**The Effects of Acacia gums incorporated with gallic acid and clove oil on tomatoes quality stored in different storage conditions**

**1. ABSTRACT.**

Tomato (*Solanum lycopersicum*) is one of the most common vegetables cultivated worldwide for its fleshy fruits. It is among the perishable goods that require postharvest handling to reduce the losses during transportation and storage to retain quality before consumption or processing into various products. This research investigated the influence of postharvest treatments and storage on the quality of tomato fruits after harvesting. An experiment was conducted to study the effects of Acacia gums incorporated with gallic acid and clove oil when coated on the tomatoes and stored in different storage environments, Cold room (16⁰C), Refrigerator (8⁰C), and Ambient. Treatments were made from the solution of gallic acid, clove oil, and acacia gum, whereby acacia gum solution was prepared from 10%(w/v) acacia gum and 90% of distilled water, followed by warming at 40⁰C to dissolve acacia gum. Four hundred eighty tomatoes were then coated with four different treatment ratios of gallic acid, Clove oil, and Acacia gum solution mixtures in proportions of T1(0:0:100), T2(0.5:0.5:99), T3(1.0:1.0:97), and T4(1.5:1.5:97), respectively. Each treatment was applied to one hundred twenty tomatoes and left to dry at ambient temperature, followed by storage allocation. It was observed that lycopene contents, in cold room (16°C) storage, were T1(3.363±0.021) mg/100g, T4(3.038±0.009) mg/100g, T2(2.842±0.035) mg/100g, and T3(2.612±0.001) mg/100g, respectively. And β-carotene content in the tomatoes, were T2(0.821±0.007) mg/100g T1(0.954±0.007) mg/100g, T3(0.908±0.001) mg/100g, and T4(0.922±0.007) mg/100g, respectively. However, decay began at the 28th day of storage in the cold room, and treatments T2, T3 and T4 had low values of decay rate compared to treatment T1, having the values of T1(5.06±0.085%), T2(1.68±0.007%), T3(1.68±0.007%) and T4(1.68±0.007%) respectively. This indicated that the respiration rate was reduced compared to other treatments, which signified good treatment for tomatoes in a cold room for maintaining tomato quality and shelf-life extension.

*Keywords****:*** *β-Carotene, Decay percentage, Deformation, Lycopene, Postharvest treatment, Tomatoes, Texture.*

**2. INTRODUCTION**

Fresh or processed tomato (Solanum Lycopersicon) fruits are the commodities that are used worldwide (Thole et al., 2021). It is an important horticultural crop whose production by yield is second only to potatoes worldwide (Li et al., 2018). Small and large growers can easily cultivate tomatoes as a cash crop due to their short life cycles (90–120 days) and self-compatibility. Tomato varieties can be separated based on their various commercial uses into two categories: processing types, which are frequently field-grown for industrial purposes, and fresh market varieties, which are typically produced in greenhouses (Zsögön et al., 2017).

Tomatoes are an important source of vitamins A and C and antioxidants such as lycopene. In tomatoes and tomato products, color serves as a measure of total quality. Consumers notice color first, and their observations often supplement preconceived ideas about other quality attributes such as aroma and flavor. Color in tomatoes is due to carotenoids, a class of isoprenoid compounds varying from yellow to red (Marti et al., 2016).

Like many other crops, tomato plants and their harvested fruits are vulnerable to the effects of climate change. Tomato fruit production and ripening, including softening and the development of fruit color, flavor, and aroma, are significantly influenced by temperature. Climate change and efforts to cut energy and carbon emissions will probably impact tomato post-harvest storage and its quality toward the perception of the consumers (Thole et al., 2021)

As one of the perishable climacteric fruits, the tomato (*Solanum lycopersicum L*.) has a short postharvest life because of the numerous processes that lead to quality loss after harvest (Yadav et al., 2022). Transpiration, postharvest diseases, ripening, respiration, and senescence are some of the factors limiting storage life. Therefore, the quality of tomato fruits after harvest continuously alters due to the rapid rates of respiration and transpiration, fruit decay, and active metabolic processes, of which respiration is the main factor associated with tomato postharvest shelf life in tropical regions (Afedzi et al., 2022).

Keeping the fresh appearance of tomatoes long after harvest is the permanent challenge imposed by consumers. This has triggered the need to find a solution for maintaining the quality of tomatoes after harvesting by minimizing the rate of respiration, which is influenced by temperature.

Therefore, an economical and bio-based alternative is necessary for both prolonging the shelf life with less or no toxicity and keeping the production costs at a minimum. The utilization of both physical methods (ozone, electrolyzed water, and controlled atmospheric packaging) and natural composites (chitosan, essential oils, biocontrol agents, antifungal edible coatings, and organic acids) serves as a possible alternative and a safe way of preserving fresh produce (Droby et al., 2016). Hence, the prospects of using edible coatings such as gum Arabic and beeswax are high.

