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Postharvest losses, causes and mitigation in tomato transportation: a systematic review

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ABSTRACT

Purpose: The study aimed to provide an overview of tomato loss during road transportation with specific interest in the causes of the postharvest loss, postharvest loss mitigation measures, as well as research focus and trends over the past few decades. **Findings:** Transport conditions significantly affect tomato quality, influenced by factors like vehicle specifications and road conditions, which contribute to mechanical damage. Post-harvest losses stem from various factors such as the usage of inadequate harvesting tools, inefficient handling and transport equipment, usage of inappropriate packaging materials, poor temperature management and rough handling of fresh fruits as well as substandard road infrastructure. These issues collectively result in substantial losses, reaching up to 60%, notably impacting developing countries. **Limitations:** The study focused on existing literature published in English. Consequently, it may not offer a comprehensive overview, as other studies with abundant information on the subject might be written in languages not covered by this study's language restriction. **Directions for future research:** Future research should prioritize investigating the impact of mechanical stress, such as vibration and impact loads, experienced by fruits like fresh tomatoes during road transport and material handling. Additionally, there is a need to assess the effectiveness of different packaging materials in safeguarding transported tomatoes against mechanical stress.

INTRODUCTION

The human body requires some quantity of minerals and vitamins as well as antioxidants for its physiological and anatomical growth. These constituents are abundant in tomato fruits, which make them suitable for nutritional and medicinal purposes, and the reason why the demand for tomatoes has been increasing for the past few decades (Wakholi et al., 2015; Mibulo et al., 2020; Marcus, 2013). In line with the aforementioned, governments all over the world have focused on increasing tomato production by 50-70% from the end of the 19th century (Elijah, 2021; Sheahan & Barrett, 2017). Tomato growth and yield are favoured by high altitude, high light intensity and low relative humidity (Tilahun et al., 2017). The selective performance causes tomatoes to be produced in some locations thereby increasing the transport distance between the areas of production and the areas of processing/consumption. Nigeria for example, the major tomato-producing states in Nigeria, namely, Bauchi, Borno, Benue, Kano, Kaduna, Plateau, Jigawa and Kwara states (Ugonna et al., 2015); these states are located within the Northern part of the country resulting in transport distance of between a few hundreds of kilometres between Lagos State (The nation's commercial capital) and states in the Central regions of Nigeria (e.g. Benue and Plateau States) to over 1000 km between the same commercial capital (South-Western Nigeria) and Borno State (North-Eastern Nigeria). Such a considerable transport distance between the said locations especially with the ride quality of roads as well as the environmental temperature makes it more challenging for tomato postharvest qualities.

Almost recently, tomato production has been projected to increase by up to 50% of the current production figures by the year 2050 (Stratton et al., 2021). More interestingly, the United Nations has set a goal to reduce post-harvest losses of fruits and vegetables, generally by up to 50%, which has attracted extensive research on the causes and potential mitigation measures (Affognon et al., 2015). While both statements seem to ensure global tomato security, yet, the post-harvest losses remain high (Bani et al., 2006; Sheahan & Barrett, 2017; Sugino et al., 2022), leaving serious questions as to the effectiveness of the current tomato postharvest mitigation measures.

To highlight the postharvest loss in tomatoes from general causes, postharvest loss figures from The Food and Agricultural Organization (FAO) for ten (10) randomly selected countries were examined for a period of nine (9) years (2010-2018) (FAOSTAT, 2022). It revealed that, across the examined countries, a total postharvest loss for tomatoes increased from 296.24 thousand metric tons in 2011 to 606.26 thousand metric tons in 2018 (Table 1). Failure to reduce tomato postharvest losses to acceptable levels despite numerous researches with documented published findings has further attracted several questions that pertain to the suitability and applicability of the hitherto suggested mitigation measures. What is the current trend in researching tomato postharvest losses? What factors are responsible for post-harvest loss of tomatoes and what measures are effective to reduce losses? To provide answers to the questions rose above, this study was planned and conducted based on a systematic search.

Table 1. Tomato postharvest loss from selected countries in Africa.

	Postharvest loss estimates per year (Thousand metric tons)									
Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average by country
Ethiopia	55.64	81.73	55.73	39.37	30.7	65.21	28.4	41.2	43.8	49.09
Ghana	318.52	320.5	321	340.2	366.77	368.78	368.8	368.9	381	350.05
Kenya	539.15	396.54	444.86	494	443.3	402.5	410	507.1	599.5	470.77
Malawi	112.61	120.61	40.5	265.1	526.1	523	483.7	450	583.2	344.98
Nigeria	1799.96	1491.3	2060.3	1925.1	4083.5	4229.3	3412.7	4100	3913.99	3001.8
Rwanda	135	122.17	115	116.1	118.6	120.3	118.8	97.4	93.1	115.16
Uganda	31	30	35	34.95	36.2	38.00	39.4	40.98	39.46	36.11
Tanzania	300	350	390	423.3	387.8	400.4	403.8	359.8	356.09	374.58
Zambia	26	27	28.5	27.1	26.13	25.8	25.9	25.8	25.87	26.46
Zimbabwe	25	22.5	23.5	23.5	24	24.8	25.49	26.04	26.55	24.6
Average by year	334.29	296.24	351.44	368.87	604.31	619.61	531.5	601.72	606.26	

(Source: FAOSTAT, 2022).

METHODOLOGY FOR ARTICLE SEARCH AND INCLUSION

The systematic search was performed on January 14, 2023, with the Google Scholar search engine using the following search terms \"Transport-related Loss in Tomatoes\”, \"Tomato Mechanical Injuries based on Road Transport\" AND \” Road transport Vibration effects on Fresh Tomato Cargo\”.

Literature mapping and inclusion were conducted following the documented PRISMA guidelines (Moher et al., 2009). Only documents that matched all or part of the search terms were included and 150 documents were returned based on the initial search. The search was further refined by the year of publication being narrowed down to 2001 and 2023; as the range of publication years chosen is sufficient to show the trend of interest among researchers over more than three decades (34 years); this yielded 105 documents (conference papers, published articles and reports, as well as theses and dissertations).

