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A systematic review on the various biochemical treatments for preservation of fresh tomato

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ABSTRACT

Purpose: Despite the worldwide rise in annual tomato production, approximately 15-50% of harvested tomatoes are lost each year, posing a significant challenge to global food security. This review seeks to assess the efficacy of biochemical treatments in preserving tomatoes to mitigate post-harvest losses. A machine-based search mapped articles on "Chitosan coating and tomato preservation," "Calcium chloride and tomato preservation," and "Potassium permanganate and tomato preservation" using Google Scholar. Seventy relevant articles published between 1995 and 2024 were included in the systematic literature review. **Findings:** Calcium chloride, Chitosan coating, and Potassium permanganate exhibit promise in enhancing tomato shelf life, yet their efficacy is contingent upon variables like tomato variety and storage conditions. Achieving a universally effective treatment proves challenging due to variations in study outcomes, highlighting the complexity of preserving tomatoes optimally. **Limitations:** The variability observed in reported outcomes poses significant challenges when it comes to discerning the most effective and optimal treatment. This inherent inconsistency in results not only complicates the identification of a universally applicable solution but also underscores the intricate nature of the factors influencing treatment effectiveness. **Directions for Future Research:** Future research should examine treatment combinations, consider responses to tomato cultivars, assess ecological impacts, implement safety protocols, and utilize advanced analytical techniques to refine tomato preservation methods.

INTRODUCTION

The global demand for tomatoes has been steadily increasing due to growing awareness of their health and medicinal benefits. This, along with the increase in human population, has led to an increase in global tomato production. Global tomato production in 2018 was estimated at 182.3 million tons (FAOSTAT 2022 as cited in Schreinemachers et al., 2022; Vats et al., 2022) and is expected to increase by 50% by 2050 (Stratton et al., 2021). However, despite this growth, excessive post-harvest losses in tomatoes continue to pose a significant challenge to food security. Post-harvest losses in fresh fruits and vegetables, including tomatoes, are estimated at 15-50% with developing countries recording higher post-harvest losses (35-50%) (Adeola, 2020; Shehu et al., 2014; Stratton et al., 2021) compared to developed countries (less than 15%) (Arah et al., 2016; Farooq et al., 2023). Post-harvest losses in tomatoes directly impact the income of farmers and traders (Kitinoja, 2013). Farmers lose money when their tomatoes are lost after harvest, and retailers lose money when tomatoes are lost in the supply chain. This can lead to financial difficulties and difficulty in repaying loans (Abdullahi et al., 2021; Dandago et al., 2021). Post-harvest losses in tomatoes can also impact the national economy by reducing food availability and leading to higher prices for consumers (Onwualu & Olife, 2013; Stratton et al., 2021). Consequently, post-harvest loss of tomatoes may also reduce the availability of jobs in the agricultural and food processing sector (Adeola, 2020). Furthermore, post-harvest loss of tomatoes has been documented to have negative environmental impacts; as tomatoes decompose, they release methane, a greenhouse gas that contributes to climate change as well as the waste of water, fertilizer, and other resources in tomato production (Ali et al., 2021; Jones et al., 2012; Martínez-Blanco et al., 2011).

In recent decades there has been a growing interest in exploring the causes of these losses and implementing remedial measures (Dandago et al., 2021; Kitinoja, 2013). Many studies have suggested a wide range of remedies for post-harvest loss. One of the commonly used approaches was the use of hot water for a short period (Ghaouth et al., 2019; Tonna et al., 2016). Another approach involved the use of chemical treatments such as organic acids (e.g. citric acid and lactic acid) (Al-Obeed, 2012; López–Gómez et al., 2020) as well as essential oils (Romanazzi et al., 2017) as well as biological coatings (Chitosan, Aloe vera and Moringa) (Athmaselvi et al., 2013; Ragab et al., 2019; Rayees et al., 2013; Tesfay & Magwaza, 2017) to reduce the impact of microorganisms on tomatoes.

Current research extensively addresses the causes and mitigation strategies for postharvest losses in tomatoes, with a particular focus on the widespread use of calcium chloride, chitosan and potassium permanganate (Betchem et al., 2019; Chepngeno et al., 2016; Salgado-Cruz et al., 2021; Silva et al., 2009; Sohail et al., 2015; Xing et al., 2015). However, despite the popularity of these methods, there is a significant gap in existing studies regarding sufficient data on their suitability and potential risks. Furthermore, identifying the most effective biochemical treatment remains an ongoing challenge. This review aims to fill this gap by addressing commonly used biochemical treatments, assessing their relative effectiveness, and examining the associated benefits and challenges.

