

Preservation of Fresh Tomatoes using Biochemical Treatments: A Systematic Review

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Abstract: This systematic review investigates the efficacy of diverse postharvest interventions, including potassium permanganate (KMnO₄), calcium chloride (CaCl₂), and chitosan coatings, in prolonging the shelf life and quality of tomatoes. Employing Boolean operators for literature mapping, the following search queries were utilized: "Chitosan coating AND tomato preservation," "Calcium chloride AND tomato preservation," and "Potassium permanganate AND tomato preservation." Additionally, other search terms encompassed: Efficacy OR Benefits OR performance AND Limitation OR challenge OR Health implication of Chitosan OR Calcium Chloride OR Potassium permanganate on post-harvest attributes OR shelf-life of tomato fruit. After the literature search, 274 scholarly articles were identified, with 73 articles being incorporated into the review. The investigations underscore the potential of these treatments to maintain texture, colour, firmness, and overall quality; however, notable variability in outcomes is attributed to variables such as concentration, application techniques, ripeness at the time of treatment, and storage conditions. KMnO₄ has exhibited promise as an ethylene absorber, yet elevated concentrations may adversely affect lycopene levels and texture. CaCl₂ has proven effective in preserving firmness and augmenting shelf life, although its influence on flavour and texture necessitates scrutiny. Chitosan coatings, particularly in conjunction with natural compounds, have shown promise in tomato preservation, albeit optimal concentrations and methodologies remain ambiguous. While these interventions present valuable approaches for postharvest management, additional research is imperative to standardize protocols, enhance efficacy, and address issues about safety, environmental ramifications, and the interactions among multiple treatments.

Keywords: Tomato, Chitosan, Calcium, Permanganate, Preservation

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1 Introduction

The global demand for tomatoes has been increasing steadily due to the growing awareness of their health and medicinal benefits. This, coupled with the increase in human population, has led to a rise in global tomato production. In the year 2020, as

documented by the Food and Agricultural Organization, global tomato production was estimated to be 186.821 million metric tonnes (FAO, 2022), and it is projected to increase by 50% by the year 2050 (Stratton et al., 2016). However, despite this growth, excessive postharvest losses of tomatoes continue to pose a significant challenge to food security, globally.

Postharvest losses in fresh fruits and vegetables, including tomatoes, have been estimated to range between 15% to 50% (Hailu and Derbew, 2015; FAO, 2022; Balana et al., 2022), with developing countries

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experiencing higher levels of postharvest loss (35%-50%) (Nnoli et al., 2024; Ogedengbe et al., 2022) compared to developed countries (less than 15%) (Arah et al., 2015; Saeed and Khan, 2010). Postharvest losses of tomatoes have a direct impact on the income of farmers and traders (Hailu and Derbew, 2015). Farmers lose money when their tomatoes are lost after harvest, and traders lose money when tomatoes are lost in the supply chain. This can lead to financial hardship and difficulty repaying loans (Dandago et al., 2021).

Postharvest losses of tomatoes can also harm the national economy, as they reduce the availability of food and lead to higher prices for consumers (Hailu and Derbew, 2015). Consequently, tomato postharvest loss can also reduce the availability of jobs in the agricultural and food processing sectors (Sibomana et al., 2016). More so, tomato postharvest loss has been documented to exert a negative impact on the environment (Zewdie et al., 2021); as tomatoes decompose they release methane, a greenhouse gas that contributes to climate change as well as wastages of water, fertilizer, and other resources that were used to produce the tomatoes (Kefas et al., 2024).

Consequently, there has been a growing interest in researching the causes of these losses and implementing mitigation measures over the past few decades (Dandago et al., 2021; Kefas et al., 2024; Elik et al., 2019; Zewdie et al., 2021). Many studies have suggested a wide range of mitigation measures against the postharvest loss. One of the most commonly employed approaches was to use hot-water dip for a short period (Anyasi et al., 2016; El Ghaouth et al., 1992; Kumar et al., 2017).

Other approach involved the usage of chemical treatments such as organic acids (e.g. citric acid and lactic acid) (Gharezi et al., 2012; Mekawi et al., 2019; Kader, 2003) as well as essential oils (Mekawi et al., 2019; Abdolahi et al., 2010) as well as biological coatings (Chitosan, Aloe-Vera and Moringa) (Athmaselvi et al., 2013; Ragab et al., 2019; Riaie et al., 2017; Tesfay and Magwaza, 2017; Zhu et al., 2008) to reduce the impact of microbial organisms on

tomatoes. However, the results of these studies have been inconsistent, and it is still challenging to identify the most effective biochemical treatment. This review examines the most commonly used biochemical treatments for tomatoes, to understand their relative effectiveness and the benefits and challenges of using them.