To avoid duplication of articles, conference papers were isolated during review; as presented conference papers can be published and both versions can be found on the same search engine under the same search term, textbooks were also excluded from the search results; hence 54 published articles were used in the review.

To simplify the analysis, the review was further conducted and reported in the following subtopics; i) overview of reviewed articles, (ii) Tomato post-harvest loss estimates iii) Transport-related causes of tomato post-harvest losses iv) Proposed mitigation measures and related success.

OVERVIEW OF REVIEWED ARTICLES

Distribution of reviewed articles by research focus

54 articles published between the years 2001 and 2023 were used in this review, and this is composed of review articles (20.37%) and original research articles (79.63%). Most of the research focused on examining the effects of the relationships between road transport vibration levels and post-harvest loss of tomatoes (12.96%), the influence of packaging and cushioning materials (11.11%) and the estimation of the transport-related post-harvest loss in tomatoes (9.26%) and the application of modelling techniques in the study of roadside tomato losses (9.26%) (Fig. 1).

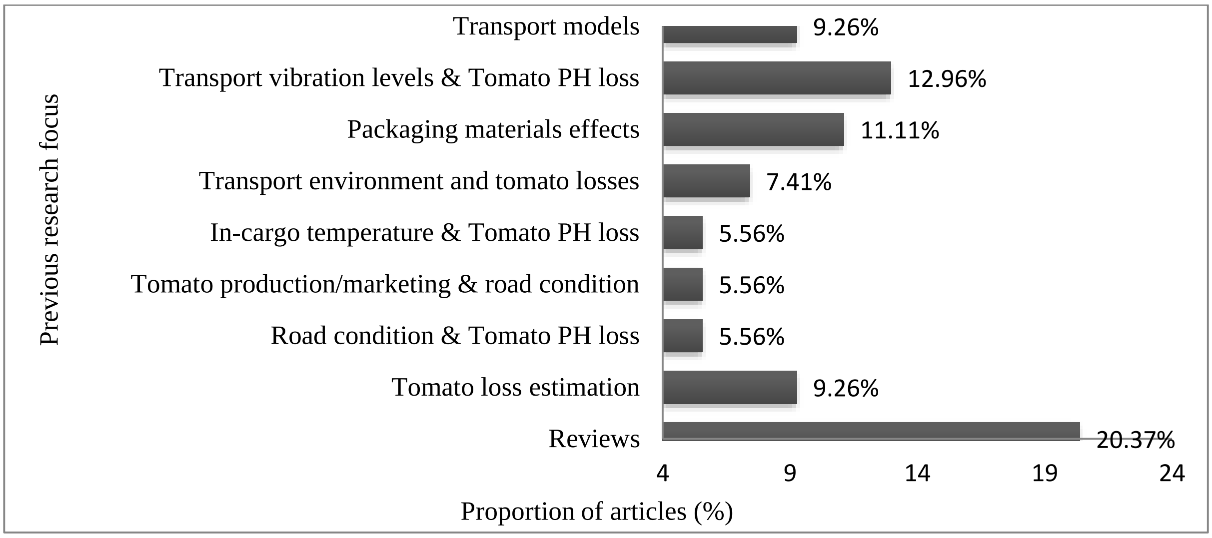

Fig. 1. Overview of the reviewed articles. PH: Postharvest.

Distribution of reviewed articles by continent

Contrary to most of the research fields conducted globally, which seem to indicate the USA and Europe spearheading most of the researches, this study revealed that most of the research on the postharvest loss of tomatoes were conducted in Africa and Asia. Of the 54 published articles reviewed in this study, most of the studies were conducted in Africa (70.4%) and Asia (20.4%), with the European continent indicating less research on the subject (Fig. 2).

The distribution of published articles observed for the various continents in this study followed previously published post-harvest loss estimates, in which Africa and Asia were known to have the highest post-harvest loss figures in fresh fruit and vegetables, generally (Arah et al., 2016; Bwade et al., 2019). The concentration of research in developing countries observed in this study is a good omen if the research results to reduce post-harvest losses are successfully implemented. The countries with the highest number of published articles on this topic are Nigeria (18 articles), South Africa (8 articles), Ghana (4 articles) and India (3 articles).

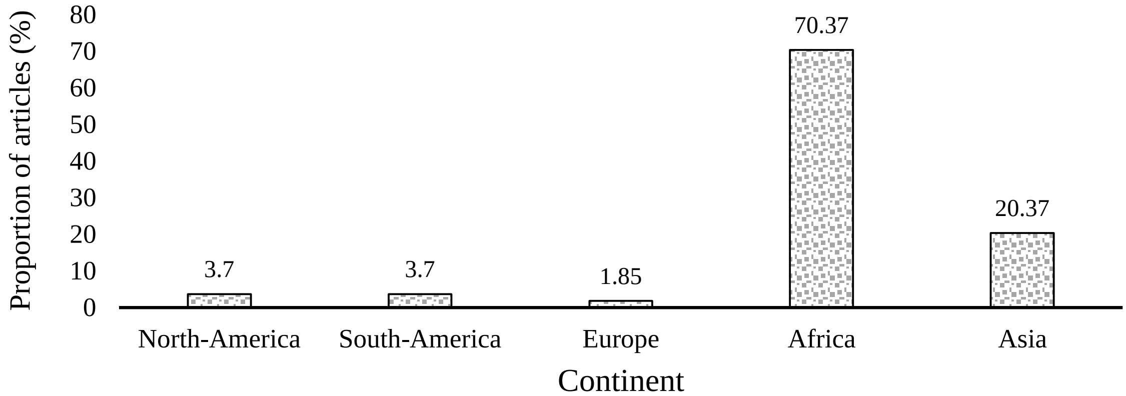

Fig. 2. Distribution of reviewed articles by continent.

Distribution of reviewed articles by year of publication

The articles used in this study covered the period between 2001 and March 2023, which were grouped into three decades (2001-2010, 2011-2020, and 2021-2023) to examine whether research interest in transport-related post-harvest losses in tomatoes is increasing or decreasing within the period under review (2001-2023); the stated range was chosen to provide an overview of the recent research trend on the reviewed subject matter (Fig. 3). The distribution of published articles per decade was highest in the second decade of the study (2011-2020) (59.3%). However, the average number of articles published per year showed a steady increase from 2.59 articles per year in the first decade of the study (2001-2010) to an average of 7.4 articles per year in 2023. This seems to indicate increased interest among researchers on the topic of research.