**2.1. Acacia gum**

Acacia gum or Gum Arabic refers to organic exudates that naturally form on the trunk, branches, or fruit of trees as a result of scission, injury (intentional or unintentional), or fungal infection. Gums are among the polysaccharides and hydrocolloids utilized in food, pharmaceutical, and several other industries (Prasad et al.*,* 2022). Gum Arabic is easily soluble in water even at greater concentrations, generates a low-viscosity solution, and stabilizes in oil-in-water emulsions (Kumar et al, 2021). It functions as a stabilizing, emulsifying, thickening, carrier, bulking, glazing, humectant, firming, and antioxidant agent (Prasad et al., 2022).

**2.2. Gallic acid**

Gallic Acid is a common phenolic acid with a strong antioxidant activity (Zhang et al., 2019). Most of the active packaging involves incorporating gallic acid to enhance antioxidant and antimicrobial activities towards the handling of products. Coating fruits with a film that has antioxidant and antimicrobial materials like gallic acid and clove oil enhances the antioxidant and antimicrobial activities of the fruits (Gangadharan et al, 2024).

**2.3. Clove oil**

Clove oil (*Syzygium aromaticum*) is a flavoring agent and a natural essential oil that has antioxidant and antibacterial properties. It is widely used as an antibacterial and in food preservation due to its broad-spectrum bactericidal, biodegradable, safe, and non-toxic side effects (Cui et al., 2018). It has numerous bioactive substances, including sesquiterpenes and triterpenoids, and the primary bioactive component of Clove oil, eugenol (4-allyl-2-methoxy phenol), exhibits potent insecticidal, antioxidant, and antifungal properties (Mulla et al., 2017)

The quality of tomato fruit is influenced by several developmental and biochemical processes that alter its qualities. This research was conducted to investigate the influence of the organic coatings of tomato fruits on quality attributes based on lycopene, beta-carotene, Decay, and texture (deformation energy and penetration depth of parenchyma).

**3. MATERIALS AND METHODS**

**3.1. Chemicals and reagents**

L-ascorbic acid (99 % purity) and Gallic acid (98.9% purity) standards were acquired from Loba Chemie Pvt., and the analytical grade solvents and chemicals employed in this investigation were all obtained from Maharashtra (India) Loba Chemie PVT. LTD chemicals.

**3.2. Fresh tomato (*Solanum lycopersicum L.)***

Fresh tomato (Solanum Lycopersicon L.) fruits harvested at the ripening stage were purchased at the Iringa municipal market, as per the USDA standard tomato color classification chart USDA, 1991;( Li et al., 2018). The fruits were brought to the laboratory in less than a day after being visually inspected for consistency in size, color, lack of flaws, and fungal infection. Fruits were air-dried by ceiling fans at room temperature for one hour after being cleaned with distilled water before treatment.

**3.2. Preparation of acacia gum solutions.**

Acacia gum particles were collected from Acacia trees in the Iringa region by the farmers and transported to the Sokoine University of Agriculture laboratory. According to the work by (Mahdi et al., 2020), gum Arabic solution (10%, w/v) was prepared by dissolving 10 g of gum Arabic particles in 100 mL of distilled water. The solution was stirred at low heat (40⁰C) for 60 min in a water bath (Wagtech Heidolph heizbad wb serial no. 010003898), then filtered to remove any undissolved impurities using a Muslin cloth. After cooling to room temperature (27.8◦C) in the laboratory, the solution was divided into portions, and Gallic acid and clove oil were added for the improvement of antioxidant activity and antibacterial properties of the prepared gum Arabic solution. The Control and the three solutions of Gallic acid, Clove Oil, and Arabic gum in the ratio of (0:0:0), (1:1:98), (1.5:1.5:97) and (3:3:94) respectively, were then prepared for the treatment of tomato berries cleaned with distilled water for the experiment at ambient temperature (At), cold room (16⁰C), and Refrigeration (8⁰C).