MATERIALS AND METHODS

The selection criteria were based on the documented PRISMA guidelines (Moher et al., 2009). Articles published between 1995 and 2024 were searched based on predefined search terms. Considering that much may have changed over the years, at the end, only articles published between 1999 - 2024 were used in the review. The procedures for article selection and data extraction are presented as follows.

The systematic search was carried out using Google Scholar Search Engine on two dates and for both searches, the “Keywords Search” was used. The first search was conducted on July 14, 2023 with the following search terms “Chitosan coating” OR “Calcium chloride” OR “Potassium permanganate” AND “Tomato preservation”. Documents that were wholly or partially related to the Search terms matched and 274 documents were returned based on the initial search. The search was further refined by year of publication that was narrowed to publications between 1995 and 2023; this resulted in 105 documents (conference papers). These included published articles and reports as well as theses and dissertations.

The second search was conducted with the same Search Engine and procedure on January 05, 2024. The search terms used in the second search are: “Chitosan coating” OR “Calcium chloride” OR “Potassium permanganate” AND “Tomato preservation” OR “Tomato storage”. A total of 74 records (articles).

The articles from the first and the second search were combined on an EXCEL spread sheet for easy identification of duplicate records. A total of 52 articles were identified as duplicates and excluded from the records. The articles were again refined by the Year of Publication. Seventeen (17) articles were published between 1995 and 1998 and were discarded for being relatively too old. Twenty-four (24) articles were incomplete (Abstract only) as access to full article could not be obtained. Both the older and incomplete articles were discarded leaving a total of 86 articles. The 86 articles were checked for suitablity, from which 60 articles were used for the review.

To simplify the analysis, the review was carried out and reported under the following subtopics: i) calcium chloride, ii) chitosan coating, iii) potassium permanganate and the related implementation of biochemical treatments of tomato qualities

RESULTS AND DISCUSSION

Calcium chloride

There is an extensive discussion in the literature about the use of calcium chloride to preserve fresh fruits and vegetables. Table 1 provides a summary of the different treatments used in previous research to investigate the effects of calcium chloride concentration on the postharvest quality of tomato fruits. Prakash et al. (2018) examined the efficacy of calcium dip (1% $CaCl_2$) and irradiation (1 and 1.5 kGy) treatments on the postharvest qualities of tomatoes. Mujtaba et al. (2014) examined the effects of calcium chloride (1%, 2%, and 3%); Sati and Qubbaj (2021) calcium chloride ($CaCl_2$) 6% (w/v), gum arabic solution 10% (w/v), and cactus mucilage extract (2/1) (w/w). Other researchers have even looked at the effects of pre-harvest spraying of calcium chloride (3 and 5% w/v) in single and multiple applications on the postharvest qualities and shelf life of tomatoes. Other studies have examined the effects of similar levels of calcium chloride (0-6% $CaCl_2$) but for a dipping duration of between 10-30 minutes (Arthur et al., 2015; Coolong et al., 2014). Some of the studies have even examined the effects of combining calcium chloride (1% $CaCl_2$) and chitosan (0.5%) as well as hydrogen peroxide (0.12% H_2O_2) and 1% ozonated water. Furthermore, some previous studies have examined the combination effects of Calcium chloride (0.1%, 0.2%, and 0.4%) and potassium thiosulphate (0.0%, 0.2%, and 0.4%) under cold storage conditions (Semida et al., 2019) and that of the combination of gibberellic acid (0.075%, 0.1% and 0.125%) and Calcium chloride (1%, 1.5% and 2%) (Demes et al., 2021). Nonetheless, others have even examined the effect of hot water treatment (40-50 °C) besides calcium chloride (2% $CaCl_2$) on the postharvest qualities of tomatoes (Hao et al., 2020).

Table 1. Effects of calcium chloride on the postharvest qualities of tomato fruits.