Transport-related postharvest loss estimates

Tomato is associated with considerably high moisture content at harvest (≤ 75%) (Bwade et al., 2019; Isack & Lyimo, 2015) and as with fresh horticultural materials, they continue to undergo a physiological metabolic process (Cherono & Workneh, 2018; Mutari & Debbie, 2011). During the post-harvest metabolic and physiological processes, nutrient reserves and moisture are depleted from the tissues of tomatoes; as a result, their quality variables (fruit weight, firmness, colour and chemical components such as vitamins, antioxidants and other minerals) change significantly (Cui et al., 2018).

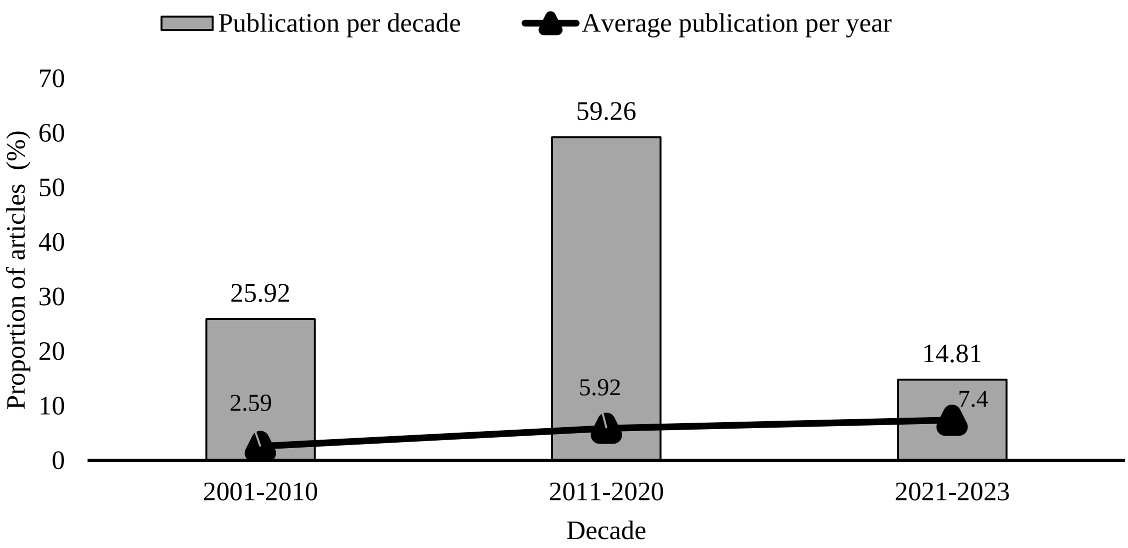

Fig. 3. Distribution of articles by year/decade of publication.

Regarding post-harvest losses of tomatoes and other food and agricultural materials, it is notable that countries and sub-regions with the greatest demands for food/agricultural materials have the highest percentage of post-harvest losses (Kamrath et al., 2016; Mibulo et al., 2020), maybe a cause for concern, but this shows the link between the technological/economic growth of the countries/sub-regions and the ability to implement post-harvest loss mitigation techniques. Several studies in the past have examined the post-harvest losses of tomatoes during transportation, some of the results are as follows: It has been reported that up to 40% of harvested tomatoes are lost to various spoilage agents in developing countries (Macheka et al., 2017). Higher tomato loss rates (up to 50%) have also been reported in sub-Saharan Africa (Mibulo et al., 2020). The post-harvest loss figures for fruit and vegetables are even much higher, as indicated by Sipho and Tilahun (2020) who studied the post-harvest loss of fresh fruit and vegetables in Africa by sub-region and reported the following post-harvest estimates in East Africa in Ethiopia (50%), Rwanda in Central Africa (30–80%), Ghana in West Africa (30–80%) and Swaziland in Southern Africa (20–50%).

Even related to the quantitative losses, researchers have relied on different methods for postharvest loss (PHL) estimation such as modelling, direct observation or residual methods, while other studies have relied on case studies that are not robustly representative of actual post-harvest loss statistics. The implication is that a PHL study performed on tomatoes within the same geographical area and cultivar wills most likely result in significantly different estimates of post-harvest loss, simply because different estimation methods were used. Second, the differences in the adopted PHL estimation method affect the validity of comparisons/conclusions drawn between independent PHL studies. From this, it can be concluded that there is a need to develop international protocols or guidelines that eliminate discrepancies between PHL estimation studies, which is very necessary since it will put an end to the conflicting figures published from PHL studies so far.

Postharvest loss causes and mitigation measures

As mentioned earlier post-harvest losses in tomatoes and other fresh horticultural materials can be quantitative, qualitative or economic, the severity of post-harvest losses depends on several factors (Idah et al., 2007b). The factors commonly associated with this are temperature and relative humidity management systems, packaging material, degree of ripeness at harvest, presence/absence of pre-chill treatment, road quality and vehicle type (Aba et al., 2012; Ileada & Ayodele, 2023). Other factors are insufficient or lack of efficient harvesting machinery/equipment and packaging/handling equipment. For example, in Nigeria, most of the tomato producers are small-scale farmers (60%), with medium and large-scale farmers accounting for 30 and 10% of tomato growers, respectively. Regardless of the category of farmers (small, medium or large farm), tomato harvesting and handling is done manually and in most cases with the help of poor or inefficient tools/packaging materials (Ugonna et al., 2015). The use of poor/inefficient harvesting equipment as well as packaging materials has been linked to significant mechanical damage to a variety of fresh fruits and vegetables such as tomatoes (Zaman, 2023; Waghmare et al., 2022).