**3.3. Lycopene extraction**

Lycopene was extracted according to the method of Gordon and Diane (2007), with some slight modifications. Fresh tomato pulp samples (2 g) were dissolved in 10 ml of distilled water and homogenized (Omni mixer homogenizer, 500- 18,000 RPM, snmx21177 USA) at room temperature (27.8⁰C) for 5 minutes, then 8.0 ml of hexane: ethanol: acetone (2:1:1) solution was added. The mixture was capped and vortexed immediately, followed by incubation for 30 minutes in the dark. After incubation, 20.0 ml of water was added to each sample and vortexed again. Samples were allowed to stand for 10 minutes for the phases to separate and for all air bubbles to disappear. Finally, the absorbance of samples was determined at 503 nm by spectrophotometry (using an X-mas spectrophotometer (model X-ma 3000 Human Corporation, Republic of Korea). Calculation of lycopene levels in the hexane extracts were calculated as

Lycopene (mg/kg) = (1)

**3.4.β-carotene extraction**

β-Carotene was determined according to the method of Nagata and Yamashita (Meena et al., 2017). Briefly, 10 ml of the acetone-hexane combination (4:6) was agitated violently with 100 mg of tomato pulp methanolic extract for 1 minute, and the mixture was filtered using the Whatman No. 4 filter paper. A Human Corporation X-mass spectrophotometer (model x-ma 3000) was used to test the filtrate's absorbance at 453nm, 505nm, and 663 nm. The following equation was then used to determine the β-carotene contents:

β-Carotene (mg/100 ml) (2)

**3.5. Texture**

Texture is one of the most important factors guiding consumers in judging the quality of a tomato fruit (El-Mesery et al., 2024). Fruit texture is influenced by a variety of characteristics, mostly sensory characteristics including juiciness, crispness, meltiness, hardness, and mealiness of the fruit flesh (Gallardo et al., 2023). As the fruit ripens, significant textural changes take place, primarily related to softening, which considerably influences post-harvest performance. The texture of tomato fruits was measured in terms of puncture energy and deformation depth using a fruit texture analyzer, Brookfield

model CT3 10K (0-50 Kg) (Brookfield serial no. 8550289, U.S.A) with a plunger with a diameter of 4 mm cylindrical inserted into the fruit skin automatically. i.e. transportation, storage, shelf life, and pathogen resistance (Wang et al., 2017).

**3.6. Decay Index (DI)**

The DI was evaluated visually according to the methodology described in (Peralta-Ruiz et al, 2020). The results of fungal presence, mechanical damage, and physical skin deterioration were calculated using the following Equation:

**   **

1n 2n 3n 4n

Figure 1: Hedonistic damage scale used for scale of the tomato damage, where (1n) refers to no damage (0% damage), (2n) mild damage (10%–15% damage), (3n) moderate damage (25%–50% damage), and (4n) severe damage (>50% damage)

Decay Index(DI),% = (3)

Where n = number of fruits classified in each level (1,2,3,4,) of the damage scale, and N = number of total fruits analyzed in each treatment per day (See Figure 1). The decay index of fruits was then evaluated on days 0, 7, 17, 21, 28, and 35 of storage time schedules.

**3.7. Data analysis.**

Laboratory data analysis was performed in triplicate using SPSS (IBM SPSS Statistics version 26). Specific differences between means were determined with Duncan’s multiple-range test and a significant difference test (LCD, P≤0.05) applied after analysis of variance (ANOVA)

**4. RESULTS AND DISCUSSION**

Research was conducted to investigate the effect of post-harvest treatments and storage conditions on the quality of tomatoes. Tomatoes were stored at ambient and cold storage conditions for 35 days after receiving post-harvest treatments, whereby weekly observations of numerous physical and chemical changes during storage were recorded and analyzed. The results were tabulated and analyzed to evaluate their significant effects under applied treatments.

**4.1. Lycopene concentration**

The data in Table 1 shows that the level of lycopene in tomato pulps was not significantly different among the treatments, but significantly different between storage conditions. In the case of cold storage conditions set at 16⁰C, the level of lycopene in tomatoes undergoing treatment T1(0:0:100) increased rapidly during storage compared to other treatments until 14 days of storage, whereas treatments T2, T3, and T4 had little increment of lycopene. This indicates that sole coating with acacia gum had less resistance to respiration compared to treatments that incorporated gallic acid and clove oil (As shown in Table 1). Lycopene reached a climax after 21 days of storage for T1, while for treatments T2, T3, and T4, climax values were reached after 28 days of storage, indicating the extension of shelf-life and quality of tomato fruits. Under refrigerator storage at 8⁰C, there was no significant difference among treatments. The quantity of lycopene increased slowly due to the influence of post-harvest treatment and the low temperature storage environment until the end of 35 planned storage periods. This verifies that controlling the storage temperature for fruits and vegetables enhances the extension of the availability of horticultural products.