2 Methodology for literature mapping and article inclusion criteria

A comprehensive search was executed on July 14, 2023, utilizing the Google Scholar database. The application of Boolean operators facilitated the mapping of literature with the following search phrases: "Chitosan coating AND tomato preservation," "Calcium chloride AND tomato preservation," and "Potassium permanganate AND tomato preservation." Only those documents aligning wholly or partially with the search phrases were considered, resulting in an initial retrieval of 274 documents. Earlier, search parameters were subsequently refined by restricting the publication years to the range of 1995 to 2023, which produced a total of 105 documents, encompassing conference proceedings, published articles, reports, as well as theses and dissertations.

A further search was conducted on November 24, 2024, employing the search terms "Efficacy OR Benefits OR performance AND Limitation OR challenge OR Health implication of Chitosan OR Calcium Chloride OR Potassium permanganate on post-harvest qualities OR shelf-life of tomato fruit."

The literature identified in the initial search (conducted on July 14, 2023) was integrated with that acquired on November 24, 2024, into an Excel Spreadsheet, where duplicate records were detected and expunged. This process culminated in the selection of approximately 73 articles for inclusion in the review.

3 Results and discussion

3.1 Chitosan effects

Several scientific investigations have

meticulously examined the effectiveness and overall efficacy of coatings derived from chitosan in the context of preserving the quality of tomatoes after harvest and prolonging their edible shelf life. Chitosan, which is a naturally occurring polysaccharide extracted from the shells of crustaceans, has attracted considerable attention in the scientific community due to its multitude of advantageous properties, which include notable antimicrobial activities, robust antioxidant capabilities, and superior moisture-retention characteristics, thereby positioning it as a highly promising candidate for the preservation of various fruits, including tomatoes (Salehi, 2020).

Extensive research has been conducted on the use of chitosan for preserving harvested tomatoes and other fresh horticultural products. Chitosan, a natural polysaccharide derived from crustacean shells, boasts various properties, including antimicrobial, antioxidant, and moisture retention capabilities (Salehi, 2020). Xing et al. (2016) demonstrated that coatings based on chitosan effectively enhance the storage quality, microbial safety, and shelf life of fruits and vegetables.

A review by Firdous (2021) focusing on the extension of tomato shelf life in Pakistan through edible coatings concluded that coatings are indeed a practical method for prolonging tomato shelf life. Zain (2009) found that combining chitosan with cinnamic acid is an effective method for extending the shelf life of tomatoes by up to 14 days. However, this review has uncovered several factors affecting the efficiency of chitosan coatings in preserving harvested tomatoes. These factors include the concentration of chitosan (El Ghaouth et al., 1992; Canché-López et al., 2023), the specific tomato cultivar used (Eroğul et al., 2023), storage temperature (Chutichudet and Chutichudet, 2014), and the method of application (Lopez-Polo et al., 2021).

Concerning chitosan concentration, studies have explored concentrations ranging from 0.1% to 2% in preserving tomato quality and shelf life (Meenu et al.,

2023). While 0.5% chitosan was effective in maintaining fruit colour, reducing weight loss, and extending shelf life (El Ghaouth et al., 1992; Salehi, 2020), other research indicated that 1% chitosan was the most effective concentration for these functions (Canché-López et al., 2023; Lopez-Polo et al., 2021). However, Chutichudet and Chutichudet (2014) found that even a 1% chitosan coating did not have a significant effect in preserving the postharvest qualities of tomato fruits after harvest.

In a similar vein, Taher and Elsherbiny (2023) conducted an experiment that investigated the combination of isonicotinic acid (INA), chitosan, and polyvinyl alcohol (PVA) on green tomatoes subjected to ambient room temperature conditions, yielding noteworthy results. Their comprehensive analysis indicated that formulations containing 0.5 mM and 1.0 mM concentrations of CS/PVA/INA were particularly effective in preserving the firmness of the tomatoes while simultaneously delaying undesirable changes in colour and acidity levels. Nonetheless, it is crucial to note that certain inconsistencies emerge when one attempts to compare these findings with other studies that have tested chitosan at varying concentrations or in combination with other chemical compounds.

In a separate investigation focusing on the efficacy of chitosan with strawberries, apples, sweet cherries, grapes, and Indian jujube, Duan and Zhang (2013) highlighted chitosan's insufficient microbial inhibitory capabilities; it remains unclear whether these conclusions can be applied to tomato fruits. Furthermore, the structure of chitosan coatings may not adequately modify the permeability of gases such as carbon dioxide and oxygen (Duan and Zhang, 2013). Moreover, the elevated water vapour permeability rate could restrict its utilization in edible coatings and films, as the risk of moisture loss in coated produce may adversely influence the quality of chitosan-treated fruits and vegetables (Zhang et al., 2021).

