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Postharvest handling and value added products of tomato to enhance the profitability of farmers

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Abstract

Effective postharvest handling and value addition of tomatoes are crucial for enhancing farmers' profitability. Tomatoes, as a highly perishable crop, often experience significant losses during postharvest stages due to insufficient storage and handling practices. Postharvest losses of horticultural crops, ranging from 20% to 40%, create a substantial gap in market potential. This study explores various postharvest handling techniques and value addition strategies to reduce losses and enhance economic outcomes for tomato growers. The review highlights key postharvest practices, including optimal storage conditions, efficient sorting and grading and advanced preservation methods, which collectively extend the shelf life of tomatoes and reduce spoilage. Additionally, the study underscores the potential of value added products, such as tomato sauces, powders and canned goods, to enhance the market value of tomatoes. Transforming raw tomatoes into high demand products enable farmers to access new revenue streams and decrease reliance on fresh market sales. The findings indicate that adopting improved postharvest handling methods and leveraging value addition opportunities can significantly boost farmers' profitability. These practices not only reduce waste but also provide economic benefits through higher value products and improved market positioning. Overall, the study highlights the importance of innovative postharvest management and product development approaches for achieving sustainable economic growth in the tomato farming sector.

Keywords

postharvest handling; postharvest loss mitigation; profitability of farmers; tomato processing; value added products of tomato; value chain optimization

Introduction

India is the world's second largest producer of fruits and vegetables, ranking after China (1). Tomatoes are a widely consumed vegetable in India, enjoyed both fresh and in a variety cooked dishes. Beyond the economic value, tomatoes offer significant nutritional benefits, including vitamins C, A and K, potassium, carotenoids (80-90%), lycopene (5-10%), all of which function as antioxidants (2, 3). As a result, tomatoes have become highly significant in human nutrition for their rich phytochemical content and potential medical and pharmacological applications. Furthermore, by-products from the tomato processing industry, such as peels and seeds, can be repurposed to create additional value added products. One example of a value added product derived from tomatoes is tomato seed oil, a natural extract rich in essential fatty acids, antioxidants and vitamins. This oil finds extensive applications in the cosmetics, skincare and health industries. Additionally, tomato peel can be

processed into peel powder or peel flour, which serves as a gluten-free alternative in baking products such as cookies, bread and pasta. While tomatoes are refreshing and appetizing, their short shelf life poses a significant challenge. Because of their perishability and the lack of cold chain storage and processing facilities, approximately 25-40% of tomatoes valued Rs. 25-30 thousand crores are wasted, resulting in a substantial national loss. These losses can be reduced through effective postharvest handling and conversion of tomatoes into valuable processed products. Developing novel value-added products can enhance the profitability for farm women and entrepreneurs, thereby improving rural women's livelihood (3, 4). Additionally, diversifying tomatoes into lycopene extracts and health supplements addresses the expanding health and wellness market. Lycopene, known for its antioxidant benefits, can be utilised in supplements and cosmetics, while tomato based products such as powders and juices cater to the demand for natural, plant based health solutions, creating new revenue streams for farmers and processors.

Importance of postharvest handling

Postharvest management is crucial for maintaining the quality and safety of produce from harvest to consumption. Proper handling practices help preserve the flavour, texture and nutritional value of fruits and vegetables, ensuring freshness and appeal (5). Effective management of temperature, humidity and physical damage in postharvest handling significantly extends produce shelf life, reducing spoilage and waste. This approach enhances economic benefits by maximizing crop value and minimizing financial losses while ensuring consumers receive safe, high-quality products (6). Technologies such as cold chain storage, controlled atmosphere storage (CAS) / modified atmosphere storage (MAS), as well as humidification system for storage rooms, helps to maintain optimal temperature and humidity.

Furthermore, effective postharvest practices enhance the marketability of produce, resulting in improved sales opportunities and greater consumer satisfaction. These practices also promote sustainability by reducing waste, improving supply chain efficiency, supporting responsible resource use and minimizing agriculture's environmental impact. In summary, effective post-harvest handling is vital for preserving quality, extending shelf life, ensuring safety, enhancing economic returns and fostering sustainability (Fig. 1).

Current scenario of postharvest losses

India's agricultural sector is increasingly shifting towards horticulture and livestock production, driven by escalating incomes, urbanization and evolving consumption patterns. These factors have substantially increased the demand for fresh and processed food products. According to a recent Nabcons report, postharvest losses of horticultural crops in India result in an annual financial loss of 1.5 trillion, equating to 2.35% of the national GDP (gross domestic product) and surpassing the Ministry of Agriculture and Farmers Welfare's 2022 budget. Mitigating these inefficiencies through technological innovation, improved infrastructure and policy support can reduce wastage, enhance food availability, boost rural incomes and strengthen economic stability. The majority of economic losses are linked to livestock products, including milk, meat, fish and eggs (21.70%), followed by fruits (19.34%) and vegetables (17.97%). Postharvest losses (PHL) of perishable horticultural commodities, such as fruits and vegetables, account for approximately 30-40% of the total production. Around 30% of households reported 30% of their total fruit production, 21.62% of households lost 10% of their vegetable yield, 50% of root crop production was affected and 60% of other cash crops were lost (7).

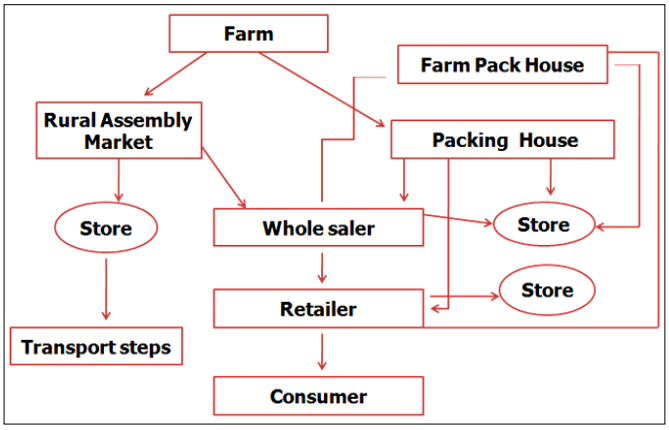

Fig. 1. Postharvest handling steps for typical commodity.