Under the ambient storage conditions, the postharvest treatments had significant differences in the level of lycopene. Tomato fruit ripening was high in treatments T1 and T4, while treatments T2 and T3 showed a low level of lycopene at 21 days of storage. The values of lycopene were T1(3.363±0.021) mg/100gT4(3.038±0.009) mg/100g, T2(2.842±0.035) mg/100g and T3(2.612±0.001) mg/100g at those treatments respectively. This indicates that the controlling of respiration in treatments T2 and T3 was better than in other treatments (As shown in Table 1). Under the ambient conditions, treatment T3 extended the shelf life of tomatoes up to 28 days of storage compared to other treatments, while in other treatments, the level of lycopene started decreasing due to reaching a climax at 21 days of storage

Table 1: The influence of postharvest treatments and storage conditions on Lycopene content in tomatoes from 1 to 35 days of storage

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Lycopene(mg/100g) | | | | | | | |
| STORAGE | TREATMENT | DAS 1 | DAS 7 | DAS 14 | DAS 21 | DAS 28 | DAS 35 |
| Cold room(16°C) | T1, 0:0:100 | 1.413±0.000a | 2.042±0.001l | 2.952±0.001l | 3.035±0.001g | 2.932±0.071i | 2.706±0.007d |
| T2, 0.5:0.5:99 | 1.413±0.000a | 1.649±0.007e | 1.627±0.033e | 3.232±0.008k | 2.782±0.707g | 2.786±0.707g |
| T3, 1.0:1.0:98 | 1.413±0.000a | 1.881±0.071i | 1.613±0.707d | 2.360±0.007a | 3.049±0.007k | 2.780±0.071f |
| T4, 1.5:1.5:97 | 1.413±0.000a | 1.895±0.078j | 1.878±0.007i | 3.088±0.001j | 3.172±0.001l | 2.762±0.007e |
| Refrigerator (°8C) | T1,0:0:100 | 1.413±0.000a | 1.522±0.007a | 1.528±0.001a | 2.660±0.071e | 2.519±0.011c | 2.396±0.007b |
| T2,0.5:0.5:99 | 1.413±0.000a | 1.569±0.008c | 1.542±0.014b | 2.603±0.007c | 2.293±0.006a | 2.825±0.001i |
| T3,1.0:1.0:98 | 1.413±0.000a | 1.544±0.007b | 1.636±0.007g | 2.578±0.007b | 2.351±0.028b | 2.797±0.028h |
| T4,1.5:1.5:97 | 1.413±0.000a | 1.583±0.100d | 1.685±0.001h | 3.057±0.007i | 2.715±0.001f | 2.472±0.001c |
| Ambient | T1,0:0:100 | 1.413±0.000a | 1.761±0.001h | 1.990±0.707k | 3.363±0.021l | 2.594±0.002e | 0.00 |
| T2,0.5:0.5:99 | 1.413±0.000a | 1.952±0.001k | 1.634±0.001f | 2.842±0.035f | 2.581±0.007d | 0.00 |
| T3,1.0:1.0:98 | 1.413±0.000a | 1.726±0.003f | 1.603±0.000c | 2.612±0.001d | 2.939±0.014i | 0.00 |
| T4,1.5:1.5:97 | 1.413±0.000a | 1.753±0.004g | 1.894±0.014j | 3.038±0.009h | 3.041±0.007j | 0.00 |
|  | MEAN | 1.413±0.00 | 1.740±0.17 | 1.799±0.38 | 2.872±0.30 | 2.747±0.28 | 1.794±1.30 |

T1,0:0:100=%gallic acid: %clove oil: %acacia gum, T2,0.5:0.5:99=%gallic acid: %clove oil: %acacia gum, T3,1:1:98=%gallic acid: %clove oil: %acacia gum, T4,1.5:1.5:97=%gallic acid: %clove oil: %acacia gum, DAS=Days after storage

Figure 2: Histogram showing the influence of postharvest treatments and storage conditions on Lycopene content in tomatoes from 1 to 35 days of storage

**4.2.β-carotene content**

The data in Table 2 shows β-carotene content in tomato fruits as influenced by the postharvest treatments and different storage temperatures. The data indicates no significant difference between storage temperatures. The β-carotene under ambient storage, cold room (16⁰C) storage, and refrigeration (8⁰C) increased until 21 days of storage, beyond which it started decreasing. Tomatoes stored at ambient temperature managed to reach the 28th day of storage, while those stored at the cold room (16⁰C) and in the refrigerator (8⁰C) managed to reach 35 days. This was due to high temperature, which implied that the rate of respiration under ambient storage was higher compared to cold room and refrigerator storage, having a low and monitored temperature (As shown in Table 2).

Under cold storage (16°C), treatment T2(0.5:0.5:99) shown low respiration rate compared to T1(0:0:100), T3(1:1:98) and T4(1.5:1.5:97) up to 14 days of storage which indicated less ripening speed of the tomatoes due to having less increment in beta-carotene with values of T2(0.821±0.007) mg/100g compared to other treatments T1(0.954±0.007) mg/100g, T3(0.908±0.001) mg/100g and T4(0.922±0.007) mg/100g respectively. This implied that the respiration rate of tomato was low for T2(0.5:0.5:99) compared to other treatments, which signified good treatment for fruits and vegetables in a cold room for maintaining tomato quality and shelf-life extension.