In another significant investigation, Zhu et al. (2024) focused their research on chitosan films that

were reinforced with lignosulfonate (LS) specifically for the preservation of cherry tomatoes and discovered that the incorporation of a 2% lignosulfonate addition led to a remarkable enhancement in various parameters, including water vapour permeability, ultraviolet (UV) shielding capabilities, fruit hardness, and a notable reduction in weight loss after a storage duration of two weeks. This finding stands in contrast to other studies that implemented lower concentrations of chitosan, where some level of efficacy was still observable, albeit the observed improvements were considerably less pronounced. Additionally, another study conducted by Taher et al. (2024) demonstrated the effectiveness of composite coatings made from chitosan, gum arabic (GA), and methyl salicylate (MeSA) in preserving ripening tomatoes, with the 1 mM CS/GA-MeSA formulation yielding the most promising outcomes in terms of maintaining both firmness and titratable acidity levels. However, it is important to acknowledge that such formulations raise interesting questions regarding the potential synergistic effects of the added compounds and whether chitosan alone would have achieved comparable levels of effectiveness in preserving the quality of tomatoes.

While the potential of chitosan as an effective preservative is extensively documented and supported by various scientific literature, ongoing disagreements and debates remain prevalent within the academic community regarding the optimal concentration necessary to achieve maximum effectiveness in its preservative capabilities. Recent studies conducted by Meenu et al. (2023) and Tafi et al. (2023) have elucidated that concentrations as low as 0.5% to 1% of chitosan were indeed sufficient to preserve the quality of tomatoes, with the 2% chitosan treatment identified in the research by Meenu et al. (2023) being particularly effective in minimizing weight loss, maintaining the titratable acidity of the tomatoes, and decelerating the ripening process. Conversely, alternative research endeavours, such as those undertaken by Venkatachalam et al. (2024), which explored the incorporation of

cinnamon oil into chitosan coatings, illustrated that higher concentrations, specifically 1.0% and 1.5%, were found to be more effective in sustaining the quality of tomatoes and retaining essential phytochemicals. These contrasting findings serve to underscore a significant controversy within the field of food preservation: while higher concentrations of chitosan may exhibit enhanced effectiveness in certain scenarios, they do not categorically emerge as the universally superior option across all contexts. For instance, research conducted by El Ghaouth et al. (1992) and Chutichudet and Chutichudet (2014) demonstrated that even lower concentrations, such as 0.5% of chitosan, were capable of yielding beneficial effects in terms of reducing weight loss and preserving the overall quality of the fruit.

Compounding this ongoing debate, it is essential to recognize that the method of application employed in the utilization of chitosan also plays a pivotal role in determining the overall efficacy of chitosan-based treatments in food preservation. Investigative studies by Lopez-Polo et al. (2021) have convincingly shown that the incorporation of nanoparticles into chitosan coatings can significantly enhance the antimicrobial effectiveness of the treatment applied. However, it is noteworthy to mention that when chitosan is applied in isolation, its effectiveness may be notably diminished in comparison to when it is combined with other enhancing agents. This observation underscores the critical fact that, while the concentration of chitosan undoubtedly holds significant importance, its physical form and the method of application can substantially influence the outcomes observed in terms of preservation. For instance, research conducted by Ali et al. (2024) involved testing various formulations of chitosan-based coatings, including combinations such as Chitosan (CS), CS+Levan, and CS+Mucilage, applied to cocktail tomatoes that were subsequently stored under cold conditions. The findings indicated that the CS-MCLG-LVN coating emerged as the most effective formulation in minimizing weight loss and extending the overall shelf life of the tomatoes,

thereby emphasizing the notion that the formulation utilized is just as crucial as the concentration of chitosan itself. Nonetheless, the efficacy of chitosan may be affected by some factors such as the fact that encapsulation may lead to liposome instability over time (Lopez-Polo et al., 2021). More so, direct mixtures can alter coating properties and functionality. Again, limited knowledge of the health effects of chitosan coating exists, as well as the high cost of polymers and equipment for industrial use.

Furthermore, several studies have raised pertinent questions regarding the necessity and potential benefits of combining chitosan with other natural compounds to enhance its overall efficacy as a preservative. Umbayda et al. (2024) conducted a comprehensive investigation into the performance of chitosan in conjunction with macadamia nut oil, utilizing concentrations that ranged from 1% to 2.5%, as well as testing a composite formulation that involved mixing macadamia nut oil in the range of 1% to 2% with 1% (w/v) chitosan. In this experiment, tomato samples were subjected to storage conditions characterized by temperatures ranging from 23 to 30 degrees Celsius and relative humidity levels between 65% and 97.5% over a storage duration of 20 days, during which the effects of the specified treatments on the antioxidant and physical properties of the stored tomatoes were meticulously evaluated. The results of this study revealed that the application of macadamia nut oil could serve as a cost-effective and efficient pre-treatment method for tomato preservation; however, the specific contribution of chitosan to these positive outcomes remained less clear and thus warrants further investigation to elucidate its role in combination with other natural preservatives.