Fruit	Treatment	Effects	Reference
Tomato	Calcium dip treatment (1% $CaCl_2$) Irradiation treatment (1 and 1.5 kGy) Combination treatment of Calcium dip and irradiation	Calcium chloride stimulated ethylene production. Combination treatment showed the best effects of maintaining tomato quality, limiting softening and reducing microbial population.	Prakash et al. (2007)
Tomato	Calcium chloride, $CaCl_2$ (1%, 2% and 3%)	2% Calcium chloride was most effective in preserving tomato qualities	Mujtaba and Masud (2014)
Tomato	$CaCl_2$ (0.0%, 1.0%, 1.5%, and 2.0% (w/v)); Maturity stages (Mature green, breaker, and half-ripe stage)	Mature green stage treated with 2% $CaCl_2$ indicated the best qualities	Mazumder et al. (2021)
Tomato	Calcium chloride ($CaCl_2$) 6% (w/v), Gum arabic solution 10% (w/v), Cactus mucilage extract (2/1) (w/w)	Dipping tomato fruits in 6% $CaCl_2$ for 10 minutes + coating treatments using either 10% Gum arabic or 50% cactus mucilage was most effective in preserving tomato quality.	Sati and Qubbaj (2021)
Tomato (cultivar Rajitha)	Calcium chloride (3 and 5 %w/v), Two spraying protocols: single application at 7 days after full bloom (7 DAFB) or Weekly application from 7 DAFB to harvest	Pre-harvest calcium chloride treatment, particularly at concentrations of 3% and 5% w/v with both single and multiple applications, significantly extended the shelf life of the tomato cultivar by 2.3 to 3.8-fold, increased firmness, Calcium content, and total soluble solids, while showing a lower fresh weight at harvest and increased weight loss during storage, with no consistent impact on titratable acidity	Daundasekera et al. (2015)
Tomato	Calcium (Ca) nutrient solution (60, 180, and 360 mg/L); Foliar application of Calcium chloride (0%, 1%, and 2% $CaCl_2$)	Postharvest disease incidence was not affected by calcium treatment, but weight loss during storage was negatively impacted by calcium chloride sprays.	Coolong et al. (2014)
Tomato	Different concentrations of $CaCl_2$ (2%, 6%, 0%) by dipping for 10, 20, and 30 minutes	Tomato fruit dipped in 6% $CaCl_2$ was more effective than 2% $CaCl_2$ and 0% in maintaining quality. Dipping for 20 -30 was significantly more effective than 10 min. dip, but up to 40 minutes indicated tomato skin injuries.	Arthur et al. (2015)
Tomato (Solanum lycopersicum L. cv. 448)	Chitosan (0.5%); Calcium chloride (CaCl2) (1%); Hydrogen peroxide (H2O2) (0.12%); Ozonated water (1%)	Chitosan (0.5%) and calcium chloride ($CaCl_2$) (1%) were the most effective treatments in maintaining attributes of tomato fruit	Shehata et al. (2021)
Tomato fruit (hybrid 65010)	Calcium chloride (0.0%, 0.2%, 0.4%); Potassium thiosulfate (0.0%, 0.2%, 0.4%) Cold storage	0.4% + Potassium thiosulfate at 0.4% + cold storage showed best preservation effect	Semida et al. (2019)
Tomato (Kochoro variety)	Gibberellic acid (GA3) (0.075%, 0.1%, 0.125%); Calcium chloride (1%, 1.5%, 2%)	1.5% $CaCl_2$ and 0.125% GA3 were effective in maintaining quality and shelf life.	Demes et al. (2021)
Tomato	40°C hot water + 2% $CaCl_2$;40°C hot water treatment alone; 50°C hot water + 2% CaCl2; 50°C hot water treatment alone	40°C hot water + 2% $CaCl_2$ showed lowest weight loss; 50°C hot water + 2% $CaCl_2$ showed the highest firmness level; lycopene content was not explicitly affected by treatments	Hao et al. (2020)

Most studies have consistently agreed that calcium chloride affects the qualities of harvested tomatoes (Mujtaba & Masud, 2014; Prakash et al., 2007; Sati & Qubbaj, 2021) however; the concentrations that were considered as being effective differed between studies. Arthur et al. (2015) found that tomatoes dipped in 6% $CaCl_2$ were more effective in preserving tomato qualities than 2% and the control group. Their results further showed that while 10 -30 minutes of the dip was beneficial to tomato qualities, dipping tomatoes up to 40 minutes was damaging to tomato skin. Sati and Qubbaj (2021) reported that dipping tomato fruits in 6% $CaCl_2$ was effective especially when dipped for 10 minutes + coating treatments using either 10% gum arabic or 50% cactus mucilage was most effective in preserving tomato quality. In a related study, however, Mujtaba and Masud (2014) found that 2% $CaCl_2$ was most effective on tomato postharvest qualities. Yet, when Prakash et al. (2007) revealed that 1% $CaCl_2$ in the presence of irradiation (1- 1.5 kGy) was most effective in preserving tomato qualities. While the aforementioned studies focused on the postharvest application of Calcium chloride treatments, other studies have investigated the effects of the pre-harvest application of Calcium chloride on its postharvest qualities. For example, a study by Daundasekera et al. (2015) on a local cultivar of tomato ('Rajitha' cultivar) in Sri Lanka found that pre-harvest Calcium chloride treatment, particularly at concentrations of 3% and 5% w/v with both single and multiple applications, significantly extended the shelf life of tomato fruits as well as increased fruit firmness, calcium content, and total soluble solids.