Similarly, in the refrigerator (8⁰C), there was no significant difference in the β-carotene level between treatments; however, as storage days rose from day 1 to day 28, the β-carotene content began to decrease. The tomatoes managed to reach the planned storage days of 35 days with acceptable quality (As shown in Table 2).

Furthermore, tomatoes stored at ambient temperature had an increase in β-carotene concentration from day one to day twenty-one, after which it began to decline and only reached twenty-eight days, whereas tomatoes stored under other conditions reached thirty-five days. This was due to higher temperature conditions compared to the refrigerator and cold room conditions, which increased the metabolism of the fruits, hence ripening (As shown in Table 2).

Table 2: The influence of postharvest treatments and storage conditions on β-carotene content in tomatoes at 1 to 35 days of storage

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Βeta-carotene (mg/100g) | | | | | | | |
| STORAGE | TREATMENTS | DAS 1 | DAS 7 | DAS 14 | DAS 21 | DAS 28 | DAS 35 |
| Cold room(16°C) | T1, 0:0:100 | 0.743±0.000a | 0.786±0.001k | 0.954±0.007h | 3.074±0.007g | 0.866±0.000g | 0.854±0.007d |
| T2, 0.5:0.5:99 | 0.743±0.000a | 0.756±0.001i | 0.821±0.007a | 3.389±0.007l | 0.825±0.001d | 0.923±0.007i |
| T3, 1.0:1.0:98 | 0.743±0.000a | 0.769±0.007j | 0.908±0.001e | 2.412±0.000a | 0.897±0.000i | 0.864±0.001e |
| T4, 1.5:1.5:97 | 0.743±0.000a | 0.818±0.007l | 0.922±0.007f | 3.168±0.001i | 0.902±0.001j | 0.853±0.007c |
| Refrigerator (°8C) | T1,0:0:100 | 0.743±0.000a | 0.670±0.001b | 0.961±0.005i | 2.966±0.003d | 0.815±0.001b | 0.871±0.001g |
| T2,0.5:0.5:99 | 0.743±0.000a | 0.745±0.014h | 0.979±0.007k | 2.886±0.000c | 0.858±0.007f | 0.865±0.000f |
| T3,1.0:1.0:98 | 0.743±0.000a | 0.727±0.007e | 0.951±0.001g | 2.974±0.007e | 0.939±0.000k | 0.921±0.001h |
| T4,1.5:1.5:97 | 0.743±0.000a | 0.728±0.001f | 0.993±0.001l | 3.318±0.000j | 0.831±0.000e | 0.831±0.001b |
| Ambient | T1,0:0:100 | 0.743±0.000a | 0.734±0.001g | 0.850±0.025b | 3.369±0.005k | 0.796±0.003a | 0.00 |
| T2,0.5:0.5:99 | 0.743±0.000a | 0.646±0.006a | 0.960±0.042j | 3.014±0.006f | 0.820±0.000c | 0.00 |
| T3,1.0:1.0:98 | 0.743±0.000a | 0.686±0.001c | 0.902±0.001d | 2.662±0.000b | 0.872±0.007h | 0.00 |
| T4,1.5:1.5:97 | 0.743±0.000a | 0.706±0.001d | 0.868±0.004c | 3.134±0.001h | 0.944±0.001l | 0.00 |
|  | MEAN | 0.743±0.00 | 0.731±0.05 | 0.922±0.05 | 3.031±0.05 | 0.864±0.05 | 0.582±0.42 |

T1,0:0:100=%gallic acid: %clove oil: %acacia gum, T2,0.5:0.5:99=%gallic acid: %clove oil: %acacia gum, T3,1:1:98=%gallic acid: %clove oil: %acacia gum, T4,1.5:1.5:97=%gallic acid: %clove oil: %acacia gum, DAS=Days after storage

Figure 3. Histogram showing the influence of postharvest treatments and storage conditions on β-carotene content in tomatoes at 1 to 35 days of storage

**4.3. Decay percentage of tomato fruits**

The influence of postharvest treatment and storage conditions on the damage percentage of tomatoes is shown in Table 3. The results indicate a significant difference among the storage temperature conditions. Nevertheless, from the first day up to fourteen days of storage, no visible decay was observed, until 21 days of storage, when decay began to appear on the stored tomatoes.

