



## Postharvest quality management for preserving the shelf life of tomato

### Review Article

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### Abstract

*Tomato production has increased in recent years due to the economic and nutritional importance of the crop. This increase is made possible by the numerous research advances made along the entire value chain. Such increased production of tomato can help to get good revenue for majority of growers in most developing countries of the world. However, postharvest losses make its production non-profitable in these parts of the world. Postharvest losses in tomatoes can be either quantitative or qualitative. Although there is a growing emphasis in crop research on shifting from quantity to quality of produce, there has been little improvement in the quality of commercially produced tomato varieties, resulting in significant quality losses. Therefore, employing optimal postharvest treatments, including temperature control, modified and controlled atmospheres, modified atmosphere packaging, physical treatments, and ideal storage conditions, is essential for preserving the quality of tomatoes after harvest. The understanding and managing of these postharvest treatments appropriately can decrease the postharvest quality losses in tomatoes. In this review, the postharvest treatments responsible for improving the quality of tomato fruit have been reviewed and discussed.*

Keywords: Postharvest, quality, shelf life, tomato

### 1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated vegetable crops and is the most consumed vegetable

worldwide, belonging to the Solanaceae family (Tessema, 2013). Tomatoes, characterized by their thin skin, juicy and has fresh pulp, are important source of essential nutrients including lycopene,

organic acid, vitamins and more (Zhang and Zhang, 2009). Tomato and tomato based products are considered healthy foods due to their low calories content cholesterol-free nature, and high fiber content (Soto-Zamora *et al.*, 2005b). Additionally, tomatoes are rich in vitamin A, C,  $\beta$ -carotene, lycopene (Javanmardi and Kubota, 2006; Hernandez-Suarez *et al.*, 2007; Gharezi *et al.*, 2012) and other antioxidants.

The ripening process induces required changes in the character and chemistry of tomato fruit, enhancing its flavor, appearance, texture and nutritional quality. However, excessive textural softening during ripening leads to adverse effects and spoilage during storage. Postharvest loss is a major challenge hampering tomatoes production in most developing countries (Arah *et al.*, 2015). Specialized postharvest handling practices and treatment methods are needed in order to extend the shelf life of the crop after harvest. Failure to adhere to these specialized handling practices and treatment methods result in high amount of loss. Losses of up to 50% can be recorded in tomatoes between the harvesting and consumption stages of the distribution chain in tropical countries (Kader, 2005; Pila *et al.*, 2010) which is in line with Gustavo *et al.* (2003) who stated that between 49 and 80% of all agricultural commodities end up with the consumer whilst the remainder is lost.

Among the post-harvest treatments, storage treatment extends the length of the processing season and helps to provide continuity of product supply throughout the

seasons. For short-term storage (up to a week), tomato fruits can be stored at ambient conditions (Znidarcic and Pozrl, 2006). If there is enough ventilation to reduce the accumulation of heat from respiration; for longer-term storage, ripe tomatoes can be stored at temperatures of about 10–15°C and 85–95% relative humidity (Castro *et al.*, 2005). At these conditions, both ripening and chilling injuries can be minimized. Therefore, it is crucial to understand the appropriate handling practices and treatment methods for harvested tomatoes to reduce postharvest losses, thereby increasing profitability for handlers in developing countries.

Due to a shortage of knowledge regarding post-harvest handling, specifically in packaging and temperature control, producers or sellers degrade not only quality fruits but also incur significant losses. Therefore, it is essential to explore various post-harvest treatment methods and examine their effects on the post-harvest qualities and shelf life of harvested tomatoes.

## **2. Post-Harvest Treatments for Postharvest Storage**

### **2.1. Storage Temperature**

Tomatoes should be stored at cool temperatures (10–15°C) to extend their shelf life (Beckles, 2012). According to Saltveit (2003), for every 10°C increase above the optimal storage temperature, the rate of fruit deterioration accelerates two to three folds. This indicates that lower temperatures are preferable for long-term storage; however,

temperatures below 12.5°C can lead to chilling injury, potentially destroying entire batches of tomatoes (Saltveit and Morris, 1990). The severity of the chilling injury response is greater in green fruit than in red fruit and increases with both storage time and temperature (Morris, 1982). To complicate matters further, the normal development of sugars and volatiles in harvested fruit is inhibited in cold conditions (Kader *et al.*, 1978b; Gomez *et al.*, 2009). Therefore, reports indicating that total soluble solids (TSS) remain unchanged after chilling and reconditioning (Znidarcic and Pozrl, 2006) should be interpreted with caution, as individual sugars were not measured, and the sugar–acid balance was not assessed, which could be adversely affected (Gomez *et al.*, 2009).