The pursuit of a deeper understanding of the trend of causes of PHL in transported tomatoes, as well as the successes achieved in the implementation of proposed measures, has led to reviews with corresponding published results. Some of the reviews are as follows; an overview of packaging options for tomato smallholders in sub-Saharan Africa (Mibulo et al., 2020), factors responsible for tomato post-harvest losses and likely solutions (Bwade et al., 2019). Performance of multiple refrigeration systems (vacuum refrigeration, mechanical refrigeration, hydro-refrigeration, and evaporative coolers) to identify the most appropriate systems for smallholder farmers (Sipho & Tilahun, 2020), factors influencing tomato quality losses (nutritional value and antioxidants), and income of farmers (Tilahun et al., 2017) and overview of post-harvest losses in tomato production in Africa (causes and possible solutions) (Arah et al., 2015). Transport-related factors are reviewed below.

Transport vehicle

In developing countries, tomatoes have been transported without refrigeration units on various modes of transport, including bicycles, motorcycles, donkeys, horses, cars, and trucks, resulting in significant damage to the produce (Bwade et al. 2019; Caixeta-Filho, 1999). Even with appropriate truck selection, significant tomato damage can still occur during transport due to factors such as the degree of ripeness of the crop, suspension system on the truck, payload capacity, road conditions, and driving speed (Cherono et al., 2018; Elijah, 2021; Lu et al., 2010b; Garcia-Romeu-Martinez et al., 2007; Jarimopas et al., 2005; Rissi et al., 2008; Zhou et al., 2015; Kefas et al., 2024). A review of the literature indicates that approximately 12.96% of the studies focused on the effects of transport vibration levels on post-harvest losses resulting from the road transport environment (Fig. 1).

Trucks that transport cargo respond to bumps on the road by oscillating along three perpendicular axes, i.e., vertical, longitudinal, and transverse. The impact load transferred to the truck body and its cargo depends on the intensity of vibration, which can cause damage to the product. To minimize the transmitted load and prevent cargo damage, a suspension system is required. Leaf springs, constant rate/coil springs, rubber springs, and air spring systems are the most commonly used suspension systems on trucks (Jarimopas et al., 2005; Ranathunga et al., 2010; Sittipod et al., 2009). Studies conducted in different countries, including China, Japan, South Africa, Spain, and Thailand, have verified the effectiveness of these suspension systems in absorbing shock/impact on agricultural cargoes, with air spring systems providing the best results compared to leaf spring suspension systems (Garcia-Romeu-Martinez et al., 2008; Ishikawa et al., 2009; Pretorius & Steyn, 2016; Zhou et al., 2015).

Although medium to high-speed transport is beneficial in delivering healthy tomatoes to consumers and processors, poor road conditions or unsuitable suspension systems can increase vibration/shock intensities during transport, leading to higher losses (Al-Dairi et al., 2021; Firdous, 2021). Therefore, a balance between ground speed and vibration/shock intensity is crucial to minimize fruit damage during tomato transport. Previous studies have also investigated the effects of cargo hold temperatures during tomato transport. Sugino et al. (2022) studied the effects of transport temperatures (0, 5, 10, and 20 °C) on post-harvest quality loss of tomato variety Rinka 409 harvested in different ripening stages. Although their study showed that lower loading temperatures (0-5 °C) resulted in reduced mass loss and reddening of the tomatoes during transport, they did not examine the effects of mechanical stress such as shock/vibration. The presence of such stress during transport can increase the rate of deterioration of the transported horticultural cargo, producing different results.

The findings suggest that the transportation of tomatoes in developing countries without proper refrigeration units and suspension systems can lead to significant damage to the produce. Even with appropriate truck selection, factors such as the degree of ripeness of the crop, payload capacity, road conditions, and driving speed can cause damage to the cargo. Although suspension systems such as leaf springs, constant rate/coil springs, rubber springs, and air spring systems have been shown to effectively absorb shock/impact on agricultural cargo, a balance between ground speed and vibration/shock intensity is crucial to minimize fruit damage during transport. Additionally, while lower loading temperatures have been shown to result in reduced mass loss and reddening of tomatoes during transport, the effects of mechanical stress such as shock/vibration were not examined in a study by Sugino et al. (2022), suggesting a need for further research in this area. Overall, the weakness of these findings is that they are primarily based on studies conducted in specific countries and may not be generalizable to all developing countries. Additionally, the literature review suggests that only a small percentage of studies focus on the effects of transport vibration levels on post-harvest losses, highlighting a need for more research in this area (Bwade et al., 2019; Cherono & Workneh, 2018; Elijah, 2021; Lu et al., 2010a; Garcia-Romeu-Martinez et al., 2008; Jarimopas et al., 2005; Rissi et al., 2008; Zhou et al., 2015).

Road condition

Tomatoes can be transported by road, rail, ship or plane, but road transport is the most common mode, particularly in developing countries (Elijah 2021; Machado et al., 2020). The condition of roads varies based on road type (paved/unpaved), road design, and maintenance quality (Bwade et al. 2019; Sipho & Tilahun, 2020). When vehicles are driven on unpaved, rougher, and poorly maintained roads at higher speeds, the undulating nature of the roads increases the potential for damage to transported cargo, including tomatoes (Padilla et al., 2018). Figure 1 shows that around 5.56% of the research articles used in this study focused on the impact of road conditions on post-harvest losses of transported tomatoes.

The damage caused to tomatoes from transmitted vibrations and shocks during transportation depends on factors such as the ride quality of the road, measured by the International Roughness Index (IRI) (Mibulo et al., 2020), and vehicle speed (Pretorius & Steyn 2012; Zhou et al., 2015). The IRI ranges between 0 and 16 mm/m, with a smooth surface having good ride quality and an impassable road (Pretorius & Steyn, 2012). Ranathunga et al. (2010) found that roads with an IRI between 5 and 10 mm/m caused nearly four times as much damage to fresh agricultural produce cargo as good roads (0.9-2.0 mm/m). Cherono and Workneh (2018) evaluated the influence of packaging materials and ride quality on roads with an IRI value of 2.5 m/km (2.5 mm/m) and found that tomatoes transported on the road with the best ride quality (70% of the road length with IRI 2.5 m/km) had up to 10% higher marketability than those transported on other roads. Rather than using IRI to interpret ride quality, some studies suggest using power spectral density (PSD) to specify the energy content of shocks/vibrations generated when a truck travels on a particular road. This method takes into account the vibration response characteristics of the truck and the unevenness of the road profile and even identifies the vibration frequency at which cargo damage is most likely to occur (resonance frequency) (Singh et al., 2006; Widhiantari et al., 2016).