Under cold room storage (16 ºC), treatment T1(0:0:100) has shown a decay of 3.33±0.007% while other treatments have shown zero decay percentage. This can signify that the inclusion of gallic acid and clove oil enhances the delay of senescence. Additionally, stored tomatoes managed to reach 35 days of storage time with minimal decay in cold room storage, whereas treatment T1(0:0:100) shown an average percentage decay of 10.06±0.08 compared to T2(0.5:0.5:99), T3(1:1:98), T4(1.5:1.5:97) treatments with percentage decay of 1.68±0.007,3.34±0.007, and1.68±0.007, respectively. This implied that treatments composed of gallic acid and clove oil delay the self-decomposition of tomatoes, hence maintaining the quality of the coated fruits.

Furthermore, the influence of postharvest treatment and refrigerated storage has not shown a significant difference in decay percentage. Decaying was observed starting from the 35th day of storage, implying that coating fruits and controlling the storage temperature enhances the shelf life of tomatoes. Under ambient storage, decay started after 21 days of storage whereby the control had a large percentage of decaying compared to the treatments T1(3.34±0.007), T2(1.68±0.007), T3(1.68±0.007), and T4(0.00±0.000). in the later days, the decaying percentage continued to increase up to 35 days of storage whereby treatments with the inclusion of gallic acid and clove oil during coating showed delaying in the degradation of stored tomatoes (As shown in Table 3).

Table 3: The influence of postharvest treatments and storage conditions on the decay percentage of Tomatoes from 1 day to 35 days of storage.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Decay percentage (%) | | | | | | | |
| Storage | Treatments | 1DAS | 7DAS | 14DAS | 21DAS | 28DAS | 35DAS |
| Cold room (16 °C) | T1,0:0:100 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 3.33±0.007c | 5.06±0.085d | 10.06±0.085f |
| T2,0.5:0.5:99 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 1.68±0.007b | 1.68±0.007b |
| T3,1.0:1.0:98 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 1.68±0.007b | 3.34±0.007c |
| T4,1.5:1.5:97 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 1.68±0.007b | 1.68±0.007b |
| Refrigerator (8⁰C) | T1,0:0:100 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 1.68±0.007b | 5.06±0.085d |
| T2,0.5:0.5:99 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 1.68±0.007b |
| T3,1.0:1.0:98 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a |
| T4,1.5:1.5:97 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 1.68±0.007b |
| Ambient | T1,0:0:100 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 3.34±0.007d | 13.35±0.028f | 15.06±0.085g |
| T2,0.5:0.5:99 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 1.68±0.007b | 3.33±0.000c | 6.67±0.000e |
| T3,1.0:1.0:98 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 1.68±0.007b | 6.67±0.000e | 3.33±0.000c |
| T4,1.5:1.5:97 | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 0.00±0.000a | 5.06±0.085d | 5.06±0.085d |
|  | MEAN | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.83±1.30 | 3.35±3.75 | 4.61±4.20 |

T1,0:0:100=%gallic acid: %clove oil: %acacia gum, T2,0.5:0.5:99=%gallic acid: %clove oil: %acacia gum, T3,1:1:98=%gallic acid: %clove oil: %acacia gum, T4,1.5:1.5:97=%gallic acid: %clove oil: %acacia gum, DAS=Days after storage

**4.4. Texture parameters**

Results in Table 4 show the influence of postharvest treatment and storage conditions on the strength or hardness of tomatoes. Hardness is one of the texture attributes that contribute to the quality of the tomatoes harvested at the right time and stored. Due to postharvest treatments and respiration of fruits after harvesting, temperature facilitates the continuation of ripening of fruits, which causes softening, senescence, and degradation (Brashlyanova et al., 2014). However, there was no significant difference shown between storage conditions towards hardness or strength of the tissues or cellular of tomatoes in terms of deformability energy. The hardness and strength of tissue or cellular were decreasing as the days of storage increased at a low rate while maintaining the quality of fruits (As shown in Table 4). Additionally, postharvest treatments performed better in cold rooms and ambient storage conditions than in refrigerator storage, whereby minimum values of deformation energy were portrayed at 28 days of storage. Furthermore, the same treatments in a cold room at 16⁰C, the minimum deformation energy was 18.18±0.024mJ compared with 12.37±0.001mJ and 17.67±0.000mJ under refrigerated storage at 8°C and ambient storage conditions, respectively. This indicates that cold conditions affect the coating layers and the strength of fruit tissue or cellular (As shown in Table 4). Similarly, the hardness of the tissue of the fruits is maintained due to a low change in deformation energy on the control samples before storage, which was 26.83 mJ. This predicts that the quality of tomatoes is the same since firmness, hardness, strength of pericarp, and tissue rigidity were slightly stable during storage.