However, despite agreeing with the fact that post-harvest application of calcium chloride is important in preserving the postharvest qualities of tomatoes, a study by Coolong et al. (2014) reported the beneficial effects of the pre-harvest foliar application of Calcium chloride in the concentrations of up to 2% $CaCl_2$ on tomato weight loss after harvest, postharvest disease incidence on tomatoes was not affected by the calcium chloride treatment. From this review, it is clear that the influence of the concentration of calcium chloride in preserving the qualities of tomatoes after harvest depends on several factors such as the concentration and duration of the treatment (Arthur et al., 2015), when the treatment was applied (pre-harvest or postharvest) (Daundasekera et al., 2015), presence of other additives/treatments such as coating with Gum arabic or cactus mucilage or irradiation (Prakash et al., 2007; Sati & Qubbaj, 2021) as well as by the application method (Coolong et al., 2014). There is a need for future research to optimize calcium chloride treatments for tomatoes, investigating concentrations, durations, and coatings. Understanding mechanisms, considering environmental factors, and offering practical guidelines for farmers will enhance postharvest preservation strategies.

Chitosan coatings

Table 2 displays the different levels of chitosan used in previous research to examine its effects on harvested tomato fruits. Sucharintha et al. (2018), in their study on the effect of chitosan at concentrations between 0.25 and 0.5%, found that a lower chitosan concentration (0.25%) resulted in better maintenance of physicochemical parameters (pH, TSS, ascorbic acid, weight loss and moisture) showed this further reduced microbial growth and improved sensory properties compared to the control and the higher concentration (0.5%). Parvin et al. (2018) showed that a lower chitosan concentration (0.15%) had greater effects on protecting tomato quality. Nonetheless, vitamin C content decreased with increasing chitosan concentration after 3 weeks of storage, while acid levels increased with higher chitosan concentration, potentially affecting acceptance. Findings from Romanazzi et al. (2017), however, showed that a higher chitosan coating at a concentration of 2.0% (2000 ppm) was most effective in inhibiting the loss of firmness and colour change as well as the decline in titratable acidity and fruit weight. In their study on the effects of a chitosan concentration between zero and 1500 ppm, Sakif et al. (Islam Sakif et al., 2016) found that both 500 ppm and 1000 ppm chitosan equally protected tomatoes from decay for up to 8 days.

Table 2. Effects of chitosan on the postharvest qualities of tomato fruits.