Tafi et al. (2023) undertook an extensive and meticulous evaluation designed to assess the efficacy and overall performance of Chitosan, a biopolymer that was isolated and derived from the pupal exuviae of the *Hermetia illucens* species, utilizing both heterogeneous and homogeneous deacetylation techniques, specifically employing concentrations of

0.5% and 1% chitosan in their experimental design. The methodologies for application that were utilized within the framework of this study encompassed both dipping and spraying techniques, while the samples of tomatoes were subjected to storage conditions that included ambient room temperature, in addition to a regulated temperature setting maintained at 4°C, all during a comprehensive observation period that extended over 30 days, with a concentrated focus on the preservation of the postharvest qualities that characterize tomatoes. The results that emerged from their research revealed a significant enhancement in the total phenolic content, levels of flavonoids, and overall antioxidant activity when the homogeneous form of chitosan was employed in the application process. Moreover, it was discerned that the chitosan coatings that were applied utilizing the spraying method exhibited a marked effectiveness across all the parameters that were analysed in the study. Interestingly, the chitosan that was sourced from *H. illucens* consistently demonstrated performance metrics that were quite comparable to those observed with commercially available chitosan products, indicating a potential equivalence in functional efficacy.

Nevertheless, a prevailing trend was documented which favoured the superior performance of insect-derived chitosan concerning the concentrations of phenolic compounds, flavonoids, and antioxidant activity, particularly when juxtaposed against its commercial counterparts, thus highlighting the potential advantages of using biopolymer sourced from insects.

In a related context, the comprehensive investigations undertaken by Imani and Danaee (2023), in conjunction with the research conducted by Jehani et al. (2023), have provided substantial evidence indicating that the synergistic incorporation of chitosan with various supplementary substances, which include but are not limited to Aloe Vera gel or the essential oils that are meticulously extracted from the peel of grapefruits, culminates in a pronounced enhancement of preservation efficacy. This

enhancement is notably manifested through several mechanisms, including the significant reduction of weight loss, the sustained retention of vitamin C content, and the preservation of antioxidant capacity, all of which are critical for maintaining the quality of perishable goods. These compelling and meticulously documented findings suggest that while chitosan, when used in isolation, possesses a remarkable ability to preserve the quality of tomatoes effectively, the introduction of other complementary compounds may potentially amplify these beneficial effects even further, even though the specific role which chitosan occupies within these multifaceted composite formulations frequently remains insufficiently delineated in the existing literature.

In a notable study conducted by Yu et al. (2023), researchers implemented composite coatings consisting of 1% chitosan and 1% Curdlan on cherry tomatoes, and their results provided significant insights into the treatment's effects. After a storage period of 21 days under ambient conditions, the findings revealed that the tomatoes which had been subjected to the chitosan and Curdlan treatment exhibited a marked reduction in levels of rotteness, minimized weight loss, and a decreased respiration rate. Additionally, these treated tomatoes were found to maintain enhanced firmness, elevated levels of soluble solids, increased vitamin C concentrations, higher lycopene content, and improved antioxidant activity, thereby substantiating the general effectiveness of chitosan-based treatments within the realm of postharvest fruit preservation. However, the study by Yu et al. (2023) raises questions about the exact mechanism through which composite coating exerts its preservative effects. More so, the study was conducted over 21 days of storage; the duration may not be sufficient to fully understand the long-term effects of chitosan coating.

Furthermore, it is noteworthy that while the application of chitosan coatings has been extensively documented to confer preservative benefits upon the post-harvest qualities of tomatoes, a critical examination conducted by Nair et al. (2020) has

illuminated certain limitations associated with the efficacy of essential oils (EOs) in safeguarding the post-harvest attributes of various fruits and vegetables. Their comprehensive study has revealed that essential oils are plagued by stability challenges within food packaging contexts; they tend to undergo degradation upon interaction with food components, which can compromise their effectiveness. Additionally, the inconsistencies and uneven disturbances introduced by these oils often lead to a decrease in their antimicrobial activity, thereby undermining their potential as reliable preservative agents in the realm of post-harvest technology.