Some previous studies have recommended considering the resonant frequency of the transportation environment based on truck-roadway interaction for selecting packaging materials (Aba et al., 2012; Pretorius & Steyn, 2012). This is important because transporting packaged agricultural cargo at a natural frequency within the vibration frequency of the transport vehicle results in a significant amplification of shock/vibration amplitude, which imparts higher impact loads to the transported cargo, leading to much higher crop damage.

The studies on the impact of transportation on tomatoes have some weaknesses. One of the weaknesses is that there is a limited number of studies that have focused on the impact of road conditions on post-harvest losses of transported tomatoes, as only around 5.56% of research articles used in one study were focused on this aspect (Elijah, 2021; Machado et al., 2020). Additionally, while some studies suggest using power spectral density (PSD) to specify the energy content of shocks/vibrations generated when a truck travels on a particular road, there is no consensus on the best method to evaluate ride quality (Singh et al., 2006;

Widhiantari et al., 2016). Furthermore, some previous studies have recommended considering the resonant frequency of the transportation environment based on truck-roadway interaction for selecting packaging materials, but this has not been widely adopted in practice (Aba et al., 2012; Pretorius & Steyn, 2012). While some of the recent studies (Bwade et al., 2023) on road transport vibration and its effects on transported agricultural materials have highlighted the suitability of using International test protocols (such as ASTM D4196) for the evaluation of the safety of fresh agricultural materials within the road transport environment, yet such findings have not been independently validated. Nevertheless, more research is needed to better understand the impact of transportation on post-harvest losses of tomatoes and to identify best practices for packaging and transportation to minimize damage.

Packaging materials

Packaging materials are essential in the containment, preservation, and facilitation of handling and transportation of unitized loads, as well as providing some level of atmospheric modification for the packed produce (Bwade et al., 2019; Cherono & Workneh, 2018; Venus et al., 2013). Developed countries make use of plastic crates in handling and transporting tomatoes due to its benefits, while developing countries such as Nigeria, India, Ghana, and Egypt package tomatoes in a wide range of materials, such as jute sacs, nylon bags, raffia or cane-woven baskets, and wooden boxes (Arah et al., 2015; Idah et al., 2007a), with plastic crates used only among postharvest researchers (Anriquez et al., 2021). Various designs, shapes, and capacities of traditional baskets are used for packaging tomatoes. For example, raffia canes can be woven to fabricate a basket with a depth of 45-55 cm, a diameter of 60 cm, and a carrying capacity of 50 kg of tomatoes (Babarinsa et al., 2018). Other materials used include conical baskets with dimensions of 55 cm × 34 cm × 34 cm (top diameter × bottom diameter × depth), rectangular baskets with dimensions of 50 cm × 40 cm x 20 cm (length × width × depth) (Abubakar & El-Okene, 2015), carton boxes (8 kg capacity) and plastic bulk bins (468 kg storage capacity) (Cherono & Workneh, 2018), and wooden and plastic crates (Dari, 2018).

Previous studies have compared the performance of various tomato packaging materials. Cherono and Workneh (2018) studied the effects of packing tomatoes in large plastic bins (dimensions: 2 m × 1 m × 0.4 m; capacity: 468 kg) and small plastic crates (dimensions: 0.5 m × 0.4 m × 0.3 m; capacity: 20 kg). Kamrath et al. (2016) investigated the effects of lining the interior surfaces of wooden crates with paper or cloth on tomato post-harvest losses. Dari et al. (2018) examined the contributions of plastic and wooden crates at two levels of tomato capacity, respectively (30 and 50 kg), as well as the effects of cushioning materials (jute, paper, and foam) on the quality of tomatoes transported over a distance of 377 km. Babarinsa et al. (2018) evaluated the differences in the performance of traditional wicker and plastic crates in protecting the quality of tomatoes transported over a distance of 998 km. Abubakar and El-Okene (2015) compared the relative performance of two raffia baskets with conical and rectangular shapes and tomato capacities of 40 and 25 kg, respectively, over a transport distance of 877 km. Sibomana et al. (2018) evaluated the effect of packaging materials and chemical treatments (anolyte water and chlorinated water) on the post-harvest quality of tomatoes. Finally, Pretorius and Steyn (2019) studied the damage to tomatoes during transportation at different ripening stages (ripe-green, break, and red-ripe) and over a distance of up to 1050 km at a speed of up to 80 km/h.

While the studies mentioned provide valuable insights into the effects of packaging materials and transportation conditions on the post-harvest quality of tomatoes, it is important to note that most of these studies were conducted in specific regions and under specific conditions, and may not be representative of the global tomato supply chain. Additionally, some studies have evaluated only a limited number of packaging materials, or have focused on a narrow range of transportation conditions. For example, Babarinsa et al. (2018) only evaluated the performance of traditional wicker and plastic crates in protecting the quality of tomatoes transported over a distance of 998 km, which may not be representative of all transportation conditions. Similarly, the study by Kamrath et al. (2016) only investigated the effects of lining the interior surfaces of wooden crates with paper or cloth on tomato post-harvest losses, which may not apply to other packaging materials or transportation conditions. Furthermore, many of the studies mentioned have focused on the effects of packaging materials and transportation conditions on the physical quality of tomatoes, such as bruising, decay, and weight loss, rather than on the nutritional quality or flavour of the fruit. This is an important limitation, as the nutritional quality and flavour of tomatoes are key factors in determining consumer satisfaction and demand. Therefore, while the studies mentioned providing valuable insights into the post-harvest quality of tomatoes, further research is needed to evaluate the performance of a wider range of packaging materials and transportation conditions and to assess the effects of these factors on the nutritional quality and flavour of the fruit.