Fruit	Treatment	Effects	Reference
Cherry tomatoes	Chitosan colloid (1% [w/w]); Grapefruit seed extract (GSE) concentrations: 0.0%, 0.5%, 0.7%, 1.0%, and 1.2% [w/w].	Coating with GSE at 1.0% [w/w] was most effective on tomato qualities except for fruit colour. Efficacy was stronger at 25 °C for Chitosan-GSE coating compared to Chitosan coating without GSE	Won et al. (2018)
Tomato	Aloe vera (0, 15, 30, 45 and 60%), Chitosan (0, 0.5, 1, 1.5 and 2%)	Coating formulation with Aloe vera gel (60%) + Chitosan (2%) performed the best results. It reduced weight loss, maintained total soluble solids, pH, ascorbic acid value, acidity, and reduced microbial load. More so, it maintained the firmness and colour of tomatoes during the 12-day storage.	Farooq et al. (2023)
Tomato	Chitosan coating at concentrations (0.25% and 0.5%)	Lower Chitosan concentration (0.25%) showed better maintenance of physicochemical parameters (pH, TSS, Acidity, Ascorbic acid, Weight loss, Moisture), reduced microbial growth, and improved sensory attributes compared to the control throughout the storage period	Sucharintha et al. (2018)
Tomato	Aloevera gel (0, 20, 40, 60 and 80%)	A higher concentration of Aloe vera gel (80%) was more effective in reducing weight loss, colour changes, and maintaining firmness	Firdous et al. (2021)
Tomato	Chitosan-based films with 40% glycerol (Formulation 60/40-TM i.e. Tomato/Moringa extracts).	Coated films exhibited lower water loss (0.892 g) compared to uncoated films (1.132 g); no microbial growth in coated samples, while uncoated samples exhibited bacterial growth. Both coated and uncoated groups indicated good overall acceptability.	Canche-Lopez et al. (2023)
Tomato	Chitosan (1.0%, 1.5% and 2.0%), cinnamon extract	Combining Chitosan with cinnamon extract indicated decreased effectiveness in controlling fruit decay.	Romanazzi et al. (2017)
Tomato (Solanum lycopersicum L.)	Chitosan solutions at concentrations of 0.5%, 1.0%, and 2.0%.	2.0% Chitosan coating was most effective in inhibiting loss of firmness and colour change and in inhibiting the decline in titratable acidity and fruit weight.	Meenu et al. (2023)
Tomato	Chitosan (0.5% and 1%) applied either by dipping or spraying	Chitosan coatings applied by spraying were more effective in all analyses.	Tafi et al. (2023)
Tomato	Chitosan coating with a solution of 1.5% (wt/vol) Chitosan in 1% (vol/vol) lactic acid.	Chitosan-coated tomatoes exhibited less weight loss (216%) and increased firmness (140%) compared to the control group.	Pagno et al. (2018)
Tomato	Irradiated Chitosan solution with concentrations of 500 ppm, 750 ppm, 1000 ppm, 1500 ppm, and 2000 ppm.	1500 ppm Chitosan solution was most effective in preserving tomato qualities. However, vitamin C content decreased with increasing Chitosan concentration after a 3-week storage period. The acidity values increased with higher Chitosan concentration, potentially affecting acceptability.	Parvin et al. (2018)
Cherry tomatoes	Chitosan (CS)-based chickpea hull polysaccharides (CHPS) edible coating CHPS (0.25%, 0.50%, 0.75%, and 1.00% based on CS weight)	CS-incorporated CHPS coatings successfully lowered respiratory activity, total soluble solids, total polyphenols, firmness, weight loss, lycopene content, and vitamin C compared to the control. Results showed a correlation between coating concentration and observed effects.	Akhtar et al. (2024)
Tomato, banana (cvs. Shabri and Champa), strawberry, and oranges	Chitosan solutions (0 ppm (control), 500ppm and 1000 ppm)	Both 500 ppm and 1000 ppm of Chitosan equally protected tomatoes from decay until 8 days. Higher doses of Chitosan (1000 ppm) resulted in faster decay in strawberries.	Sakif et al. (2016)

Tomato	Chitosan 1% ; Chitosan 1% + Tomato plant extract 0.1%; Chitosan 1% + Tomato plant extract 0.3%.	Chitosan 1% + Tomato plant extract 0.1% exhibited the highest antioxidant capacity, total phenolic content, and overall acceptance.	Ruiz-Cruz et al. (2018)
Tomato	Blending edible coatings with essential oils and active compounds using nanotechnologies to overcome limitations.	Edible coatings were noted to have poor barrier properties. Some coatings impart undesirable flavours to produce.	Duguma (2022)

While other studies have suggested that chitosan concentrations as high as 2% was effective in preserving the postharvest qualities of tomato fruits (Meenu et al., 2023). However, some previous studies have shown that chitosan concentration as low as 0.25% is sufficient for the preservation of the total soluble solids, pH, ascorbic acid, weight loss and reduced microbial growth, it also improved sensory attributes compared to the control group (Succharintha et al., 2018). The study conducted by Tafi et al. (2023) shed light on a different perspective regarding the effects of varying levels of chitosan on the postharvest qualities of tomatoes. They compared the effect of Chitosan application methods (dipping or spraying) for concentrations of 0.1 and 1% on the postharvest qualities of tomato fruits (Table 2). Their results showed that spray-applied chitosan coatings were more effective in all analyses. The findings from the study conducted by Jianglian and Shaoyin (2013) indicate that a single application of chitosan may not fully inhibit certain microorganisms across a broad spectrum of fruits and vegetables, potentially resulting in fruit decay. Although their review encompassed various fruits and vegetables, it remains unclear how valid their assertion is specifically regarding tomato fruits. Some studies advocated the use of a combination of chitosan with other biochemical additives to improve the protective effect of these treatments on tomato qualities (Dobrucka et al., 2017; Semida et al., 2019; Zakriya et al., 2023). A study by Farooq et al. (2023) found that a coating formulation containing aloe vera gel (60%) + chitosan (2%) achieved the best results. It reduced weight loss, maintained total soluble solids, pH, ascorbic acid and acidity, and reduced microbial load. In addition, it maintained the firmness and colour of the tomatoes during 12 days of storage. Nevertheless, a study by Romananzzi et al. (2017) found that the combination of chitosan with cinnamon extract indicated reduced effectiveness in combating fruit decay. Some previous studies have shown that chitosan concentration as low as 0.25% is sufficient for the preservation of the total soluble solids, pH, ascorbic acid, weight loss and reduced microbial growth, it also improved sensory attributes compared to the control group (Succharintha et al., 2018). In a related study by Duguma (2022) examined the effects of blending edible coatings with essential oils and active ingredients using nanotechnologies to overcome limitations. His results showed that edible coatings had poor barrier properties. Some coatings impart undesirable flavours to products.

