharvest losses in Cameroon. IOP Conf. Ser.: Earth Environ. Sci., Vol. 542. 10.1088/1755-1315/542/1/012021.
11. Emana, B., V. Afari-Sefa, N. Nenguwo, A. Ayana, D. Kebede and H. Mohammed, 2017. Characterization of pre-and postharvest losses of tomato supply chain in Ethiopia. Agric. Food Secur., Vol. 6. 10.1186/s40066-016-0085-1.
12. Gebeyehu, Y.T., T. Mekuriyaw and Y. Hune, 2020. Assessment of postharvest supply chain loss of banana and tomato in Asella Town. Acta Sci. Agric., 4: 17-22.
13. Firdous, N., 2021. Post-harvest losses in different fresh produces and vegetables in Pakistan with particular focus on tomatoes. J. Hortic. Postharvest Res., 4: 71-86.
14. Haile, A., 2018. Shelf life and quality of tomato (*Lycopersicon esculentum* Mill.)fruits asaffected by different packaging materials. Afr. J. Food Sc., 12: 21-27.
15. Gebeyaw, M. and S. Tsegay, 2020. Review on: Effect of pre and post harvest treatment on the quality of tomato (*Lycopersicon esculentum* L.). Int. J. Curr. Res. Acad. Rev., 8: 75-82.
16. Sibomana, M.S., T.S. Workneh and K. Audain, 2016. A review of postharvest handling and losses in the fresh tomato supply chain: A focus on Sub-Saharan Africa. Food Secur., 8: 389-404.
17. Kader, A.A., 2004. Increasing food availability by reducing postharvest losses of fresh produce. ISHS Acta Hort., 682: 2169-2176.
18. Etefa, O.F., S.F. Forsido and M.T. Kebede, 2022. Postharvest loss, causes, and handling practices of fruits and vegetables in Ethiopia: Scoping review. J. Hortic. Res., 30: 1-10.
19. Ejeta, B., D. Ermias and G. Ashetu, 2020. Determinants of smallholder commercialization of tomato crop in Siltie Zone, Southern Ethiopia. Agric. For. Fish., 9: 163-173.
20. Kassaw, H.M., Z. Birhane and G. Alemayehu, 2019. Determinants of market outlet choice decision of tomato producers in *Fogera woreda*, South *Gonder* Zone, Ethiopia. Cogent Food Agric., Vol. 5. 10.1080/23311932.2019.1709394.
21. Sora, S.A., 2018. Review on productivity of released tomato (*Solanum lycopersicum* Mill.) varieties in different parts of Ethiopia. J. Hortic. Sci. For., Vol. 1.
22. Lendabo, G., K. Wulchafo and D. Abayechaw, 2021. Effects of irrigation frequency on yield response of two commonly grown tomato varieties at Shashogo Woreda of Southern Ethiopia. Ethiop. Int. J. Curr. Res. Acad. Rev., 9: 31-46.
23. Asfaw, D.M., 2021. Analysis of technical efficiency of smallholder tomato producers in Asaita District, Afar National Regional State, Ethiopia. PLoS ONE, Vol. 16. 10.1371/journal.pone.0257366.

24. Almaz, G., N. Workneh, W. Edilegnaw and A. Gezahegn, 2014. Constraints of vegetables value chain in Ethiopia: A gender perspective. Int. J. Adv. Res. Manage. Social Sci., 3: 44-71.
25. Kassa, M.A., 2018. Farm yield evaluation and demonstration of Melkashola tomato variety in central zone of Tigray Region, Ethiopia. Afr. J. Plant Sci., 12: 28-31.
26. Copetta, A., L. Bardi, E. Bertolone and G. Berta, 2011. Fruit production and quality of tomato plants (*Solanum lycopersicum* L.) are affected by green compost and arbuscular mycorrhizal fungi. Plant Biosyst. Int. J. Dealing Aspects Plant Biol., 145: 106-115.
27. Giovannucci, E., 2005. Tomato products, lycopene, and prostate cancer: A review of the epidemiological literature. J. Nutr., 135: 2030S-2031S.
28. Weldegiorgis, L.G., G.K. Mezgebo, H.G.E. Gebremariam and Z.A. Kahsay, 2018. Resources use efficiency of irrigated tomato production of small-scale farmers. Int. J. Veg. Sci., 24: 456-465.