## **2.2. Modified and Controlled Atmosphere**

The fundamental difference between controlled atmosphere storage (CAS) and modified atmosphere packaging (MAP) systems is that gas levels are consistently maintained at all times in a CAS system, whereas the gas mixture is introduced into the package once and changes over time in a MAP system (Choubert and Baccaunaud, 2006).

Keeping harvested fruit in a controlled or modified atmosphere can help reduce ethylene-related deterioration. This method complements, but cannot replace, low-temperature storage for maintaining freshness (Kader and Saltveit, 2003). Controlled Atmosphere (CA) and Modified

Atmosphere (MA) conditions can be achieved in large facilities, such as storage rooms and transport vessels, or in individually wrapped containers using specialized packaging coatings. This rapidly evolving area of postharvest technology is 'ripe' for innovation (Beaudry, 2010).

In both controlled atmosphere (CA) and modified atmosphere (MA) storage, carbon dioxide levels are increased while oxygen levels are decreased. The effectiveness of this approach depends on several factors, including the variety of the fruit, its maturity and initial quality, the storage temperature, and the composition and duration of exposure to CA or MA (Kader *et al.*, 1989; Brecht *et al.*, 2004). Additionally, air composition can be manipulated by introducing anti-ripening agents such as 1-methylcyclopropene (1-MCP) and ozone, which degrades ethylene (Skog and Chu, 2000). When ripening is desired, ethylene can then be added. These actions effectively manage the timing of ethylene-related senescence and decay.

### **2.2.1. Carbon dioxide, oxygen and nitrogen ratios along with relative humidity**

Modifications to inhibit senescence in tomatoes involve maintaining oxygen levels at 3–5% (v/v) for mature green and ripe fruit, and carbon dioxide levels at 1–3% (v/v) for mature green fruit and 1–5% (v/v) for ripe fruit, with nitrogen supplementation ranging from 94–96% (v/v) (Sandhya, 2010). Outside of these specified ranges, low oxygen levels can adversely affect the

fruit by promoting anaerobiosis (Kader and Saltveit, 2003). Hypoxia, characterized by a low O<sub>2</sub> to CO<sub>2</sub> ratio and anaerobic conditions, decreases both the synthesis and action of ethylene (Kanellis *et al.*, 1989a; Gorny and Kader, 1996; Mathooko, 1996). Hypoxic conditions in the microenvironment of tomato fruit have been reported to enhance the activity of pyruvate decarboxylase and alcohol dehydrogenase (Chen and Chase, 1993; Longhurst *et al.*, 1994). Consequently, the production of acetaldehyde and ethanol is also stimulated in tomatoes (Longhurst *et al.*, 1994). Despite its ability to alter fruit metabolism and delay ripening, modified atmosphere (MA) treatment does not appear to affect the total soluble solids (TSS) of tomato fruit (Sozzi *et al.*, 1999), although empirical testing is necessary to confirm this.

### **2.2. 2. 1- Methylcyclopropene (1-MCP) treatment**

1-Methylcyclopropene (1-MCP) is an ethylene action inhibitor that irreversibly binds to ethylene receptors, effectively blocking ethylene from binding. This compound reduces many changes associated with ripening, such as respiration rates, cell wall breakdown, and color change, making it a valuable tool for extending shelf life (Watkins, 2006). However, the effect is temporary, as additional ethylene receptors may be transcribed during fruit maturation (Tassoni *et al.*, 2006). The specific effects of 1-MCP depend on the duration and intensity of exposure, the sensitivity of the cultivar, and the stage of fruit development at the time of application (Martinez-Romero *et al.*,

2007). Generally, 1-MCP treatment applied at more advanced ripening stages tends to preserve fruit quality, while its application on green fruit may result in non-uniform ripening both externally (Mostofi *et al.*, 2003) and internally (Mir *et al.*, 2004a). Green fruit must be at least 'competent' to achieve full ripening for the application of 1-MCP to yield beneficial effects (Huber, 2008).