Potassium permanganate

The application of potassium permanganate in the preservation of tomatoes and other fruits and vegetables has been evaluated for tomato fruits (Mujtaba et al., 2014; Wabali and Esiri, 2021), as well as other fruits and vegetables (Dobrucka et al., 2017; Kapsiya et al., 2015; Sanches et al., 2019) (Table 3). A study by Alvarez-Hemandez et al. (2019) revealed that commercial-scale deployment of $KMnO_4$-based technology remains limited due to uncertainty about its potential as an effective post-harvest tool and health, environmental and safety concerns, but positive effects of potassium permanganate have been documented.

Potassium permanganate is used as an ethylene scavenger in fresh fruit and vegetable packaging, Dobrucka et al. (2017) examined the effect of potassium permanganate (6.4 g/100 ml) at 20 °C for different periods (between 3 minutes and 6 hours). The bags in the package contained 1 and 2 grams of the prepared ethylene absorber. They found that the group with ethylene absorbers had delayed mould growth compared to the group without absorbers. In a study examining the effects of Potassium permanganate concentration (2.5 ppm, 5.0 ppm, 7.5 ppm, 10.0 ppm, 12.5 ppm, and 15.0 ppm), Wabali and Esiri (2021) found that concentrations as low as 5.0 ppm were more effective in preserving tomato texture and colour under ambient conditions. In a study by Mohammed et al. (2022). The combination of 400 ppm $KMnO_4$ with a negative pressure of 50 kPa was the most effective in maintaining tomato quality (Muhammad et al., 2023). However, the results of Wabali and Esiri (2021) showed that only 5 ppm $KMnO_4$ (i.e. 0.0005% potassium permanagante) resulted in an acceptable quality in terms of colour and texture under ambient condition. Although several previous studies (Arthur et al., 2015; Semida et al., 2019; Romanazzi et al., 2017) have shown promising results for the effects of potssaium permanganate in preserving the qualities of tomato fruits, there is a need for future research to focus on assessing the toxicity and risk concerns raised on potassium permangante in some studies that examined their effects on fruit flavour (Wabali et al., 2017).

Table 3. Effects of potassium permanganate on the postharvest qualities of tomato fruits.

Fruit (s)	Treatment	Effects	Reference
Tomato	Potassium permanganate concentration (saturated)	Titratable acidity decreased over time, with 400 ppm Potassium permanganate exhibiting the highest acidity.	Mujtaba and Masud (2014)
Tomato	KMnO4-based ethylene scavenger	The use of KMnO4-based technology remains limited at a commercial scale due to uncertainty about its potential as an effective postharvest tool and concerns related to health, environment, and safety.	Alvarez-Hernandez et al. (2019)
Tomato	KMnO4 (2.5 ppm, 5.0 ppm, 7.5 ppm, 10.0 ppm, 12.5 ppm and 15.0 ppm)	5.0 ppm was more effective in preserving tomato texture and colour under ambient condition	Wabali and Esiri (2021)
Tomato	400 ppm of KMnO4; Hypobaric pressures (40 kPa or 50 kPa); A combination of KMnO4 with 40 kPa or 50 kPa hypobaric pressure	The combination of 400 ppm KMnO4 with 50 kPa hypobaric pressure was most effective in preserving tomato quality.	Muhammad et al. (2023)
Tomato (hybrid 65010)	pre-harvest foliar application of Calcium chloride levels (0.0%, 0.2%, 0.4%); Potassium thiosulfate levels (0.0%, 0.2%, 0.4%) on storage qualities of tomato	Calcium chloride at 0.4% × Potassium thiosulfate at 0.4% had the best effect on the storage qualities of tomato	Semida et al. (2019)
Tomato	Potassium permanganate (6.4 g/100 mL) at 20°C for varying times (between 3 min and 6 h). The sachets in the packaging contained 1 and 2 grams of the prepared ethylene absorber.	the group with ethylene absorbers experienced delayed mould growth compared to the group without an absorber	Dobrucka et al. (2017)