Even in light of the promising attributes associated with the application of chitosan, several concerns regarding its broader application within food preservation contexts continue to be a subject of discussion within the academic community. Research studies have indicated that, while chitosan coatings can indeed serve as effective agents for the preservation of postharvest quality, there exist potential drawbacks which merit consideration, such as the emergence of off-flavours and the possibility of allergic reactions among consumers (Noh, 2005; Duan et al., 2019). Another setback to the application of chitosan is seen in a study by Shiekh et al. (2013), who revealed that the high viscosity of chitosan limits its application, and more so the low solubility of chitosan at neutral PH affects its effectiveness.

The identified issues could pose significant limitations on the widespread adoption of chitosan-based coatings within the food preservation industry. Moreover, there exists a pressing need for additional research aimed at addressing these controversies and uncertainties. In particular, there is a necessity for further empirical investigations that seek to ascertain the optimal conditions under which chitosan coatings may be applied, taking into account critical variables such as the specific cultivar of tomatoes, the conditions under which they are stored, and the various formulations of the coatings themselves.

3.2 Calcium chloride

The exploration and application of postharvest

treatments aimed at preserving the quality and prolonging the shelf life of tomatoes have been an area of extensive academic inquiry, particularly highlighting calcium chloride (CaCl_2) as one of the most frequently investigated chemical agents in this context. The literature extensively discusses the use of calcium chloride for preserving fresh fruits and vegetables. Magee et al. (2003) conducted a study examining concentrations of 0.1%, 0.2%, and 0.3%, concluding that 0.3% was the most effective concentration for improving firmness and shelf life. In 2019, Naveena and Immanuel found that a 3% (w/v) calcium chloride solution outperformed sodium chloride in improving firmness and shelf life. Daraghmah and Qubbaj (2021) studied the effects of postharvest applications of calcium chloride (CaCl_2) in combination with either 10% gum Arabic or 50% cactus mucilage on tomato fruit quality attributes. They found that the combination of CaCl_2 and 50% cactus mucilage was the most effective treatment for improving firmness and shelf life.

In the research conducted by Mahesh et al. (2023), a comprehensive evaluation was performed on a variety of treatments, which included not only different concentrations of calcium chloride but also gibberellic acid (GA_3) and sodium benzoate, to thoroughly assess their individual and collective impacts on the postharvest qualities of tomatoes. The results of their extensive investigation revealed that tomatoes treated with a concentration of 3% GA_3 exhibited the longest shelf life duration, which was determined to be an impressive 31.33 days, followed closely by those subjected to a 1% GA_3 treatment, which lasted for 27 days, and 4% CaCl_2 -treated tomatoes, which maintained quality for 22 days, while it was noteworthy that the control group, which did not receive any treatment, demonstrated a significantly shorter shelf life of only 15.67 days.

Furthermore, the incidence of diseases was observed to be highest within the 3% GA_3 group, with a recorded duration of 32.33 days, followed by the 1% GA_3 treatment at 28.33 days and the 4% CaCl_2 treatment at 23 days. Nevertheless, it is crucial

to highlight that the fruits treated with the 3% GA_3 solution exhibited the least amount of physical weight loss, thereby underscoring the differential effects that varying concentrations of these treatments can have on the multitude of quality parameters associated with tomato preservation. When examining other quality metrics, such as acidity, total soluble solids (TSS), and pH, significant enhancements were observed in the treated fruits relative to those in the control group, which emphasizes the favourable influence of GA_3 when compared to CaCl_2 in these particular aspects.

In light of these promising results, it is important to acknowledge that the existing body of literature is rife with various controversies and conflicting perspectives regarding the actual effectiveness of calcium chloride as a preservative for maintaining tomato quality over time. Earlier studies, such as the one conducted by Workneh and Hussein (2023), indicated that even low concentrations of CaCl_2 , specifically at 100 parts per million (ppm), were capable of enhancing the quality of tomatoes significantly. Building upon this foundational research, Magee et al. (2003) undertook a more extensive investigation that involved testing a range of concentrations (0.1%, 0.2%, and 0.3%) of CaCl_2 and ultimately concluded that a concentration of 0.3% CaCl_2 was the most effective in terms of improving the firmness and shelf life of the tomatoes.

However, it is essential to note that other studies have yielded mixed outcomes, contributing to the ongoing debate. For instance, Naveena and Immanuel (2019) reported that a concentration of 3% CaCl_2 was found to be more effective than sodium chloride in enhancing both firmness and shelf life, while several other studies have suggested that the optimal concentration of CaCl_2 may need to be specifically tailored to accommodate the unique characteristics of different tomato varieties as well as varying storage conditions. An illustrative example of this complexity can be found in the work of Praba et al. (2007), who indicated that while treatments involving CaCl_2 generally resulted in improved firmness, they could simultaneously lead to a reduction in the soluble

solids content, which could negatively impact the flavour profile of the tomatoes in question. This revelation raises significant questions regarding the potential trade-offs that exist between enhanced physical quality and the potential adverse effects on the sensory attributes, particularly taste, of the treated fruits. Certain investigations have indicated the necessity for prudence concerning the duration of calcium chloride application on fruits to avert adverse outcomes, as demonstrated in a study conducted by Arthur (2014). While acknowledging the advantageous effects of administering calcium chloride at concentrations of 0, 2%, and 6% via a dipping methodology for varied durations of 10, 20, and 30 minutes, the author warned that extending the dipping duration beyond 40 minutes could lead to negative repercussions on the fruit's epidermis, particularly in tomatoes. This underscores the imperative for meticulous consideration of application durations within postharvest treatment frameworks.