Table 4: Effect of postharvest treatments and storage conditions on the hardness of tomatoes during storage time

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Punching energy (millijoule, mJ) | | | | | | | |
| Storage | Treatments | 1DAS | 7DAS | 14DAS | 21DAS | 28DAS | 35DAS |
| Cold room (16 °C) | T1,0:0:100 | 26.83±0.000a | 17.33±0.007a | 19.73±0.007f | 21.73±0.007i | 19.51±0.014g | 17.31±0.007d |
| T2,0.5:0.5:99 | 26.83±0.000a | 21.17±0.007g | 21.51±0.007i | 19.33±0.001f | 19.61±0.014h | 18.26±0.007f |
| T3,1.0:1.0:98 | 26.83±0.000a | 22.62±0.014i | 25.06±0.085k | 13.31±0.007a | 18.91±0.007f | 24.21±0.007h |
| T4,1.5:1.5:97 | 26.83±0.000a | 19.83±0.001c | 20.51±0.014g | 21.97±0.007j | 18.18±0.024e | 18.51±0.007g |
| Refrigerator (8⁰C) | T1,0:0:100 | 26.83±0.000a | 17.77±0.007b | 21.93±0.007j | 20.53±0.007h | 20.51±0.007i | 11.41±0.014c |
| T2,0.5:0.5:99 | 26.83±0.000a | 20.46±0.007d | 18.43±0.007c | 15.83±0.003d | 12.91±0.007b | 9.51±0.014b |
| T3,1.0:1.0:98 | 26.83±0.000a | 24.33±0.003i | 18.71±0.007e | 15.77±0.001c | 12.37±0.001a | 17.63±0.007e |
| T4,1.5:1.5:97 | 26.83±0.000a | 20.76±0.007f | 18.56±0.007d | 17.37±0.001e | 17.38±0.004c | 11.41±0.007c |
| Ambient | T1,0:0:100 | 26.83±0.000a | 23.18±0.035h | 20.93±0.003h | 19.53±0.007g | 22.25±0.071j | 0 |
| T2,0.5:0.5:99 | 26.83±0.000a | 23.09±0.018j | 14.87±0.002a | 15.31±0.007b | 27.58±0.035l | 0 |
| T3,1.0:1.0:98 | 26.83±0.000a | 22.03±0.000h | 18.53±0.000d | 22.87±0.003k | 25.77±0.002k | 0 |
| T4,1.5:1.5:97 | 26.83±0.000a | 20.61±0.007e | 16.23±0.007b | 23.27±0.000l | 17.67±0.000d | 0 |
|  | MEAN | 26.83±0.00 | 21.10±2.08 | 19.58±2.63 | 18.90±3.25 | 19.39±4.25 | 10.69±8.61 |

T1,0:0:100=%gallic acid: %clove oil: %acacia gum, T2,0.5:0.5:99=%gallic acid: %clove oil: %acacia gum, T3,1:1:98=%gallic acid: %clove oil: %acacia gum, T4,1.5:1.5:97=%gallic acid: %clove oil: %acacia gum, DAS=Days after storage

**4.5. Peak deformation**

Since texture is one of the most critical quality attributes in consumer evaluation of fresh fruits and vegetables (An et al., 2020), failure to meet the quality as demanded by customers can lead to the loss of market for tomato products.

Peak deformation of fruits is one of the indicators of texture attributes, which is due to the mechanical failure of fruits when subjected to compression forces. Deformation indicates the change of firmness and hardness of the cellular materials of fruits when subjected to an external force during postharvest handling. When the peak deformation increases, it indicates a change in the hardness of the fruits caused by the metabolic respiration or internal mechanical damage process of tomato fruits during storage. This deformation attribute contributes to the loss of quality of tomato, leading to the subsequent discarding of the product in the harvest consumption chain, which results in food wastage and seriously affects the economic benefit of the seller (Li et al., 2019)

The influence of postharvest treatments and storage conditions on tomatoes is shown in Table 5. The results have shown a significant difference between storage conditions, whereby the deformation was increasing across storage days. This signifies that the postharvest treatments and storage conditions affected the texture of the products across all storage days, except under ambient storage conditions, whereby tomatoes managed to reach a maximum of 28 days of storage.

Table 5: Influence of postharvest treatments and storage conditions on mechanical failure of tomato fruits during storage time