Postharvest losses in horticultural crops are attributed to various factors such as mechanical, physical, physiological and hygienic issues (Table 1). Postharvest losses of horticultural crops ranges from 20-40%. Such losses significantly reduce market potential. As the world's second largest producer of fruits and vegetables, India holds significant domestic and export potential owing to its large production volumes and crop diversity. However, the sector faces challenges such as limited awareness, restricted access to advanced agricultural technologies, inadequate cold chain infrastructure and market fluctuation (7).

Overcoming these challenges could enhance food and nutrition security, increase farmers' income, reduce waste and support Sustainable development goal 12.3, which aims to halve global food waste at retail and consumer levels and reduce food losses throughout production and supply chains

Table 1. Reasons for postharvest losses

S. No.	Category of causes	Specific causes
1.	Physical causes	Heating of fruits
		Cooling and freezing
		Water loss
		Reduction in relative humidity
2.	Physiological causes	Ethylene production
		Transpiration and respiration senescence
		Sprouting and rooting
3.	Mechanical causes	Damage due to cuts and bruises
		Scrapings
		Shrinkage
4.	Hygienic related causes	Dampness during storage
		Microbial action and pest infestation
		Rodent action

by 2030. The Indian government and various stakeholders are implementing several key strategies and policies, including National Food Security Mission (NFSM), Pradhan Mantri Kisan Sampada Yojana (PMKSY), the food processing industries (FPI) policy and the promotion of agro-processing units and cold storage chains (8) (Fig. 2). Vegetable production, beyond its nutritional value, plays a crucial role in economy by generating substantial income and employment opportunities. In 2020-21, India dedicated 10.86 million hectares to vegetable cultivation, producing a total of 200.45 million tonnes (Fig. 3). In the year 2020-21, three key vegetable crops tomato, onion and potato accounted for 31% of India's total horticultural output (8, 9). These crops collectively comprised more than half of the country's vegetable production. Analysis of data from 1991-92 to 2020-21 reveals significant trends in the cultivation area, total production and yield per hectare for tomato, onion and potato (Fig. 4, 5). Over the years, notable fluctuations and changes have been observed in these metrics (Table 2).

Current status and future prospects of tomato processing in India

India's tomato processing sector significantly lags behind other countries, presenting a crucial area for development. At present, India's tomato processing capabilities remain underdeveloped, leading to missed opportunities for value addition and economic growth. Enhancing tomato processing infrastructure and technologies could significantly boost India's income from the sector and generate numerous employment opportunities. Developing the tomato processing industry would reduce postharvest losses and enable the production of a diverse range of processed tomato products, thereby enhancing the overall value chain. Key processed tomato products, such as tomato paste and puree, tomato ketchup, tomato sauce, tomato powder, tomato chips and snacks are witness in rising market demand as the consumption of processed and ready-to-cook foods grows, particularly in urban areas. Tomato sauce is widely used in culinary applications, including pastas, pizzas and as a base for various dishes. Tomato powder is popular for soups, instant noodles, snack flavouring and among households seeking convenient, long shelf life alternatives. Tomato-based snack products, such as chips also cater to growing consumer demand (9).

Investing in processing facilities and promoting innovation in this field can deliver economic benefits, bolster the agricultural sector and enhance livelihoods in rural areas (Fig. 6).

Postharvest handling of horticultural crops

Postharvest handling is a critical phase in agricultural, significantly influencing the quality and shelf life of fruits and vegetables. This stage involves practices designed to preserve the freshness and nutritional value of produce from harvest to consumer delivery. Effective postharvest handling includes careful harvesting to prevent physical

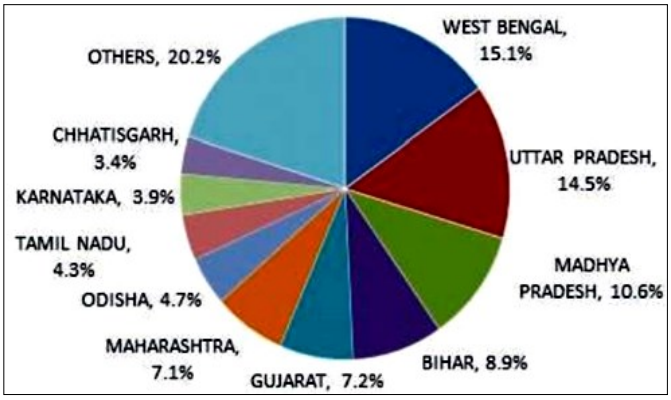

Fig. 2. Percentage share of vegetables production in major vegetables producing states for the year 2020-21.

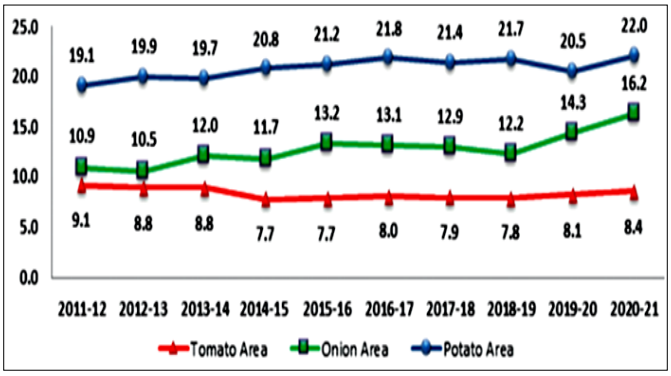

Fig. 3. Area (lakhs ha) of tomato, onion and potato from 2011-12 to 2020-21.