A range of studies suggests that the application of 1-Methylcyclopropene (1-MCP) may not significantly alter the total soluble solids (TSS) in untreated fruit (Opiyo and Ying, 2005; Cliff *et al.*, 2009). However, in certain cultivars, it can prevent the typical reduction in titratable acidity (TA) that occurs during ripening, leading to a decrease in the important TSS:TA quality parameter (Wills and Ku, 2002). This phenomenon may be more pronounced in younger fruit or at higher concentrations (5 µL L<sup>-1</sup>) of 1-MCP (Wills and Ku, 2002). The declining TSS:TA trend has been reported even when the levels of acids and sugars were not altered by 1-MCP (Sandhya, 2010). Cliff *et al.* (2009) investigated not only the analytical characteristics but also the responses of trained sensory panels after sampling pink-staged tomatoes treated with 250 ng L<sup>-1</sup> of 1-MCP and stored for 15 days at 15 °C before ripening at 22 °C. The panels found that while there was no discernible difference in flavor between the treated and control fruit, the treated tomatoes were perceived as less red and mealy, which were viewed negatively (Cliff *et al.*, 2009). This study was significant in

that the chemical measurement of TSS:TA was corroborated by sensory evaluation. However, it also suggested that the effects of 1-MCP treatment may be more complex than initially anticipated (Cliff *et al.*, 2009).

Another important application of 1-MCP is its potential to prevent the abscission of fruit sold while still attached to the vine (Passam *et al.*, 2007). Tomatoes marketed in this manner could be considered value-added products, resulting in higher profit margins (Passam *et al.*, 2007). If significant photosynthetic activity occurs in the vegetative tissues, this could lead to a sustained supply of sugars to the attached fruit, thereby increasing the potential for higher total soluble solids (TSS) at the time of consumption.

### 2.2.3. Ozone

One effective strategy to simultaneously reduce pathogen attack and delay senescence in fruit is to expose it to ozone, a potent antimicrobial agent. The application of ozone in cold storage rooms effectively reduces ethylene levels, thereby enhancing its protective effects during fruit aging (Skog and Chu, 2000; Aguayo *et al.*, 2006). Current research indicates that there are no adverse effects on total soluble solids (TSS) following ozone treatment; however, relatively few studies have been conducted on this topic (Aguayo *et al.*, 2006; Tzortzakis *et al.*, 2007). Tzortzakis *et al.* (2007) reported increased levels of fructose and glucose in ripe fruit six days after ozone enrichment (0.05 or 1.0  $\mu\text{mol mol}^{-1}$ ) compared to the control group ( $<0.0005$

$\mu\text{mol mol}^{-1}$ ), and sensory evaluations indicated that the treated fruits were perceived as sweeter. In contrast, Aguayo *et al.* (2006) found no significant differences in sugar accumulation in whole fruit subjected to cyclic ozone treatment ( $\sim 4 \mu\text{mol mol}^{-1}$ ); however, detectable differences were observed in sliced fruit, with the taste panel rating the treated fruit as superior in overall quality. Conversely, ozone treatment was found to reduce the concentration of ascorbic acid while increasing the malondialdehyde (MDA) content in tomatoes (Liang *et al.*, 2018).

### 2.3. Modified Atmosphere Packaging

Modified Atmosphere Packaging (MAP), refers to the use of specialized materials to enclose a product in an altered composition of gases, after which no active efforts are made to modify the environment. The polymers and films utilized for MAP typically permit the free diffusion of gases, maintaining equilibrium between the gas composition of the external atmosphere and that within the package due to tissue respiration (Philips, 1995).