Relative performance of biochemical treatments on tomato qualities

Various studies have examined the relative influence of different treatments on maintaining the quality of harvested tomatoes (Table 4). A study by Bal et al. (2018) focused on the effect of chitosan and calcium chloride, while other researchers (Shalini et al., 2018; Shehata et al., 2021) examined chitosan and potassium permanganate. Mujtaba and Masud (2014) aimed to improve the post-harvest storage life of tomato fruit by using treatments with Calcium chloride ($CaCl_2$). They compared various concentrations of $CaCl_2$ (1%, 2%, and 3%) to assess their impact on the quality of tomato fruit during storage. The findings showed that using a 2% $CaCl_2$ solution, packed with a ventilated 0.6 mm polyethylene cover, was highly effective in minimizing storage losses and preserving the quality of the produce. Additionally, the study revealed that both storage intervals and treatments significantly influenced the quality parameters of the tomato fruits. In conclusion, the study suggested that $CaCl_2$ treatments could mitigate economic losses of perishable fruits and promote sustainable agriculture practices. Furthermore, it observed that storage duration generally led to increases in pH, titratable acidity, weight loss, ascorbic acid, total sugar, and lycopene content, while the total soluble solids (TSS) remained constant throughout the storage period.

Semida et al. (2019) found that preharvest calcium chloride as well as potassium thiosulfate at 0.2% and/or 0.4% increased total titratable acidity, vitamin C, total soluble sugar, lycopene, and firmness content of the fruit. However, there were limitations with potassium permanganate ($KMnO_4$). Due to high toxicity and insufficient long-term effectiveness at high humidity (Gaikwad et al., 2020). In a related study on tomato fruits, 2% $CaCl_2$ + $KMnO_4$ was the most effective and the shelf life of tomatoes was up to 40 days without quality and phytochemical deterioration (Zakriya et al., 2023). But in another study on tomato fruits, the following treatments were used: Palladium-enhanced nano-zeolite (0%, 1%, 2.5%, 5%); $KMnO_4$-promoted Nano zeolite (0%, 10%, 15%, 20%); 1-MCP (1-methylcyclopropene) at 30 ppm; $CaCl_2$ (Calcium chloride) (0%, 1%, 1.5%, 2%); Salicylic acid (SA): 0% (control), 0.1%, 0.5%, 1% 6. UV-C (ultraviolet-C): 0 min (control), 5 min, 10 min, 15 Min., Mansourbahmani et al. (2018) found that palladium-promoted nano-zeolite at 5% was the most effective treatment for postharvest qualities of tomatoes. When comparing the effectiveness of chitosan, calcium chloride, potassium permanganate and Boric acid, Mujtaba and Masud (2014) found that a combination of 2% calcium chloride and 800 ppm boric acid was effective in maintaining pH, titratable acidity, lycopene and β-carotene. In a similar study on tomato fruits using the following treatments: 2% $CaCl_2$ and $KMnO_4$, 1 mM salicylic acid and $KMnO_4$, 2% $CaCl_2$ and $K_2Cr_2O_7$, 1 mM salicylic acid and $K_2Cr_2O_7$, Zakriya et al. (2023) found that 2% $CaCl_2$ and 50 g $KMnO_4$ significantly reduced weight loss and titratable acidity and extended the shelf life of tomatoes up to 40 days without deteriorating quality or secondary plant substances.

When generally assessing the performance of ethylene scavengers on fruits and vegetables, Vermeiren et al. (1999) found that C_2H_4 scavengers may not yet be very successful, possibly due to insufficient adsorption capacity. $KMnO_4$-based products are limited to sachets due to the toxicity of $KMnO_4$. A review by Arah et al. (2016) found that chitosan (0.5%) had a positive effect on total soluble solids (TSS), firmness, hue angle, and weight loss. Cinnamic acid (2 mM) influenced firmness, weight loss and TSS value of tomato fruits (Dladla & Workneh, 2023; Mior-Azmai et al., 2019).