Nuhu and Zarami (2023) conducted a comprehensive investigation into the effects that varying concentrations of calcium chloride (CaCl_2), specifically ranging from 2% to 6%, had on four distinct tomato varieties, namely ROMA, UTC, IFE, and RUKUTA, to ascertain the optimal concentration for enhancing the quality of these tomatoes. The findings from their study indicated that a concentration of 4% CaCl_2 emerged as the most efficacious treatment overall; however, it was also evident that the results displayed a degree of variability that was contingent upon the specific tomato variety being examined. Among the varieties tested, UTC exhibited the most significant weight loss, quantified at 13.019 grams, while the ROMA variety demonstrated the least weight loss, which was recorded at 4.022 grams, thereby underscoring the critical influence that the choice of tomato variety can exert on the overall effectiveness of the CaCl_2 treatments administered, sometimes leading to outcomes that appear to be contradictory. Furthermore, it was noted that RUKUTA displayed

the most pronounced changes in texture, whereas IFE exhibited the least amount of textural alteration, which further emphasizes the differing impacts that calcium chloride can have on the texture of various tomato cultivars.

In a highly relevant and methodologically rigorous investigation carried out by Zakriya et al. (2023), the researchers undertook an extensive and thorough exploration aimed at understanding the synergistic effects that emerge from the combination of calcium chloride with a range of other chemical agents, particularly focusing on potassium permanganate (KMnO_4), with the clearly defined objective of assessing the resultant implications that such combinations have on the quality attributes that are associated with tomatoes. The findings that were meticulously derived from their comprehensive research indicated that the particular amalgamation of 2% CaCl_2 and KMnO_4 was remarkably effective, resulting in a significant prolongation of the shelf life of tomatoes, achieving an impressive duration of up to 40 days during which no observable deterioration in quality was noted, thereby surpassing the efficacy of other chemical combinations that had undergone rigorous testing within the scope of the study. Nevertheless, while this specific mixture demonstrated a noteworthy level of effectiveness in preserving the quality of tomatoes, it inevitably gives rise to substantial inquiries regarding the potential effectiveness of applying CaCl_2 in isolation, which leads to the essential question of whether such an application could yield results that are comparable, or whether the inclusion of additional chemical agents is indeed critical for the overarching aim of extending shelf life and ensuring compliance with established quality standards. Furthermore, the performance of potassium permanganate in maintaining the postharvest qualities of tomatoes, as well as other fruits and vegetables, is known to vary considerably depending on the specific concentration utilized, with some concentrations potentially failing to offer any discernible benefits (Gaikwad et al., 2020; Wabali and Esiri, 2021; Mazumder et al., 2021).

Furthermore, a separate study authored by Arthur (2014) underscored the considerable toxicity risks that are inherently linked to the utilization of potassium permanganate as a preservative agent for fruits and vegetables, especially with the risks of potassium permanganate migrating into fruit tissues as this may pose potential health challenges (Fatima et al., 2023); thereby accentuating the necessity for a careful evaluation of the safety implications associated with such chemical interventions in food preservation practices.

In studies that have involved the implementation of zero-energy cooling chambers (ZECC), it was observed that tomatoes that had been treated with a 6% concentration of CaCl_2 during the turning colour stage and subsequently stored in ZECC exhibited the highest degree of firmness, alongside the lowest occurrences of weight loss, decay, and total soluble solids (TSS), with a measurement of 4.40 Brix. Although the storage conditions provided by ZECC proved to be beneficial for the preservation of tomato quality, this particular experiment serves to highlight the critical importance of effectively combining the appropriate postharvest treatments with suitable storage methodologies to optimize the preservation of quality. The observed variations in findings related to different storage methods, specifically contrasting ambient conditions with ZECC, suggest that the environmental conditions under which the tomatoes are stored are as crucial as the treatments applied in determining the overall success of calcium chloride in maintaining the quality of the tomatoes.