Temperature

The degree of hotness or coldness of tomatoes and their transport/storage environment has been found to have a significant influence on postharvest physiological processes and enzymatic and microbial activities (Cherono et al., 2018; Tilahun et al., 2017; Venus et al., 2013). Lower temperatures have been found to retard these processes, resulting in the extended shelf life of tomatoes (Cherono et al., 2018). During transportation, in-cargo tomatoes receive heat from various sources, including the sun, ground surface, and respiration (Mutari & Debbie, 2011; Sipho & Tilahun, 2020). Temperature control is particularly challenging for closed trucks without temperature management systems, especially over long distances (Idah et al., 2007b).

Various cooling systems, such as traditional ventilated storage, mechanical refrigeration, and evaporative cooling, are used for tomatoes during transit and storage, each with its pros and cons (Macheka et al. 2017; Mogaji & Fapetu, 2011; Sipho & Tilahun, 2020). While there is a significant amount of research on the impact of temperature on tomatoes during transport and storage, there are still limitations and challenges associated with the available cooling systems and pre-chilling techniques. For instance, traditional ventilated storage is limited by its lowest achievable temperature and the risk of scratching or damaging tomatoes, while mechanical refrigeration is costly and may not be suitable for adoption among subsistence farmers (Macheka et al., 2017). Additionally, the performance of evaporative coolers may be limited by prevailing weather conditions, such as high relative humidity, although active evaporative coolers with incorporated desiccating units may help overcome this limitation (Sipho & Tilahun, 2020); the associated cost of maintaining the active evaporative coolers is higher. Furthermore, the effectiveness of pre-chilling techniques, such as ice water cooling and vacuum cooling, may also be impacted by logistical challenges and delays, resulting in the loss of transported tomatoes (Cherono et al., 2019). These limitations and challenges highlight the need for continued research and innovation to develop more efficient and affordable cooling systems and pre-chilling techniques for tomatoes during transport and storage.

CONCLUSION

This study provided an overview of tomato postharvest loss resulting from road transport vibration with a specific interest in the causes and mitigation measures employed based on previously published literature. The study yielded the following conclusions: Mechanical injuries to fresh tomatoes during transportation are greatly influenced by the characteristics of the vehicle used, the quality of road infrastructure, and the effectiveness of packaging materials. Additionally, factors such as temperature and gas concentrations experienced by tomatoes during transport and storage environments affect the severity of postharvest loss. Various cooling systems, including traditional ventilated storage, mechanical refrigeration, and evaporative cooling, are employed during transit and storage, each with its advantages and disadvantages. Future research should focus on investigating the effects of mechanical stress levels during handling and transportation. By addressing these areas, researchers can develop appropriate transportation systems and policies to ensure the delivery of high-quality tomatoes to consumers and processors in developing countries.

Conflict of interest

The authors declare that they have no conflict of interests.

REFERENCES

Aba, I. P., Gana, Y. M., Ogbonnaya, C., & Morenikeji, O. O. (2012). Simulated transport damage study on fresh tomato (*Lycopersicon esculentum*) *Fruits*, *2*(2), 1–14.

Abubakar, M., & M. I. El-Okene. (2015). Postharvest transit losses of tomato in different packaging unit in Nigeria. *International Journal of Engineering Research & Technology*, *4*(08), 223–27.

Affognon, H., Mutungi, C., Sanginga, P., & Borgemeister, C. (2015). Unpacking postharvest losses in Sub-Saharan Africa: A meta-analysis. *World Development*, *66*, 49–68. https://doi.org/10.1016/j.worlddev.2014.08.002

Al-Dairi, M., P. B. Pathare, & A. Al-Mahdouri. 2021. Impact of vibration on the quality of tomato produced by stimulated transport. *IOP Conference Series: Earth and Environmental Science*, *653*(1), 1–12. https://doi.org/10.1088/1755-1315/653/1/012101

Anriquez, G., Foster, W., Ortega, J., & Rocha, J. S. (2021). In search of economically significant food losses: evidence from Tunisia and Egypt. *Food Policy*, *98*(August). https://doi.org/10.1016/j.foodpol.2020.101912

Arah, I. K., Ahorbo, G. K., Anku, E. K., Kumah, E. K., & Amaglo, H. (2016). Postharvest handling practices and treatment methods for tomato handlers in developing countries: A mini review. *Advances in Agriculture*, 6436945. http://doi.org/10.1155/2016/6436945

Arah, I. K., Kumah, E. K., Anku, E. K., & Amaglo, H. (2015). An overview of post-harvest losses in tomato production in Africa: causes and possible prevention strategies. *Journal of Biology, Agriculture and Healthcare*, *5*(16),78–89.

Babarinsa, F. A., R. B. Ogundele, O. A. Babarinsa, & M. A. Omodara. (2018). Evaluation of plastic crate as replacement for raffia basket to prevent in-transit damage of packaged tomatoes. *Journal of Postharvest Technology*, *6*(August), 70–79.

Bani, R. J., M. N. Josiah, & E. Y. Kra. (2006). Postharvest losses of tomatoes in transit. *Agricultural Mechanization in Asia Africa and Latin America*, *37*(2), 84–86.

Bwade, E. K., B. Umar, & M. U. Abba. (2019). Tomato post-harvest losses and mitigation measures: A Review. *International Journal of Engineering, Business and Enterprise Applications (IJEBEA)*, *28*(1), 9–15.

Bwade, E. K., Aliyu, B., & Tashiwa, Y. I. (2023). Sensors, standards and analysis techniques for road transport vibration: A systematic review. *Systematic Literature Review and Meta-Analysis*

Journal, *4*(4), 8-24.

Caixeta-Filho, J. V. (1999). Losses in the transportation of fruits and vegetables: a Brazilian case study. *International Journal of Logistics Research and Applications, 2*(3), 325–341. https://doi.org/10.1080/13675569908901588

Cherono, K., & T. S. Workneh. (2018). A review of the role of transportation on the quality changes of fresh tomatoes and their management in South Africa and other emerging markets. *International Food Research Journal*, *25*(6), 2211–2228.

Cherono, K., T. S. Workneh, & S. F. Melesse. (2019). Application of logisitic statistical modelling in the evaluation of fresh tomatoes in selected South African supply chain. *International Food Research Journal*, *26*(3), 979–989.