Table 2. Causes of postharvest losses in tomato

S. No.	Perceived causes of postharvest losses	Percentage (%)
1.	Lack of market avenue	86.1
2.	Lack of adequate storage facilities	100.0
3.	Bad road network	75.3
4.	Non exposure to modern trends in tomato production	100.0
5.	Lack of processing plants	75.0
6.	Drought	29.7
7.	Heavy rainfall	72.2
8.	Disease and pest infestation	100
9.	Shortage of labour	31.0

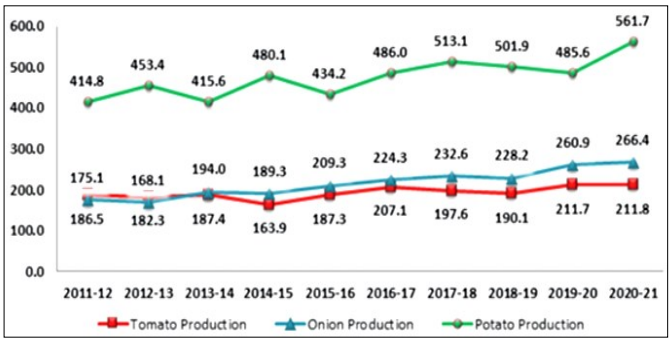

Fig. 4. Production (in lakhs MT) of tomato, onion and potato from 2011-12 to 2020-21.

Fig. 5. Productivity (MT/ha) of tomato, onion and potato from 2011-12 to 2020-21.

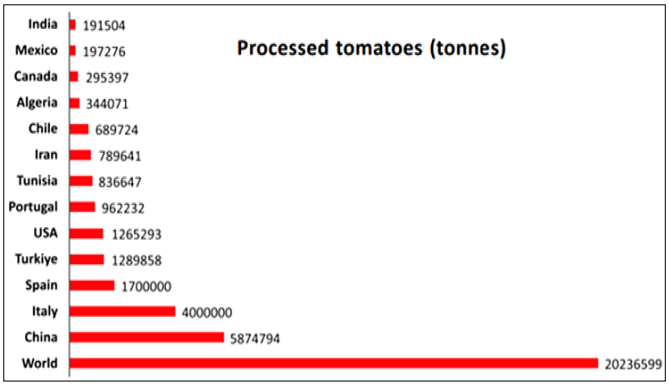

Fig. 6. Status of tomato processing countries all over the world.

damage, pre-cooling to reduce spoilage, cleaning and disinfecting to eliminate contaminants (10). Pre-cooling works by lowering the temperature of harvested crops to slow metabolic processes, such as respiration and water loss, which lead to spoilage. Rapid temperature reduction through pre-cooling inhibits bacterial and mold growth, preserves produce texture and flavour and minimizes the loss of nutrients. Common Methods of pre-cooling include hydrocooling, air cooling, room cooling, vacuum cooling and ice cooling (10). Sorting and grading ensure that only the high-quality produce progresses, while proper packaging protects items during transportation. Effective transportation and storage conditions are essential for preserving quality and extending shelf life. Each step plays a crucial role in minimizing losses; improve marketability and delivering high quality, safe produce to consumers. Proper postharvest handling reduces waste, enhances economic returns for producers and contributes to overall food security (11).

Harvesting

The physiological maturity of a fruit at harvest plays a critical role in determining its postharvest quality. Harvesting fruit at the appropriate time is essential to ensure optimal quality. Postharvest physiologists categorize the shelf life of fruits and vegetables into three stages: maturation, ripening and senescence. While the stages of maturation, ripening and senescence are universal in postharvest physiology, their timing and characteristics vary across crop types. Climacteric fruits and vegetables continue to ripen after harvest, whereas non-climacteric varieties do not. As a result, each type of produce requires customized postharvest management to optimize shelf life and minimize spoilage. The maturation stage determines when the fruit is ready for harvest (11) (Fig. 7). Tomatoes can be harvested at various maturity stages, including matured green, partially ripe, or fully ripe. Each harvest stage provides unique postharvest attributes. Harvesting tomatoes at the green stage extends shelf life; however, their nutritional value and appearance might be compromised since sugar development occurs after maturity (Fig. 8). Producers aiming to market their tomatoes over long distances should harvest them when fully green and take precautions to avoid mechanical damage during harvesting.

For industrial processing, tomatoes should be harvested at the pink stage, as they contain higher acidity, which is desirable for processing tomatoes into high acid foods (eg. tomato sauce) (9). Fully ripe tomatoes are prone to mechanical damage during harvesting, potentially reducing their shelf life (11). Therefore, careful handling of ripe tomatoes is necessary to prevent damage that could accelerate spoilage. To prevent damage, bruising and puncturing, sharp edged harvesting and packaging materials should be avoided. Harvesting should be done in the early morning or late afternoon to reduce excessive field heat. Significant losses of fully ripened tomatoes often result from the failure to follow essential harvesting practices, compounded by inefficiencies in the value chain, including limited market access and inadequate processing facilities.

In many developing countries, accessing a ready market for highly perishable crops, such as tomatoes is a significant challenge. This issue arises largely due to production patterns that result in surpluses. Because a significant portion of tomato production relies on rainfed agriculture, production often peaks during the rainy seasons that exceed local consumption needs. This problem is further exacerbated by the lack of processing facilities or equipment to convert tomatoes into more durable forms for future use. Processing tomatoes into such forms not only extends their shelf life but also adds value, thereby improving their market appeal (12). For example, tomato powder made from dried tomatoes ground into a fine powder is commonly used in seasoning blends, soups and as a flavoring agent. It is increasingly in demand in the health conscious food sector, as well as in the spice and seasoning industry for domestic markets. For

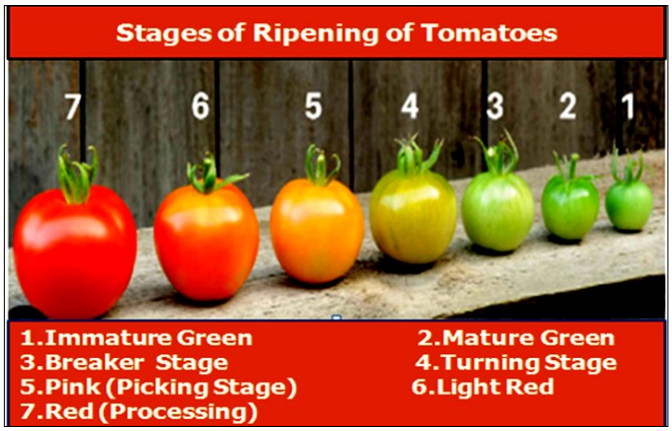

Fig. 7. Six stages of maturity in tomato.