Table 4. Comparison of the efficacy of calcium chloride, potassium permanganate and chitosan on the postharvest qualities of tomato fruits.

Fruit (s)	Treatment	Effects	Reference
Tomato	Potassium permanganate applied as sachets and polymeric films	limitations of Potassium permanganate (KMnO4) due to high toxicity and inadequate long-term effectiveness in high moisture conditions	Gaikwad et al. (2020)
Tomato (hybrid 65010)	Pre-harvest foliar application of Calcium chloride (0.0%, 0.2%, and 0.4%) and Potassium thiosulfate at (0.0%, 0.2%, and 0.4%)	pre-harvest foliar Calcium chloride or Potassium thiosulfate at 0.2% and/or 0.4% increased fruit total titratable acidity, vitamin C, total soluble sugars, lycopene, and firmness contents	Semida et al. (2019)
Tomato	Palladium-promoted nano zeolite (0%, 1%, 2.5%, 5%); KMnO4-promoted nano zeolite (0%, 10%, 15%, 20%); 1-MCP (1-methyl-cyclopropene) @30 ppm; CaCl2 (Calcium chloride) (0%, 1%, 1.5%, 2%); Salicylic acid (SA): 0% (control), 0.1%, 0.5%, 1% 6. UV-C (ultraviolet-C): 0 min (control), 5 min, 10 min, 15 min	Palladium-promoted nano zeolite at 5% was the most effective treatment for the postharvest qualities of tomato.	Mansourbahmani et al. (2017)
Tomato	Calcium chloride concentrations (1%, 2%); Boric acid concentrations(400 ppm, 800 ppm); Potassium permanganate concentration (Saturated)	2% Calcium chloride and 800 ppm boric acid were effective in maintaining pH, titratable acidity, lycopene, and β-carotene.	Mujtaba and Masud (2014)
Tomato	2% CaCl2 and KMnO4 1mM salicylic acid and KMnO4 2% CaCl2 and K2Cr2O7 1 mM salicylic acid and K2Cr2O7	2% CaCl2 and 50 g KMnO4 significantly reduced weight loss and titrable acidity and extended tomato shelf life to up to 40 days with no quality or phytochemicals deterioration.	Zakriya et al. (2023)
Fruits and vegetables	KMnO4 (4 - 6%) Charcoal + PdCl Mineral packaging films (zeolites, clays, and Japanese Oya)	C2H4 scavengers are noted as not yet very successful, potentially due to insufficient adsorbing capacity. Products based on KMnO4 are limited to sachets due to the toxicity of KMnO4	Vermeiren et al. (1999)
Tomato (cv. 'Ruchi 618').	500 ml of Aloe vera-based coating with 0.3% antioxidant-rich herb, a thickening agent (20 g), glycerol (2%), oleic acid (3 ml), cinnamaldehyde (0.2 ml)	Coated tomatoes indicated a longer shelf life (39 days) than the control group (19 days).On the 20th day of storage, weight loss was 7.6% and 15.1% for the coated and control groups, while firmness value was 36 N for control and 46.2 N for coated tomatoes.	Athmaselvi et al. (2013)
Tomato	Chitosan coating at 0.5% Cinnamic acid coating at 2mM	Chitosan (0.5%) positively impacted total soluble solids (TSS), firmness, hue angle, and weight loss. Cinnamic acid (2mM) influenced firmness, weight loss, and TSS value.	Tonna et al. (2016)

CONCLUSION AND RECOMMENDATION

This review highlights some biochemical treatments for tomato preservation and recognizes their potential to reduce postharvest losses. Treatments studied include calcium chloride, chitosan coating, and potassium permanganate solution. The review found that the choice of treatment depends on several factors, such as tomato variety, concentration, storage conditions, ripeness and method of application. More so, the selection of treatments should be context-specific and tailored to individual needs and limitations.

There is a need for future research to explore treatment combinations considering the synergies between calcium chloride, chitosan and potassium permanganate. It will be crucial to study how different tomato varieties respond to treatments and to assess the ecological impact of synthetic chemicals such as potassium permanganate. In addition, consumer studies, safety protocols, innovative application methods and advanced analytical techniques should be prioritized to improve preservation methods and deliver high-quality tomatoes to consumers.

Declaration of interest

The authors declare that there is no conflict of interest.

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