29. Khatun, M. and M.S. Rahman, 2022. Postharvest loss assessment of tomato in selected locations of Bangladesh. Bangladesh J. Agric. Res., 45: 43-52.
30. Degefa, K., G. Biru and G. Abebe, 2020. Economic efficiency of smallholder farmers in tomato production in Bakotibe District, Oromia Region, Ethiopia. J. Agri. Sci. Food Res., Vol. 11.
31. Arah, I.K., G.K. Ahorbo, E.K. Anku, E.K. Kumah and H. Amaglo, 2016. Postharvest handling practices and treatment methods for tomato handlers in developing countries: A mini review. Adv. Agric., Vol. 2016. 10.1155/2016/6436945.
32. Bantayehu, M., M. Alemayehu, M. Abera and S. Bizuayehu, 2017. Postharvest losses assessment of tropical fruits in the market chain of North Western Ethiopia. Food Sci. Qual. Manage., 66: 13-24.
33. Bantayehu, M., M. Alemayehu, M. Abera and S. Bizuayehu, 2018. Determinants and extent of pre-and postharvest losses of fruits in Northwestern Ethiopia. Int. J. Sustainable Agric. Res., 5: 68-75.
34. Aidoo, R., R.A. Danfoku and J.O. Mensah, 2014. Determinants of postharvest losses in tomato production in the Offinso North District of Ghana. J. Dev. Agric. Econ., 6: 338-344.
35. Asrat, F., A. Ayalew and A. Degu, 2019. Postharvest loss assessment of tomato (*Solanum lycopersicum* L.) in Fogera, Ethiopia. Turk. J. Agric. Food Sci. Technol., 7: 1146-1155.
36. Kitinoja, L. and H.Y. AlHassan, 2012. Identification of appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia-Part 1. Postharvest losses and quality assessments. Acta Hortic., 934: 31-40.
37. Buyukbay, E.O., M. Uzunoz and H.S.G. Bal, 2011. Post-harvest losses in tomato and fresh bean production in Tokat Province of Turkey. Sci. Res. Essays, 6: 1656-1666.
38. Woldemariam, H.W. and B.D. Abera, 2014. Development and evaluation of low cost evaporative cooling systems to minimise postharvest losses of tomatoes (Roma vf) around Woreta, Ethiopia. Int. J. Postharvest Technol. Innovation, 4: 69-80.
39. Kasso, M. and A. Bekele, 2018. Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa Region, Ethiopia. J. Saudi Soc. Agric. Sci., 17: 88-96.
40. Sisay, Z., K. Abegaz and A. Fisseha, 2021. Assessment on post-harvest losses of tomato (*Lycopersicon esculentem* Mill.) in selected districts of Sidama Zone-Ethiopia. J. Food Process. Technol., Vol. 12.
41. Tadesse, E.E., H. Assaye, M.A. Delele, S.W. Fanta and D.F. Huluka *et al*., 2021. Quantitative Postharvest Loss Assessment of Tomato Along the Postharvest Supply Chain in Northwestern Ethiopia. In: Advances of Science and Technology, Delele, M.A., M.A. Bitew, A.A. Beyene, S.W. Fanta and A.N. Ali (Eds.), Springer, Cham, Switzerland, ISBN: 978-3-030-80621-7, pp: 110-122.
42. Sipho, S. and S.W. Tilahun, 2020. Potential causes of postharvest losses, low-cost cooling technology for fresh produce farmers in Sub-Sahara Africa. Afr. J. Agric. Res., 16: 553-566.
43. Thole, V., P. Vain and C. Martin, 2021. Effect of elevated temperature on tomato post-harvest properties. Plants, Vol. 10. 10.3390/plants10112359.
44. Mohan, A., R. Krishnan, K. Arshinder, J. Vandore and U. Ramanathan, 2023. Management of postharvest losses and wastages in the Indian tomato supply chain-A temperature-controlled storage perspective. Sustainability, Vol. 15. 10.3390/su15021331.
45. Pathare, P.B., M.A. Dairi and A. Al-Mahdouri, 2021. Effect of storage conditions on postharvest quality of tomatoes: A case study at market-level. J. Agric. Mar. Sci., 26: 13-20.

46. Elik, A., D.K. Yanik, Y. Istanbullu, N.A. Guzelsoy, A. Yavuz and F. Gogus, 2019. Strategies to reduce post-harvest losses for fruits and vegetables. Int. J. Sci. Technol. Res., 5: 29-39.