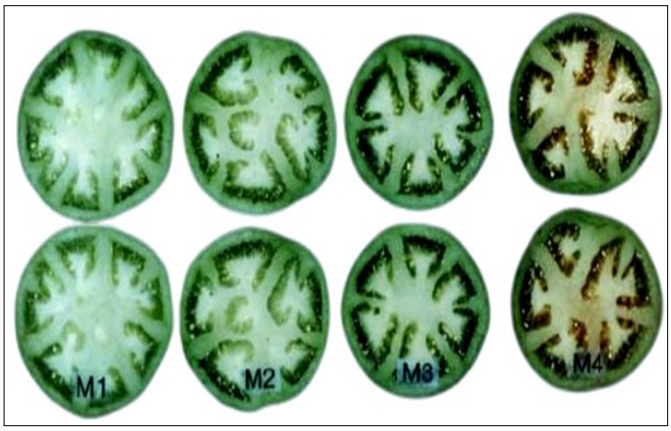

Fig. 8. Internal appearance matured green tomatoes.

export purposes, it is popular in markets that require convenient, lightweight food products, such as convenience foods or military rations (13).

Pre-cooling after harvest

Pre-cooling is a crucial process that involves rapidly lowering the temperature of freshly harvested fruits and vegetables to remove field heat before transportation or storage. This technique slows down metabolic activities, such as respiration and transpiration which would otherwise accelerate spoilage and deterioration (14). Lowering the temperature also inhibits the development of postharvest diseases and delays ripening, thereby extending shelf life and preserving the quality of the produce. Tomato growers often rely on tree shade to cool their harvested produce and reduce field heat. However, tree shade alone is neither a reliable nor an effective method for this purpose. Instead, it is recommended to use a basic on-farm structure, such as a small thatched hut, to significantly improve the precooling of harvested tomatoes. Precooling can be achieved using various techniques, such as room cooling, hydro-cooling, vacuum cooling, forced air cooling and the contact icing method. The most commonly used precooling techniques for tomato are hydro-cooling and air cooling (10) (Fig. 9).

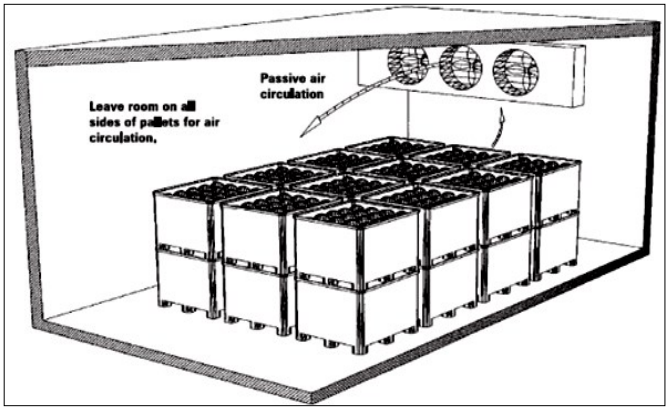

Fig. 9. Pre-cooling of the tomato product after harvest.

Hydro-cooling

This method is often preferred for tomatoes due to its efficiency in rapidly removing field heat. Tomatoes are either sprayed with or submerged in cold water to quickly reduce their temperature. Hydro-cooling is effective in maintaining quality and extending the shelf life of tomatoes by cooling them rapidly and evenly. An affordable and effective approach for pre-cooling harvested tomatoes, especially for farmers in developing countries, is to immerse the fruits in cold water combined with disinfectants, such as thiabendazole and sodium hypochlorite. This hydro-cooling method effectively cools the tomatoes and reduces microbial contamination (14). The ideal temperature range for tomato handling, approximately 13-20°C, can be achieved either early in the morning or late in the evening (10). Hydro-cooling offers the advantage of rapid and uniform cooling, which helps preserve product quality, reduce shrinkage and extend shelf life. However, it requires significant water usage and can pose contamination risks if the water isn't properly sanitized. Additionally, hydro-cooling may cause damage if the water temperature is too cold or the pressure is too high (10).

Air-cooling

Air-cooling is a process used to lower the temperature of perishable goods such as fruits, vegetables and processed foods, to maintain freshness, reduce spoilage and extend shelf life. This method is often employed when tomatoes are packed in bins or crates. Forced air coolers circulate cold air around the tomatoes, effectively removing heat and preserving freshness. Although less intense than hydro-cooling, air-cooling is still effective in extending the shelf life of produce. This method is particularly suitable for large scale operations involving bulk products with packaging that allows for sufficient airflow. Air-cooling is cost effective, efficient for cooling large quantities and adaptable to various packaging types, including breathable cartons, mesh bags and bulk crates. However, it is less effective for rapid cooling or for tightly sealed packaging, where other methods might be more appropriate. For specific types of packaging, air-cooling works best with products that require gradual, uniform cooling and where packaging design facilitates air circulation (11). Air-cooling is cost effective, doesn't require water and poses less risk of contamination, making it ideal for smaller scale operations. However, it is slower, less uniform and consumes more energy, offering less effective cooling compared to hydro-cooling, which can result in a shorter shelf life (11).