In their research, Dhama et al. (2023) investigated a range of postharvest treatments, which included 1.5% CaCl_2 , 0.1% gibberellic acid (GA_3), aloe vera gel, and neem leaf extract, specifically focusing on their efficacy concerning the *Heemsohna* tomato variety. Their findings revealed that tomatoes subjected to treatment with 1.5% CaCl_2 exhibited the longest shelf life of 21 days, coupled with the lowest percentage of decay observed among the treatments evaluated. However, the research also highlighted the noteworthy effectiveness of alternative treatments

such as aloe vera gel and neem leaf extract, which demonstrated performance levels comparable to that of CaCl_2 in delaying decay and extending the shelf life of the tomatoes. This observation suggests that, while calcium chloride is indeed an effective treatment option, other alternatives may provide similar advantages, indicating that the selection of a particular treatment should be guided by the specific needs and conditions relevant to the situation at hand.

Compounding the complexity of this discourse, the research conducted by Beckles (2012) revealed that the application of CaCl_2 treatment could lead to an increase in the pH levels of tomatoes, which, in certain instances, may ultimately result in a reduction of shelf life. This particular finding presents a stark contrast to other research studies that have proposed that CaCl_2 can indeed be beneficial in maintaining the quality of tomatoes, especially by mitigating the rates of decay and minimizing weight loss. The existence of these inconsistencies within the literature suggests that the effects of calcium chloride are not always straightforward and can exhibit considerable variability based on a multitude of factors, including the specific concentration employed, the variety of tomatoes being tested, as well as the particular storage conditions to which the tomatoes are subjected.

3.3 Potassium permanganate

Potassium permanganate, scientifically denoted as KMnO_4 , has increasingly come to the forefront of research focused on the postharvest preservation of tomatoes, primarily due to its recognized function as an ethylene scavenger, which effectively inhibits the ripening process and significantly prolongs the shelf life of this widely consumed fruit. Researchers actively employ Potassium permanganate (KMnO_4) in the preservation of a wide range of fresh horticultural materials, as indicated by various studies (Anyasi et al., 2016; Bal, 2018; Wabali and Esiri, 2021) and have investigated varying levels of KMnO_4 , ranging from 2-5 ppm (Anyasi et al., 2016; Bal, 2018), 5-10 ppm (Dobrucka et al., 2017; Wabali and Esiri, 2021), 10-20 ppm (Hernando et al., 2019;

Ragab et al., 2019), to 20-400 ppm (Köstekli et al., 2016).

Fatima et al. (2023) examined the effectiveness of potassium permanganate on the quality parameters of colour and texture under ambient storage conditions in extending the shelf life of tomatoes. 50 g each of mature unripe tomato fruits were weighed into a plastic container containing different concentrations of potassium permanganate (2.5 ppm, 5.0 ppm, 7.5 ppm, 10.0 ppm, 12.5 ppm and 15.0 ppm) and the control treatment. Their findings revealed that a concentration of 5 ppm of KMnO_4 showed a higher or acceptable quality in terms of colour and texture. While longer shelf life was shown by 7.5 ppm of KMnO_4 under ambient conditions and it kept the tomatoes in an acceptable quality for 11 days. Moreover, Mansourbahmani et al. (2018), Nassarawa and Salamatu (2019), and Wabali et al. (2017) found that 0.5% (50 ppm) of KMnO_4 was the most effective level for delaying ripening, inhibiting ethylene generation, and maintaining fruit firmness in tomatoes. On the other hand, other researchers (Köstekli et al., 2016; Ragab et al., 2019; Shaukat et al., 2023) reported that 0.1% (100 ppm) of KMnO_4 was the most effective level for preserving tomato postharvest quality.

To illustrate the performance of a combination of chitosan and other chemical pre-treatments on tomato post-harvest qualities, Hayat et al. (2014) conducted an investigation that yielded positive outcomes when utilizing a specific combination of 2% calcium chloride and 800 ppm of boric acid, which they suggested was particularly effective in prolonging the shelf life of tomatoes while simultaneously preserving their functional attributes, such as texture and flavour. In a similar vein, Khalid et al. (2023) discovered that the strategic application of 50 kPa hypobaric pressure combined with 400 ppm of KMnO_4 resulted in the maintenance of superior quality in tomatoes over a storage duration of 21 days, thus supporting the notion that KMnO_4 can effectively preserve quality when utilized under precise and controlled conditions. However, a

contrasting study conducted by Zakriya et al. (2023) introduces a level of scepticism regarding the interaction dynamics between KMnO_4 and other chemical agents, as their findings suggested that combinations of KMnO_4 with salicylic acid and chromium salts were not as effective, particularly in the preservation of vital compounds such as lycopene and phenolic content, which are crucial for the nutritional value of tomatoes. This notable discrepancy draws attention to the intricate chemical interactions at play and underscores the challenges inherent in pinpointing the most effective chemical combinations for postharvest preservation endeavours.