The most commonly used materials for modified atmosphere packaging (MAP) include low-density (LD) polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene, along with their chemically modified derivatives (Tzortzakis *et al.*, 2007; Sandhya, 2010; Liang *et al.*, 2018). In addition to facilitating modified atmospheres and controlling ripening, Kader and Watkins (2000) identified several

positive benefits of MAP. These benefits include reducing water loss—critical for small-fruited cherry and grape tomatoes—improving sanitation, and minimizing bruising and the spread of disease. These effects can be further enhanced by incorporating ethylene scrubbers or other chemicals into the packaging (Kader and Watkins, 2000; Bailen *et al.*, 2007). Numerous studies demonstrate that MAP effectively slows senescence. Although various cultivars, packaging materials, storage temperatures, and initial air compositions were employed, the results consistently indicate that the primary effect of MAP is to delay the accumulation of total soluble solids (TSS) and titratable acidity (TA). However, amounts comparable to the control are achieved when the fruits are fully ripened (Suparlan and Itoh, 2003; Vanndy *et al.*, 2008). In some studies, TSS increased depending on the polymeric properties of the packaging (Batu and Thompson, 1998), while other studies reported small but significant decreases compared to the controls (Srinivasa *et al.*, 2006).

At the ripe stage, the firmness, soluble solids, titratable acidity, and overall sensory quality of modified atmosphere packaging (MAP) fruits for each variety did not significantly differ from those of fruits stored in the open (Table 1). In fact, MAP fruits exhibited slightly higher firmness and soluble solids, as well as superior sensory quality compared to fruits stored in the open (Vanndy *et al.*, 2008).

Table 1. Fruit firmness, soluble solids, titratable acidity and overall sensory acceptability at the ripe stage of different tomato varieties held in MAP (25 $\mu$ -thick LDPE) or in the open

## Edible Coatings

Edible coatings are materials that encapsulate the surface of food and are consumed along with the product (Vargas *et al.*, 2008). These coatings have demonstrated positive effects on managing senescence in fruit (Zhuang and Huang, 2003) because the protective barriers create a modified atmosphere and can serve as a more cost-effective and portable alternative to controlled atmosphere (CA) storage (Baldwin *et al.*, 1995). Edible coatings consist of natural compounds, including carbohydrates such as starch and alginate; proteins such as whey and casein from milk, as well as zeins and gluten from maize and wheat seeds; and lipids such as beeswax, carnauba wax, candelilla wax, and fatty acids along with their derivatives (Kader *et al.*, 1989; Baldwin *et al.*, 1995; Zhuang and Huang, 2003; Zapata *et al.*, 2008; Vargas *et al.*, 2008). The final effect on fruit quality depends on the extent to which the coating agent creates a desirable internal gas composition (Kader *et al.*, 1989) and manages relative humidity. The application of edible coatings on tomato fruit has resulted in unchanged or enhanced total soluble solids (TSS) levels (Tasdelen and Bayindirli, 1998; Zapata *et al.*, 2008; Mejia-Torres *et al.*, 2009; Ali *et al.*, 2010).

Variety/MAP	Firmness (%)	Soluble solids (%)	% Citrate	Overall sensory acceptability
TLCV15				
Open	2.2	4.1	0.2	7.2
MAP	2.2	4.6	0.27	7.3
CLN1462A				
Open	1.4	3.6	0.24	6.3
MAP	2.3	4	0.18	6.6
T56				
Open	1.3	3.7	0.17	8
MAP	1.9	4.4	0.33	8.6
TMK1				
Open	1.8	3.5	0.35	6.3
MAP	1.8	3.8	0.39	7.1

Where: TLCV15, CLN1462A, T56, and TMK1 were different tomato varieties held in MAP or in the open. Source (Vanndy *et al.*, 2008).

A cultivar, ‘Rambo,’ was coated with alginate and zein at the Mature Green stage, which preserved total soluble solids (TSS), primarily fructose, after nine days of storage at 20 °C (Zapata *et al.*, 2008). Cultivar ‘144’ was coated with a sucrose polyester, Semper Fresh T, at the Pink stage, which slowed the reduction of TSS (Tasdelen and Bayindirli, 1998). Similarly, Mature Green fruit of cultivar ‘Moneymaker’ coated with gum arabic and stored at 20 °C for 20 days also exhibited reduced TSS loss (Ali *et al.*, 2010). A sensory panel found that the fruits in the study conducted by Ali *et al.* (2010) had a superior taste compared to the control group. Notably, one study found that coated Mature Green tomatoes stored at either 5 °C or 12 °C exhibited better tolerance to chilling injury than the controls; however, low temperatures reduced TSS (Mejia-Torres *et al.*, 2009).