Cleaning or disinfecting

Cleaning or disinfecting fruits is essential for removing dirt, pesticide residues, germs and other contaminants. This process also helps lower the risk of foodborne illnesses that could be transferred to consumers. The pathogens most commonly associated with tomatoes are *Salmonella*, *Escherichia coli* and *Shigella,* pose significant health risks, particularly for vulnerable populations. Proper agricultural practices, such as safe water use, hygiene during handling and temperature control during transportation and storage, are critical in reducing the risk of contamination. Consumers can also reduce the risk by thoroughly washing tomatoes and ensuring they are properly stored and cooked when necessary. Effective cleaning and disinfection are crucial for reducing postharvest losses and ensuring proper storage and long term packaging. Various disinfectants used during washing can protect fruits and vegetables from postharvest and foodborne diseases. Dipping tomato fruits in a thiabendazole, sodium hypochlorite solution is employed both before and after harvest to sterilize the tomatoes and minimize fungal infections (15). Fruits and vegetables are usually treated with chlorinated water after washing to reduce the microbial load prior to packaging. According to a report from the Indian government, fresh fruits and vegetables can harbour several microorganisms that may lead to illness in consumers, including *Salmonella*, *Cryptosporidium*, *Cyclospora* and the hepatitis A virus (Monthly Newsletter, NCDC, 2024). Tomatoes can also be cleaned by wiping them with a wet cloth. However, it's essential to ensure that both the water and the cloth are clean to avoid contaminating the fruit (16). By maintaining rigorous cleaning and disinfection protocols, the quality and

Fig. 10. Wiping of tomato with moist cloth.

safety of vegetables are significantly enhanced, making them safer for consumption and extending their marketability (Fig. 10, 11).

Sorting and grading

Sorting and grading are essential steps in the postharvest handling of tomatoes, significantly impacting their quality and market value. Sorting involves the separation of tomatoes based on various criteria, such as size, colour and ripeness. This process ensures that only the highest quality fruits move forward in the supply chain, while those that are overripe, underripe or damaged are removed from the healthy and cleaned fruits (Fig. 12).

Grading further classifies the tomatoes into different categories or grades based on established standards, which may include size, shape, colour, stage of maturity, degree of ripening and overall quality (17). This systematic approach helps meet market requirements and consumer expectations. Proper sorting and grading not only enhance the aesthetic appeal of tomatoes but also improve their shelf life and reduce waste by ensuring that only tomatoes of similar quality are packaged together. Sorting helps prevent the transfer of infectious microorganisms from damaged or spoiled tomatoes to healthy ones during post-harvest handling.

Electronic colour grading is employed for highly perishable fruits and vegetables due to its high accuracy, although it is more expensive (17). This method categorizes produce into grades, such as A, B, C, or 1, 2, 3, or into size categories like large, medium and small. For example, tomatoes are graded based on colour, while vegetables such as bitter gourd and okra are graded according to size. Grading assists handlers in categorizing fruits and vegetables according to common criteria, which facilitates easier management and processing. By implementing effective sorting and grading practices producers can optimize their produce's marketability and maintain high standards in postharvest handling.

Fig. 12. Grader for fruits and vegetables.

Fig. 11. Cleaning the product by using sprayer.

Packaging

Packaging is essential in postharvest handling to minimize losses by protecting food products from biological and mechanical damage. For tomatoes, effective post harvest management involves dividing the produce into manageable sections, including size, variety, packaging material and ripeness. In India, the most common packaging materials include wooden boxes, cardboard, woven plastic baskets, plastic crates, nylon sacks and polythene bags used for packing the fruits (18). Tomatoes can be packaged using various materials, such as polythene, grease resistant paper and fresh paper to ensure their protection and quality. Depend upon the commodity, packaging materials should be selected to ensure good aeration and maintain the quality of the produce. Several developing countries utilize woven palm baskets and wooden crates as standard tomato packaging materials (Fig. 13, 14). The purpose of packing tomatoes in polythene bags was to improve quality and give them a 28-day shelf life over other packaging. Compared to the control fruits, tomatoes that were harvested at the breaker stage and packaged in 300-gauge polyethylene bags with three vents exhibited minimal variation in moisture, total soluble solids, acidity and sugar content. Tomatoes packed in black plastic bags experienced minimal weight loss of 77.5 g/kg, whereas unpacked fruits lost up to 224.16 g/kg (7). Black polyethylene bags were found to provide good firmness and colour retention.

In India, 80.7% farmers utilize wooden boxes, 16.1% sacks and 3.2% plastic boxes for packaging fruit products. A major drawback of wooden crates is their height, which

Fig. 13. Tomatoes packed in wooden boxes.

Fig. 14. Tomatoes packed in plastic crates.

exerts significant compressive forces on the tomatoes at the bottom of the crate. These unwanted compressive forces can lead to internal injuries, ultimately diminishing the post harvest quality of the tomatoes (18). Modifying crate depth may be an effective approach for minimizing the accumulation of compressive pressures and limiting mechanical destruction of fruits at the bottom of the crate during packaging. Fruit can be punctured or bruised by the sharp inside edges of the woven palm baskets used by tomato workers. To protects against this kind of damage the baskets should be woven with the smooth side of the material facing inward to prevent such damage (19). Even tough, it has several disadvantages; farmers continue to utilize the wooden boxes for packaging of tomatoes and other agricultural products due to their strength, breathability, sustainability and cost effectiveness in certain regions, as well as their ability to provide reliable protection during transportation.

Active packaging, intelligent packaging and controlled atmosphere packaging are distinct techniques used to enhance the storage and quality of products. Active packaging involves incorporating additives into or onto the packaging material to extend shelf life, improve safety, enhance sensory qualities and maintain overall product quality and reduces the food loss by nearly 20-40%. This approach can include features such as moisture absorbers, antimicrobial agents and oxygen scavengers, all designed to interact with the product to mitigate spoilage and degradation. The active biofilm packaging can effectively absorb ethylene and slow down the ripening of tomato fruits (20).