Cherono, K., Sibomana, M., & Workneh, T. S. (2018). Effect of infield handling conditions and time to pre-cooling on the shelf-life and quality of tomatoes. *Brazilian Journal of Food Technology,* 21, e2017016. https://doi.org/10.1590/1981-6723.01617

Cui, J., Yang, M., Son, D., Park, S., & Cho, S. I. (2018). Estimation of tomato bruising by mechanical impact force using multivariate analysis. *HortScience,* 53(9), 1352–1359. https://doi.org/10.21273/HORTSCI13066-18

Dandago, M. A., Gungula, D. T., & Nahunnaro, H. (2019). Effect of chemical dips and packaging materials on quality and shelf life of tomatoes (*Lycopersicon esculentum*) in Kura, Nigeria. *Journal of Horticulture and Postharvest Research*, *2*(2), 117-130. https://doi.org/10.22077/jhpr.2019.2054.1039

Dari, L . (2018). Evaluation of packaging liners in wooden and plastic crates for handling tomatoes. *Journal of Postharvest Technology*, *6*(October), 36–40.

FAOSTAT. (2022). Crop and livestock production data. *Statistics Division of the Food and Agriculture Organization*. Retrieved March 27, 2023 from https://www.fao.org/faostat/en/#data/QCL

Firdous, N. (2021). Significance of edible coating in mitigating postharvest losses of tomatoes in Pakistan: a review. *Journal of Horticulture and Postharvest Research*, *4*(Special Issue - Fresh-cut Products), 41-54. https://doi.org/10.22077/jhpr.2020.3469.1152

Jahanshahi, B., Jafari, A., & Gholamnezhad, J. (2023). Effect of edible tragacanth coating on fruit quality of tomato cv. Falkato. *Journal of Horticulture and Postharvest Research*, *6*(1), 43-54. https://doi.org/10.22077/jhpr.2022.5478.1282

Lu, F., Ishikawa, Y., Kitazawa, H., & Satake, T. (2010a). Impact damage to apple fruits in commercial corrugated fiberboard box packaging evaluated by the pressure-sensitive film technique. *Journal of Food, Agriculture and Environment*, *8*(2), 218–22.

Lu, F., Ishikawa, Y., Kitazawa, H., & Satake, T. (2010b). Effect of vehicle speed on shock and vibration levels in truck transport. *Packaging Technology and Science, 23*(2), 101–109. https://doi.org/10.1002/pts.882

Garcia-Romeu-Martinez, M. A., Singh, S. P., & Cloquell-Ballester, V. A. (2008). Measurement and analysis of vibration levels for truck transport in Spain as a function of payload, suspension and speed. *Packaging Technology and Science: An International Journal*, *21*(8), 439–451. https://doi.org/10.1002/pts.798

Garcia-Romeu-Martinez, M. A., Singh, S. P., & Cloquell-Ballester, V. A. (2007). A model for the statistical distribution of road vehicle vibrations. *World Congress on Engineering, 2007, Vols 1 and 2* II(1), 1225.

Idah, P. A., E. S. A. Ajisegiri, & Yisa, M. G. (2007a). An assessment of impact damage to fresh tomato fruits. *AU Journal of Technology, 10*(4), 271–275.

Idah, P. A., E. S. A. Ajisegiri, & Yisa, M. G. (2007b). Fruits and vegetables handling and transportation in Nigeria. *Assumption University Journal of Technology (Au J.T.), 10*(3), 175-183.

Ileada, A. F., & Ayodele, D. (2023). Kogi state college of education technical zero energy cooling chamber. *International Journal of Progressive Research in Engineering Management and Science*, *3*(1), 25-31. https://doi.org/10.58257/ijprems30544

Isack, M. E., & Lyimo, M. (2015). Effect of postharvest handling practices on physicochemical composition of tomato. *International Journal of Vegetable Science, 21*(2), 118–127. https://doi.org/10.1080/19315260.2013.837134

Ishikawa, Y., Kitazawa, H., & Shiina, T. (2009). Vibration and shock analysis of fruit and vegetables transport-cherry transport from Yamagata to Taipei. *Japan Agricultural Research Quarterly, 43*(2), 129–135. https://doi.org/10.6090/jarq.43.129

Jarimopas, B., Singh, S. P., & Saengnil, W. (2005). Measurement and analysis of truck transport vibration levels and damage to packaged tangerines during transit. *Packaging Technology and Science, 18*(4), 179–188. https://doi.org/10.1002/pts.687

Kamrath, C., Rajendran, S., Nenguwo, N., & Afari-Sefa, V. (2016). Traders' perceptions and acceptability on use of linings for improving tomato packaging in wooden crates. *International Journal of Vegetable Science*, 22(6), 530-540. https://doi.org/10.1080/19315260.2015.1076920

Kefas, E. B., Aliyu, B., & Tashiwa, Y. I. (2024). A systematic review on the various biochemical treatments for preservation of fresh tomato. *Journal of Horticulture and Postharvest Research, 7*(Special Issue - Postharvest Technologies), 61-76. https://doi.org/10.22077/jhpr.2024.7136.1353

Machado, T. D. A., Costa, A. G., Rodrigues, R. E., Santos, M. A. D., Ribeiro, A. C. D. L., & Megguer, C. A. (2020). Quality of tomatoes under different transportation conditions by principal component analysis. *Revista Ceres*, *67*(6), 448–453. https://doi.org/10.1590/0034-737X202067060004

Macheka, L., Spelt, E., van der Vorst, J. G., & Luning, P. A. (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. https://doi.org/10.1016/j.foodcont.2017.02.037

Marcus, J. B. (2013). Culinary nutrition: The Science and Practice of Healthy Cooking. Pp. 1-77, Academic Press.

Mibulo, T., Banadda, N., & Kiggundu, N. (2020). A review of packaging options for tomato smallholder farmers in sub-Saharan Africa. *Open Journal of Organic Polymer Materials, 10*(4), 35–48. https://doi.org/10.4236/ojopm.2020.104004

Mogaji, T. S., & Fapetu, O. P. (2011). Development of an evaporative cooling system for the preservation of fresh vegetables. *African Journal of Food Science*, 5(4),255–66.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ (Online)*, *339*(7716), 332–336. https://doi.org/10.1136/bmj.b2535

Mutari, A., & Debbie, R. (2011). The effects of postharvest handling and storage temperature on the quality and shelf of tomato. *African Journal of Food Science*, *5*(7), 446–52.