## 2.4. Other Physical Treatments

### 2.4.1. Heat

Because tomatoes are sensitive to chilling injury, especially during the early stages of ripening, the use of low temperatures for tomato storage is limited. Consequently, several studies have investigated pre-storage treatments designed to maintain fruit quality during storage and reduce the fruit's susceptibility to chilling injury.

According to Saltveit (2001), applying heat shock to tomatoes before exposing them to low temperatures enhances their resistance to chilling injury. A method based on measuring ion leakage from tissue discs was used to assess chilling injury, revealing that a brief heat treatment (45°C for 10 minutes) could mitigate the development of chilling symptoms, even after the fruit had been subjected to low temperatures. Soto-Zamora *et al.* (2005a) exposed mature green

tomatoes to heat treatments (34 or 38°C at 95% relative humidity for 24 hours) prior to storage at 4 or 20°C for four weeks, aiming to reduce chilling injury at 4°C. While the higher temperature resulted in significant injury, treatment at 34°C was only slightly detrimental, leading to greater weight loss compared to the untreated control. When stored at 20°C, fruits exposed to 34°C ripened similarly to those in the control group. However, at 4°C, chilling injury occurred in both the control and treated fruits, despite the latter exhibiting higher lycopene synthesis.

In parallel experiments conducted by Soto-Zamora *et al.* (2005b), fruits were exposed to high temperatures (38°C) under low oxygen concentrations (5%) to inhibit the activity of oxidative enzymes associated with the induction of thermal injury. Since neither the thermal injury induced at this treatment temperature nor the chilling injury during storage was reduced, such heat treatments are clearly inappropriate for tomato storage. In contrast, Fallik *et al.* (2002), in an effort to delay ripening and reduce chilling injury, found that brief exposure of tomatoes at the pink stage of ripeness to high temperatures (52°C) through washing and brushing for 15 seconds or total immersion of the fruit for 1 minute prevented the appearance of chilling injury symptoms at 5°C for 15 days. In the case of washing, this treatment also transiently increased the fruit's resistance to Botrytis. For commercial application of this technique, the authors recommended the shorter treatment time. According to

Iwahashi and Hosoda (2000), the delay in ripening of mature green tomatoes following heat treatment (37°C for one day in their study) is related to a loss of existing proteins in the pericarp and the synthesis of new proteins, including antioxidant enzymes and heat shock proteins.

Heat treatment has been proposed as a method to inhibit microbial activity and prevent fruit cracking under high humidity conditions in modified atmosphere packaging (Suparlan and Itoh, 2003). It has also been used to delay color changes in cherry tomatoes (*L. esculentum* var. *cerasiforme*) (Ali *et al.*, 2010). Subjecting tomatoes at the light rose stage to anoxia for 24 hours delayed the development of Botrytis, but this effect lasted only up to four days after treatment when the fruits were stored at 20°C. Although this treatment delayed the color development of the fruit, it did not impact their organoleptic characteristics (Fallik *et al.*, 2003). However, when the treatment duration was extended, fruit quality was negatively affected due to the accumulation of acetaldehyde and ethanol (Polenta *et al.*, 2006).

#### **2.4.2. Irradiation**

Irradiation is classified as either non-ionizing or ionizing, with the latter characterized by high frequency and the ability to cause the loss of ions from the materials it contacts. Radiation can induce a stress response in harvested fruit. However, at 'hormetic' doses, fruit tissues can activate

a variety of protective mechanisms, including the production of antioxidants, which are beneficial to human health when consumed (Sharma, 2004). Additionally, radiation can reduce the colonization of fruit by pathogens due to contamination, insect infestation, and postharvest diseases, as well as delay the ripening process (Bruhn *et al.*, 2009). The three most commonly used types of irradiation are Ultraviolet-C, X-rays, and gamma rays, which correspond to lower to higher frequencies of electromagnetic waves.