Modified atmosphere packaging (MAP) adjusts the levels of oxygen and carbon dioxide within the package by sealing actively respiring produce in polymeric film packages (21). This technique extends the shelf life of produce by enhancing moisture retention and while not sterilizing, significantly reducing exposure to diseases and pollutants (Fig. 15, 16). The adoption of biodegradable packaging materials in the food processing industry, including for products like tomatoes, is gaining momentum due to growing environmental concerns and regulatory pressures. Unlike conventional plastic, which can take hundreds of years to decompose, biodegradable packaging breaks down more quickly in natural environments, reducing pollution and waste. Materials such as polylactic acid (PLA), cellulose-based films and starch based packaging offer sustainable alternatives, especially for perishable goods like tomatoes, which often require protective packaging for transport and storage (22).

Storage

Storage is a critical aspect of postharvest handling for tomatoes, playing a key role in maintaining their quality and extending shelf life. Proper storage conditions help prevent spoilage and preserve the freshness of the fruit. Tomatoes have high moisture content, making them challenging to store at ambient temperatures for extended periods. Tomatoes should be stored in a cool, well ventilated environment to slow ripening and minimize the risk of decay. For short-term storage (up to a week), tomatoes can be kept at ambient temperature, provided there is adequate ventilation to prevent heat build up caused by respiration. For longer-term storage, ripe tomatoes should be stored at temperatures between 10°C and 15°C (50°F to 59°F) with a relative humidity of 85% to 95% (18). Extremely low storage temperatures can negatively impact both the quality and shelf life of tomatoes and other tropical fruits. Refrigeration can extend the shelf life of tomatoes for several days but may slightly reduce their flavour, total soluble solids (TSS) and pH levels. The poor aroma associated with refrigeration is due to the loss of key volatile components.

Tomatoes treated with chlorine, packed in perforated polyethylene bags (0.25% perforation) and stored at ambient temperature (20-25°C) with relative humidity of 70 to 90%, showed a significant reduction in losses due to decay and weight loss. This treatment delayed compositional changes in TSS, total sugars, reducing sugars, vitamin C and β-carotene, extending the shelf life of the tomatoes to up to 17 days. In contrast, untreated

Fig. 15. Tomatoes fruit are damaged due to improper packaging.

Fig. 16. Tomatoes packed in red mesh sacks.

tomatoes stored at ambient conditions without packaging or in gunny bags lasted only 7 days (23). Proper storage at 12°C to 15°C can extend shelf life by 7-10 days, reducing waste and enhancing the appeal in distant markets.

Several advanced technologies have been developed to enhance the storage of tomatoes, aiming to extend their shelf life and maintain their quality. Controlled atmosphere storage (CAS) is one such technology that regulates oxygen, carbon dioxide and humidity levels within storage environments to slow the ripening process. Modified atmosphere packaging (MAP) uses specialized materials to adjust atmospheric conditions around tomatoes, reducing oxygen and increasing carbon dioxide to prevent spoilage (21). Cold Storage facilities equipped with precise temperature and humidity controls can preserve tomatoes for extended periods. For instance, unripe tomatoes can be stored for 4 weeks at 8°C to 10°C with 85% to 90% relative humidity. Fully ripe tomatoes can be stored at 7°C with 90% relative humidity for up to one week. Applying heat shock by dipping tomatoes in water at 45°C for 10 minutes before exposing them to low temperatures enhances their resistance to chilling injury (24, 25). Similarly, mature green tomatoes can be treated with heat at 34°C or 38°C with 95% relative humidity for 24 hours before being stored at 4°C for four weeks to reduce chilling injury. These advanced handling methods can become cost effective for small and marginal farmers when supported by subsidies, cooperatives or government backed financing. Such initiatives reduce postharvest losses and improve market access.

Active packaging technologies interact with the produce to manage moisture and inhibit microbial growth. Smart Packaging, embedded with sensors, monitors environmental conditions inside the packaging to ensure optimal storage. Ethylene control systems (ECS) manage ripening by removing or neutralizing ethylene gas, further extending shelf life (21). Innovative storage solutions like smart packaging and ethylene management systems are transforming how produce is stored, significantly enhancing shelf life. Smart packaging, which integrates sensors to monitor factors such as temperature, humidity and gas composition, ensures optimal conditions during storage and transport, reducing spoilage and waste. Additionally, biodegradable packaging offers eco-friendly solutions that help preserve quality while reducing environmental impact. Lastly, cooling techniques such as hydro-cooling and forced air cooling rapidly lower the temperature of tomatoes immediately after harvest, mitigating field heat and maintaining freshness. Storage technologies extend the processing season and ensure a continuous supply of products throughout the year. Collectively, these advancements address the challenges of tomato storage, reducing post harvest losses and ensuring high quality produce reaches consumers (Fig. 17).

Transportation

Transportation is a critical component of post harvest handling that ensures the safe and efficient movement of produce from farms to markets or processing facilities. Proper transportation practices are vital for maintaining

Fig. 17. Goods were placed at cold storage chamber.

the quality and freshness of fruits and vegetables. In many developing countries, tomato production sites are often located far from marketing centres and are frequently difficult to access by road.

The challenge of transporting harvested tomatoes to the market is compounded by poor road conditions and the absence of suitable transportation, such as refrigerated vans, posing significant difficulties for both producers and distributors. This challenge results in significant delays in delivering the produce to the market. Producers can experience losses of up to around 20% due to transportation delays. To mitigate transportation delays and losses in tomato distribution, improving road infrastructure, investing in refrigerated transport and forming farmer cooperatives to share resources are key strategies. These interventions would reduce spoilage, lower individual costs and improve logistical efficiency. Better coordination between producers and distributors would further streamline the supply chain, ensuring fresher, timely deliveries. Various transportation methods are used, including human labour, donkeys, public transport, trucks, buses, lorries, fuel tankers and pickup vans. However, selecting the right mode of transportation is vital for effective post harvest handling of tomatoes that protect the produce from physical damage, temperature fluctuations and contamination (26).