Padilla, M. P. B., Canabal, P. A. N., Pereira, J. M. L., & Riaño, H. E. H. (2018). Vehicle routing problem for the minimization of perishable food damage considering road conditions. *Logistics Research*, *11*(1), 1–18. https://doi.org/10.23773/2018_2

Pretorius, C. J., & W. J. M. Steyn. (2016). The influence of road condition on the shelf-life of tomatoes." *functional pavement design - Proceedings of the 4th Chinese-European Workshop on Functional Pavement Design*, *CEW 2016* (Satc 2016), 1381–1392. https://doi.org/10.1201/9781315643274-146

Pretorius, C. J., & Steyn, W. J. V. D. M. (2012). Influence of road roughness on the transportation of fresh produce. *Southern African Transport Conference*, (31st), 142–153.

Pretorius, C. J., & Steyn, W. J. V. D. M. (2019). Quality deterioration and loss of shelf life as a result of poor road conditions. *International Journal of Postharvest Technology and Innovation*, *6*(1), 26–45. https://doi.org/10.1504/IJPTI.2019.104178

Ranathunga, C. L., H. H. E. Jayaweera, S. K. K. Suraweera, & S. C. Wattage. (2010). Vibration effects in vehicular road transportation. *Proceedings of the Technical Sessions Sri Lanka, 26*, 9–16.

Rissi, G. O., S. P. Singh, G. Burgess, & J. Singh. (2008). Measurement and Analysis of Truck Transport Environment in Brazil. *Internal Journal of Packaging Technology and Science*, *24*(4), 231–246. https://doi.org/10.1002/pts.797

Sheahan, M., & Barrett, C. B. (2017). Food loss and waste in sub-Saharan Africa: A Critical Review. *Food Policy*, *70*, 1–12. https://doi.org/10.1016/j.foodpol.2017.03.012

Singh, J., Singh, S. P., & Joneson, E. (2006). Measurement and analysis of US truck vibration for leaf spring and air ride suspensions, and development of tests to simulate these conditions. *Packaging Technology and Science*, *19*(6), 309–323. https://doi.org/10.1002/pts.732

Sibanda, S., & Workneh, T. S. (2020). Potential causes of postharvest losses, low-cost cooling technology for fresh produce farmers in Sub-Sahara Africa. *African Journal of Agricultural Research*, *16*(5), 553–566. https://doi.org/10.5897/ajar2020.14714

Chonhenchob, V., Singh, S. P., Singh, J. J., Sittipod, S., Swasdee, D., & Pratheepthinthong, S. (2009). Effect of truck vibration during shipments in Thailand. *Journal of Applied Packaging Research*, *3*(1), 27–38.

Stratton, A. E., Finley, J. W., Gustafson, D. I., Mitcham, E. J., Myers, S. S., Naylor, R. L., ... & Palm, C. A. (2021). Mitigating sustainability tradeoffs as global fruit and vegetable systems expand to meet dietary recommendations. *Environmental Research Letters*, *16*(5). https://doi.org/10.1088/1748-9326/abe25a

Sugino, N., Watanabe, T., & Kitazawa, H. (2022). Effect of transportation temperature on tomato fruit quality: chilling injury and relationship between mass loss and a* values. *Journal of Food Measurement and Characterization*,*16*(4), 2884–2889. https://doi.org/10.1007/s11694-022-01394-2

Tilahun, S., Seo, M. H., & Jeong, C. S. (2017). Review on factors affecting the quality and antioxidant properties of tomatoes. *African Journal of Biotechnology*, *16*(32), 1678–1687. https://doi.org/10.5897/ajb2017.16054

Ugonna, C. U., Jolaoso, M. A., & Onwualu, A. P. (2015). Tomato value chain in Nigeria: issues, challenges and strategies. *Journal of Scientific Research and Reports*, *7*(7), 501–515. https://doi.org/10.9734/jsrr/2015/16921

Venus, V., D. K. Asare-Kyei, L. M. M. M. Tijskens, M. J. C. C. Weir, CAJM A. J. M. de Bie, S. Ouedraogo, W. Nieuwenhuis, S. L. M. M. Wesselman, G. A. Cappelli, & E. M. A. A. Smaling. (2013). Development and validation of a model to estimate postharvest losses during transport of tomatoes in West Africa. *Computers and Electronics in Agriculture*, 92, 32–47. https://doi.org/10.1016/j.compag.2012.11.011

Waghmare, G. M., Gawade, R. N., & Pavhane, S. B. (2022). Post-Harvest Losses of Fruits, In *Advances in Agriculture Sciences* (Ed. Naresh, R. K.) (pp. 93-110). AkiNik Publications, India.

Wakholi, C., Cho, B. K., Mo, C., & Kim, M. S. (2015). Current state of postharvest fruit and vegetable management in East Africa. *Journal of Biosystems Engineering*, *40*(3), 238-249. https://doi.org/10.5307/jbe.2015.40.3.238

Widhiantari, I. A., Sutan, S. M., & Gunomo, D. (2016). Optimization of tomato fruit color after simulated transport using response surface methodology (RSM), *6*(2), 42–47. https://doi.org/10.5923/j.food.20160602.03

Yusuf I. E. (2021). The impact of road transport on tomato production and marketing in Nigeria. *Journal of Nigeria Transport History (JNTH)*, *1*(July), 1–8. https://doi.org/10.5777/j.JNTH.20190105.04

Zaman, Q. U. (2023). Precision agriculture technology: A pathway toward sustainable agriculture. In *Precision Agriculture* (pp. 1-17). Academic Press.

Zhou, R., Yan, L., Li, B., & Xie, J. (2015). Measurement of truck transport vibration levels in china as a function of road conditions, truck speed and load level. *Packaging Technology and Science*, *28*(11), 949–957. https://doi.org/10.1002/pts.