In a comprehensive investigation, Muhie et al. (2023) explored the efficacy of KMnO_4 when used in conjunction with polyethene bags, finding that this combination proved beneficial in enhancing the quality of tomatoes throughout the storage process. However, the implications of varying KMnO_4 concentrations regarding their effectiveness were met with scepticism, as conflicting reports emerged from Umeohia and Olapade (2024), who specifically tested KMnO_4 at a concentration of 3 g L^{-1} . Their research indicated that KMnO_4 was instrumental in diminishing the increase of reducing sugars while stabilizing pH levels, particularly in fully ripened tomatoes, highlighting the critical roles that both concentration and the stage of ripeness play as influential variables in the preservation of tomato quality. Conversely, other studies did not yield similarly clear-cut results regarding the impacts of KMnO_4 at these concentrations, thus emphasizing the inherent variability in the effects of KMnO_4 on tomatoes at different maturity stages.

Fatima et al. (2023) provided compelling evidence that a KMnO_4 concentration of 5 ppm was effective in maintaining acceptable levels of colour and texture, while a slightly higher concentration of 7.5 ppm was shown to extend the shelf life of tomatoes by as much as 11 days, demonstrating the potential benefits of using KMnO_4 appropriately. However, contrasting findings from Anyasi et al. (2016) revealed that there were no significant

enhancements in quality beyond a concentration of 5 ppm, suggesting that higher concentrations may not always yield additional advantages, thereby prompting an essential discourse regarding the threshold concentration of KMnO_4 that is necessary to optimize its beneficial effects without inadvertently causing adverse changes in flavour or texture.

Moreover, the existing literature reveals a range of divergent results on the methodologies employed in the application of KMnO_4 . Dobrucka et al. (2017) concluded that immersing tomatoes in KMnO_4 was a more effective approach for delaying the ripening process when compared to spraying the chemical onto the surface of the tomatoes. In stark contrast, Bal (2018) contested this assertion by finding that the method of application did not appear to have any substantial effect on the efficacy of KMnO_4 in preserving tomato quality. These conflicting findings serve to complicate the establishment of a standardized application protocol, thereby highlighting the urgent necessity for further research aimed at elucidating the role that various application techniques may play in determining the overall effectiveness of KMnO_4 as a postharvest preservative.

The timing of KMnO_4 application also presents an area of ongoing debate. Dobrucka et al. (2017) found that applying KMnO_4 shortly after harvest (within three days) was more effective than applying it later, which suggests that postharvest timing can influence the results. However, other studies, including those by Ragab et al. (2019), did not find significant differences in tomato quality between treatments applied at different harvest stages. This lack of consensus further complicates recommendations for optimal application timing.

One notable concern raised in the literature is the safety and environmental impact of KMnO_4 . While it is effective as an ethylene inhibitor and preservative, its use at high concentrations raises questions about its potential harm to tomato taste, texture, and overall consumer acceptance. Ragab et al. (2019) and Wabali and Esiri (2021) highlighted these concerns, noting that high concentrations of KMnO_4 might adversely

affect fruit quality, while others, such as Shaukat et al. (2023), argued that lower concentrations (5-10 ppm) maintain an acceptable balance between effectiveness and quality preservation. Moreover, KMnO_4 's environmental impact, particularly when used on a large scale in agriculture, has not been adequately addressed in the literature (Dobrucka et al., 2017). More so, it is essential to exercise caution when using KMnO_4 , as it is a potent oxidizing agent; as some studies have raised safety concerns about its impact on the taste and texture of tomatoes (Ragab et al., 2019; Wabali and Esiri, 2021).

4 Conclusion

The studies reviewed underscore the potential of various postharvest treatments, including potassium permanganate (KMnO_4), calcium chloride (CaCl_2), and chitosan coatings, to enhance the shelf life and quality of tomatoes. However, significant variability in results arises from factors such as concentration, application methods, storage conditions, and the presence of additional treatments. KMnO_4 , while effective in extending shelf life and preserving quality, shows mixed outcomes depending on concentration, application method, and storage conditions, with some studies noting reduced lycopene content or texture changes at higher concentrations.

Similarly, while CaCl_2 is widely recognized for improving firmness and shelf life, its effectiveness is influenced by concentration, tomato variety, and storage conditions, and its use may sometimes alter flavour or texture. Combining CaCl_2 with other treatments like KMnO_4 or cactus mucilage appears promising but requires further exploration.

Chitosan coatings also hold potential, particularly when combined with natural compounds, but inconsistencies in optimal concentrations and formulations remain a challenge. Overall, while these treatments show promise, more research is needed to standardize protocols, address safety concerns, and resolve conflicting findings to optimize postharvest management of tomatoes.

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