Additionally, loading and unloading procedures must be executed with care to minimize bruising and other damages of fruits. During transport, proper packaging and stacking are essential to immobilize the produce and prevent excessive movement or vibration. Vibration and impact from road undulations are significant causes of post-harvest losses, particularly for tomatoes and other fruits and vegetables. Vibration bruising and abrasion damage causes increased fruit moisture loss, discoloration and wounding (27). Effective transportation operations also include regular inspections of vehicles and adherence to hygiene standards to prevent the spread of diseases. By adopting effective transportation strategies, handlers can ensure that produce reaches its destination in excellent condition, which improves its market value and boosts up the consumer satisfaction (Fig. 18).

Several regions and crops have successfully adopted transportation systems that minimize post harvest losses; ensuring produce reaches its destination in optimal condition. For example, In India, the exportation of mango (Kesar and Alphonso varieties) by the Agricultural and Processed Food Products Export Development Authority

Fig. 18. Transportation of the goods.

(APEDA) has implemented a robust cold-chain logistics system. This system includes refrigerated trucks, air freight and temperature controlled storage facilities to ensure the quality of the produce during export (28).

Value addition in tomato

India ranks as the world's second largest producer of fruits and vegetables, trailing only China. Unfortunately, a large amount of this produce is lost due to insufficient postharvest practices, such as problems with handling, storage, transportation and processing. It is estimated that fruit and vegetable losses range from 20-40% amounting to nearly Rs. 30,000 million annually (29).

Tomatoes, a major source of umami flavour are used in various forms including raw, cooked in sauces, salads and beverages. They are rich in lycopene, carotenoids, flavonoids, vitamin C, K_1, B_2 and B_9, as well as rich in minerals like potassium, copper, iron and phosphorus among other beneficial compounds. The estimated postharvest loss for tomatoes is 25.5%. Implementing appropriate processing technologies is a practical approach to effectively minimize postharvest losses in fruits and vegetables (30). Tomatoes are used to produce a variety of value-added products like pickles, paste, juice, powders, jams, puree, cocktail, soup and ketchup. As global demand for diverse snacks grows, products such as instant tomato pickles, chips, sauces, powders and other dried foods are becoming increasingly popular. By incorporating ingredients like tomatoes, sugar, salt, spices, chilies, coriander, lemon, black pepper, cumin seeds, dry ginger, tamarind and fenugreek seeds these products ensure safety, nutrition and convenience. Value added tomato products provide ease of use, health benefits and reduced preparation time for consumers (31). Different value added products of tomato are given below.

Tomato juice

Ripe, fully red tomatoes are selected for juice production, while green, blemished and overripe fruits are discarded. High quality tomato juice should be deep red, exhibit the characteristic taste and flavour of tomatoes and contain approximately 0.4% citric acid. It should also be uniform in appearance and have high nutritional value, with a composition of 0.5% salt and 15% sugar. For producing one litre of juice, add 10 g of sugar, 5 g of salt, 1 g of citric acid and 1 g of sodium benzoate. Tomato juice or pulp can be extracted using either hot or cold pulping methods. Hot pulping is preferred over cold pulping due to its ease of juice extraction, higher yield, reduced oxidation of vitamin C and lower risk of microbial spoilage (9). On a commercial scale, a pulper or continuous spiral press is used for extraction, while at home; tomatoes are typically strained through a steel sieve. The juice is then heated to 82-88°C for 2 minutes, hot filled into bottles and subsequently sterilized and cooled. Tomato juice that has not been opened should be kept in a dry, cold place where it can be preserved for up to a year. Once opened, tomato juice should be refrigerated at around 4°C (39°F) and used within 7-10 days for optimal freshness (Fig. 19).

Fig. 19. Tomato juice.

Tomato jam

Tomato jam is a delightful and versatile condiment that combines the natural sweetness of tomatoes with sugar, spices and sometimes a hint of acidity. It can be used in various dishes to add a unique flavour profile.

Tomato powder

Tomatoes leftover from juice extraction and pulping can be turned into powder through tray drying, drum drying, or freeze drying (31). Drying is the oldest technique for preserving food. Tomato powder is created by drying and grinding tomatoes. Lycopene, a compound found in tomatoes, can be extracted from by-products like tomato peels or seeds, or through chemical and microbial methods. In the process, tomatoes are first cleaned with running water, blanched and sliced. The slices are then placed on trays covered with aluminum foil and dried in a cabinet dryer at 60°C for 12 hours. After drying, the slices are ground into powder using a commercial mixer or grinder. The resulting powder is sifted through a BS-60 mesh to ensure particle size is less than 0.25 mm. The powder is stored in a freezer at 20°C and then powdered tomato samples are packed in low density polythene (LDPE) pouches and kept at room temperature. One kg of fresh tomato yielded 50-55 g of dehydrated powder with desirable quality in terms of moisture content (12). The resulting tomato powder is suitable for use in fortifying tomato soups, manufacturing ketchup or adding to rice dishes (Fig. 20).

Tomato paste

Tomato paste is a highly concentrated product made from tomato juice or pulp with a minimum of 25% tomato solids and without skins and seeds. Tomato paste can be categorized based on its concentration level into three

Fig. 20. Tomato powder.

main types: light tomato pastes which contains 25-29% salt free tomatoes; medium tomato pastes with 29-33% salt free tomatoes and heavy tomato pastes which includes at least 33% salt free tomatoes (9). In tomato paste, common salt, citric acid, ascorbic acid, spices, acceptable colorants and preservatives are the only additions that are acceptable. The finished product should have a strong, fresh tomato flavor and be free from any

Fig. 21. Tomato paste.

unpleasant or undesirable tastes. Tomato paste is used to produce various products such as ketchup, soups and sauces. It must have excellent shelf stability and should not exhibit any signs of fermentation when incubated at 37°C for seven days (Fig. 21).