Ultraviolet (UV) radiation is non-ionizing and is commonly used for postharvest fruit management. Most experiments have focused on Ultraviolet-C (UV-C), although Ultraviolet-B (UV-B) has recently been investigated. Fruit exposed to UV-C at doses of 1.3–4 kJ m<sup>-2</sup> (Charles and Arul, 2007) showed an accumulation of antioxidants. In studies where it was reported, UV-C treatment did not adversely affect total soluble solids (TSS) (Jagadeesh, 2007). Furthermore, sensory evaluations conducted by Charles and Arul (2007) indicated that the taste of UV-C treated fruit was more favorable compared to the control group.

Gamma and X-rays are high-frequency wavelengths that can significantly affect fruit quality if not properly calibrated (El-Assi, 1997). However, they are particularly effective in eliminating parasitic microbes, fungi, and insects (Sharma, 2004). Although there are limited studies on the impact of gamma and X-rays on Total Soluble Solids (TSS), specific doses have been shown to act as effective biocides while preserving

quality. Shurong *et al.* (2005) demonstrated that cherry tomatoes treated with doses ranging from 0.5 to 3 Gy and subsequently stored for 10 days at room temperature experienced a loss of firmness but did not show a significant difference in TSS. In contrast, irradiated tomatoes stored at 4°C exhibited higher TSS levels compared to the controls (Shurong *et al.*, 2005). Additionally, Horak *et al.* (2005) exposed cherry tomatoes in a salad to doses between 0 and 3 Gy, which again resulted in reduced firmness; however, the sensory panel did not distinguish between the control and irradiated treatments (Horak *et al.*, 2005).

## 2.5. Optimal Condition for Postharvest Storage of Tomatoes

Although each postharvest treatment is discussed separately for clarity, in practice, a combination of approaches is employed. As previously noted, the maturity of fruit at harvest is the most significant factor influencing total soluble solids (TSS) and the TSS:TA ratio (Kader *et al.*, 1977; Kader *et al.*, 1978a). Senescence can be effectively managed through postharvest storage at 12.5 °C, which is the simplest and most efficient strategy. Modified atmosphere (MA) storage, consisting of 4% oxygen balanced with high nitrogen levels and high humidity (greater than 85%), can further slow ripening when combined with cool temperatures. To mitigate crop loss due to disease, fruit may be treated with heat or ozone (Das *et al.*, 2006); however, more effective sanitation can be achieved by irradiating fruit with ultraviolet (UV), X-ray, or gamma rays. Irradiation is particularly

advantageous as it not only enhances antioxidant levels but also preserves TSS. Additionally, 1-Methylcyclopropene (1-MCP) at concentrations of 0.5–1 mL L<sup>-1</sup> can be utilized in conjunction with low temperatures and MA to extend shelf life, although some studies indicate that the benefits may be limited (Cantwell *et al.*, 2009), suggesting it is most effective when MA cannot be implemented. At the point of sale, previously cold-stored fruits in MA or controlled atmosphere (CA) can be exposed to ethylene (100 ppm) at room temperature to hasten ripening, as prompt ripening enhances the sugar content of red fruits by minimizing respiratory losses during reconditioning (Salunkhe *et al.*, 1974). Extensive research has resulted in the development of guidelines for optimal postharvest storage of tomatoes to maintain quality (Suslow and Cantwell, 2009); however, greater precision will always be necessary, as it will vary by cultivar and the specifics of the postharvest supply chain, ultimately aiming to sustain or enhance profitability.

### 3. Conclusion

Postharvest quality management of tomato fruits begins in the field and continues until they reach the final consumer. The quality of any fruit after harvest cannot be improved through postharvest treatment techniques or handling practices; it can only be preserved. Understanding and effectively managing the various roles of postharvest treatments—such as temperature control, modified and controlled atmospheres, modified atmosphere packaging, physical treatments,

and optimal conditions for storage—is crucial for ensuring high-quality tomatoes. Given that tomato fruits are highly perishable and susceptible to rapid quality deterioration after harvest, it is essential to implement postharvest treatments appropriately to maintain their quality.

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### Data Availability

Primary data were not utilized to support this study.

### Disclosure

The author confirms that the content of the manuscript has not been published or submitted for publication elsewhere.

### Conflicts of Interest

The author declares that he has no conflicts of interest.

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