47. Onuk, E.G., N.D. Shehu and T.A.K. Anzaku, 2018. Factors affecting the marketing of perishables agricultural produce in Minna metropolis, Niger State, Nigeria. J. Agric. Sci. Pract., 3: 71-78.
48. Porat, R., A. Lichter, L.A. Terry, R. Harker and J. Buzby, 2018. Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention. Postharvest Biol. Technol., 139: 135-149.
49. Veringa, D., I.L. Dumitrescu and M. Bogoescu, 2023. The effect of storage conditions on some tomato varieties, during the postharvest period. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, Vol. 51. 10.15835/nbha51113027.
50. Bateno, T. and T. Buke, 2018. Postharvest losses and management assessment of commercial fruit and vegetable at Wolaitazone, at Sodo Market. Int. J. Res. Innovations Earth Sci., 5: 99-105.
51. Tadesse, E.E., H. Assaye, M.A. Delele, S.W. Fanta and D.F. Huluka *et al*., 2022. Assessing tomato postharvest loss through the supply chain using load tracking technique in Northwest Ethiopia. Int. J. Postharvest Technol. Innovation, 8: 360-381.
52. Etana, M.B., B.O. Fufa and M.C. Aga, 2019. A detailed review on common causes of postharvest loss and quality deterioration of fruits and vegetables in Ethiopia. J. Biol., Agric. Healthcare, 9: 48-52.
53. Yeshiwas, Y. and E. Tadele, 2021. An investigation into major causes for postharvest losses of horticultural crops and their handling practice in Debre Markos, North-Western Ethiopia. Adv. Agric., Vol. 2021. 10.1155/2021/1985303.
54. Yeshiwas, Y., D. Belew and K. Tolessa, 2016. Tomato (*Solanum lycopersicum* L.) yield and fruit quality attributes as affected by varieties and growth conditions. World J. Agric. Sci., 12: 404-408.
55. Hailu, G. and B. Derbew, 2015. Extent, causes and reduction strategies of postharvest losses of fresh fruits and vegetables-A review. J. Biol. Agric. Healthcare, 5: 49-64.
56. Wondim, D., 2021. Value chain analysis of vegetables (onion, tomato, potato) in Ethiopia: A review. J. Agric. Sci. Food Technol., 7: 108-113.
57. Wongnaa, C.A., E.D. Ankomah, T.O. Ojo, E. Abokyi, G. Sienso and D. Awunyo-Vitor, 2023. Valuing postharvest losses among tomato smallholder farmers: Evidence from Ghana. Cogent Food Agric., Vol. 9. 10.1080/23311932.2023.2187183.
58. Sahoo, A., A. Dwivedi, P. Madheshiya, U. Kumar, R.K. Sharma and S. Tiwari, 2024. Insights into the management of food waste in developing countries: With special reference to India. Environ. Sci. Pollut. Res., 31: 17887-17913.
59. Yadav, P., S.K. Dhankhar and R. Mehar, 2023. Waste to worth: A review on utilization of vegetable waste. Int. J. Environ. Clim. Change, 13: 1385-1398.
60. De, B., I. Hussain and R.C. Das, 2023. Environmental Implications of Food Waste: A Study on South-Asian Countries. In: Renewable Energy Investments for Sustainable Business Projects, Dinçer, H. and S. Yüksel (Eds.), Emerald Publishing Limited, Leeds, England, ISBN: 978-1-80382-884-8, pp: 45-58.
61. Facchini, F., B. Silvestri, S. Digiesi and A. Lucchese, 2023. Agri-food loss and waste management: Win-win strategies for edible discarded fruits and vegetables sustainable reuse. Innovative Food Sci. Emerging Technol., Vol. 83. 10.1016/j.ifset.2022.103235.
62. Khan, M.N., T.A. Sial, A. Ali and F. Wahid, 2024. Impact of Agricultural Wastes on Environment and Possible Management Strategies. In: Frontier Studies in Soil Science, Núñez-Delgado, A. (Ed.), Springer, Cham, Switzerland, ISBN: 978-3-031-50503-4, pp: 79-108.
63. Saha, A., 2023. Circular economy strategies for sustainable waste management in the food industry. J. Recyl. Econ. Sustainability Policy, 2: 1-16.