Tomato puree

Tomato puree is made from ripe tomatoes that are first pulped using either a hot or cold method. The resulting pulp or juice is then concentrated, typically using a vacuum pan, which allows it to boil at a lower temperature of 71°C. This process helps preserve the tomato's original red color, flavor and natural vitamin C content. The concentrated pulp is adjusted to achieve a solid content of 9-12% then packaged in pre-sterilized bottles, sealed with crown caps and processed in boiling water for 25-30 minutes to ensure safety and quality. Alternatively, tomato puree can be preserved by using sodium benzoate (250 ppm benzoic acid). When packaged in tin cans, the hot puree, maintained at 82-88°C, is filled into cans, sealed and processed for 20 minutes at 100°C to achieve long term preservation (9, 32) (Fig. 22).

Fig. 22. Tomato puree.

Tomato ketchup

Tomato ketchup is a commercial product made from fresh tomatoes either by converting them into juice or pulp or by using tomato puree or paste. It is created by concentrating tomato juice or pulp, which excludes seeds and skin. Ingredients such as spices, salt, sugar, vinegar, onion and garlic are added, ensuring that the ketchup contains at least 12% tomato solids and a minimum of 25% total soluble solids. Previously prepared tomato juice or puree can also be used to make tomato ketchup. Benzoic acid may also be used as a preservative to enhance the shelf life of the product without spoilage or growth of microorganisms. Ketchup should be stored at a cool room temperature, typically between 10°C and 21°C. Unopened ketchup can be stored for up to 12 months and to preserve the freshness and quality of the product it should be refrigerated after opening, with a storage temperature of about 4°C. Although it can stay safe and usable for up to a year if properly refrigerated, ketchup should ideally be consumed within six months of opening for the best flavour and quality. This process will create one of the best opportunities for women to strength their livelihood (33) (Fig. 23).

Freezing tomatoes

Tomatoes can be frozen in several forms such as sliced, chopped or pureed. For freezing, fully ripened, firmed

Fig. 23. Tomato ketchup.

fruits were selected and damaged; decayed or any other spoiled fruits are discarded. The stem scared tomatoes are removed and they are cut into the desired shapes before frozen. Unlike many vegetables, tomatoes do not need to be blanched before freezing. Whole tomatoes are generally not frozen for commercial use because they lose their firmness and texture upon thawing, making them less suitable for many applications where fresh tomatoes are used. Instead of chopped or pureed, tomatoes are

Fig. 24. Freeze dried tomato.

ideal for freezing and can be stored at 0°F for 6 to 9 months. By the freezing technique, lycopene loss was reduced. Average lycopene loss was around 18.5% after 50 days and 20.6% after 150 days (34). Additionally, tomato based products like purees, sauces and pastes can also be frozen and are often used as ingredients in other frozen foods (Fig. 24).

Tomato soup

Tomato soup is currently very popular and can be prepared using either tomato pulp or juice. The addition of ingredients like butter or cream, spices and starch are adjusted according to the preferred taste. A variety of recipes are available to help produce a high quality tomato soup. Commercially prepared tomato soup is available in a variety of forms including preserved, condensed and in dehydrated powder forms (9) (Fig. 25).

Tomato pickle

Whole ripe tomatoes were thoroughly cleaned with running water, then blanched, cut into pieces and dried in a tray dryer at 60°C for 6 hours. The dried tomatoes were ground in a grinder and sifted through a 300 µm mesh sieve. A spice mix was made by grinding red chillies, cumin seeds and dry ginger in a 15:2:2 ratio and sifting it through a 300 µm sieve. The composition of the spice mix was adjusted by adding fatted white sesame meal and salt in a 38:22:40 ratio. All the ingredients including the tomato powder were combined to prepare an instant tomato mix (9).

Fig. 25. Tomato soup.

Profitability through processing of tomato

The production of value added tomato products can significantly boost the income of farm women and serve as a viable startup opportunity for small scale entrepreneurs in rural areas. The benefit cost ratio for improved practices was found to be 1.36, compared to 1.22 for traditional methods, with additional gross profits increasing by 22.95% over traditional practices (35). Farmers can increase their earnings by processing fruits and vegetables, which helps control market price fluctuation and reduces losses. In addition to that, contract farming and processing integration, to start rural processing hubs innovative and development of value added product was the potential business models or public private partnerships to support tomato processing ventures in rural areas.

Conclusion

Integrating effective postharvest handling practices with innovative value addition strategies enables farmers to enhance profitability. Tomato value added products are particularly popular in India and are increasingly produced on both small and large scales. Since tomatoes are available throughout the year, there is significant potential for setting up processing units, which can reduce postharvest losses and improve farm women's profit. Tomato value added products are more appealing to women because technology assessment boosts gross profit by 22.95% and product output per unit by 8.33% compared to traditional practices. This represents a form of women's empowerment, as farm women can earn money by processing of fruits and vegetables. Several government schemes and support systems are available to encourage tomato processing initiatives, such as National Food Processing Mission (India), Pradhan Mantri Kisan Sampada Yojana (PMKSY) and Agri Processing Infrastructure Development Fund (APIDF). Emerging technologies, including automation in tomato grading and AI (artificial intelligence) driven quality control, offer opportunities to improve postharvest handling. Automation sorts tomatoes by size, colour and ripeness, ensuring uniformity and reducing waste, while AI systems use machine learning to detect defects and assess ripeness for better quality control. These innovations optimize storage, reduce labour costs and ensure high quality tomatoes reach the market, boosting profitability and aligning with sustainability goals by minimizing waste and improving resource efficiency.

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Authors' contributions

AB carried out the writing of original draft and conceptualization. KRR revised the draft. SM contributed to inclusion of tables and figures. JR contributed for proof reading. TA provided technical support for writing the review article. AB, KRR, SM carried the revision, formatting and supervision. All the authors read and approved the final version of the manuscript.

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For paraphrasing few sentences, I have used the Chat GPT-AI tool. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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