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Peak deformation(mm) | | | | | | | |
| Storage | Treatments | 1DAS | 7DAS | 14DAS | 21DAS | 28DAS | 35DAS |
| Cold room (16 °C) | T1,0:0:100 | 3.18±0.014a | 4.08±0.007de | 5.20±0.021h | 5.10±0.071f | 4.66±0.007c | 4.35±0.007d |
| T2,0.5:0.5:99 | 3.19±0.021a | 3.73±0.000c | 4.57±0.141f | 4.60±0.021e | 4.06±0.078b | 4.41±0.007d |
| T3,1.0:1.0:98 | 3.19±0.028a | 3.43±0.035b | 5.99±0.007i | 3.74±0.007b | 4.86±0.007cd | 5.33±0.007g |
| T4,1.5:1.5:97 | 3.15±0.028a | 4.61±0.007f | 3.68±0.000c | 4.63±0.007e | 4.92±0.014cde | 5.06±0.085fg |
| Refrigerator (8⁰C) | T1,0:0:100 | 3.15±0.028a | 3.99±0.028d | 3.71±0.014cd | 4.11±0.014c | 4.71±0.014cd | 5.34±0.007g |
| T2,0.5:0.5:99 | 3.20±0.035a | 3.84±0.007c | 6.18±0.007j | 4.31±0.014d | 3.33±0.000a | 3.91±0.007c |
| T3,1.0:1.0:98 | 3.15±0.035a | 4.14±0.148e | 3.31±0.134a | 4.54±0.099e | 4.59±0.587c | 4.85±0.445e |
| T4,1.5:1.5:97 | 3.18±0.007a | 3.83±0.007c | 3.83±0.007d | 3.11±0.014a | 5.31±0.007e | 3.33±0.007b |
| Ambient | T1,0:0:100 | 3.22±0.071a | 3.20±0.071a | 3.45±0.035b | 3.79±0.007b | 4.09±0.021b | 0 |
| T2,0.5:0.5:99 | 3.22±0.071a | 4.73±0.007g | 3.37±0.000ab | 4.28±0.042d | 4.21±0.014b | 0 |
| T3,1.0:1.0:98 | 3.18±0.007a | 5.59±0.028h | 4.86±0.007g | 5.88±0.007g | 5.31±0.007e | 0 |
| T4,1.5:1.5:97 | 3.17±0.007a | 3.49±0.014b | 4.06±0.007e | 4.61±0.007e | 5.09±0.028de | 0 |
|  | MEAN | 3.18±0.04 | 4.05±0.65 | 4.38±1.05 | 4.39±0.69 | 4.59±0.58 | 3.05±2.27 |

T1,0:0:100=%gallic acid: %clove oil: %acacia gum, T2,0.5:0.5:99=%gallic acid: %clove oil: %acacia gum, T3,1:1:98=%gallic acid: %clove oil: %acacia gum, T4,1.5:1.5:97=%gallic acid: %clove oil: %acacia gum, DAS=Days after storage

Figure 4. Histogram showing the Influence of postharvest treatments and storage conditions on mechanical failure of tomato fruits during storage time

**5. CONCLUSION**

The study found that organically coating tomatoes with acacia gum incorporated with gallic acid and clove oil in proportions of T1(0:0:100), T2(0.5:0.5:99), T3(1:1:98), and (1.5:1.5:97), at a regulated temperature, effectively reduces postharvest loss. Furthermore, due to an increase in temperature, respiration was found to influence lycopene, β-carotene, texture, and decaying rate. Rotting decreased significantly for tomatoes treated with a mixture composed of acacia gum solution, gallic acid, and clove oil compared with tomatoes coated with acacia gum solution alone. The antibacterial properties of clove oil and gallic acid help maintain the quality of fruits, hence extending shelf life.

**REFERENCES**

1.Thole, V., Vain, P., & Martin, C. (2021). Effect of elevated temperature on tomato post-harvest properties. *Plants*, *10*(11), 2359.2.Li, B., Lecourt, J., & Bishop, G. (2018). Advances in non-destructive early assessment of fruit ripeness towards defining optimal time of harvest and yield prediction—A review. *Plants*, *7*(1), 3.

3.Zsögön, A., Cermak, T., Voytas, D., & Peres, L. E. P. (2017). Genome editing as a tool to achieve the crop ideotype and de novo domestication of wild relatives: a case study in tomato. *Plant Science*, *256*, 120-130

4.Martí, R., Roselló, S., & Cebolla-Cornejo, J. (2016). Tomato is a source of carotenoids and polyphenols targeted to cancer prevention. *Cancers*, *8*(6), 58.

5.Yadav, A., Kumar, N., Upadhyay, A., Sethi, S., & Singh, A. (2022). Edible coating as postharvest management strategy for shelf‐life extension of fresh tomato (Solanum lycopersicum L.): An overview. *Journal of Food Science*, *87*(6), 2256-2290.

6.Afedzi, A. E. K., Ahadjie, V., & Quansah, L. (2022). Gum Arabic and beeswax as edible coatings for extending the postharvest shelf life of tomato (Lycopersicon esculentum L) fruit. *Ghana Journal of Science*, *63*(2), 31-42.

7.Droby, S., Wisniewski, M., Teixidó, N., Spadaro, D., & Jijakli, M. H. (2016). The science, development, and commercialization of postharvest biocontrol products. *Postharvest Biology and Technology*, *122*, 22-29.

8.Prasad, N., Thombare, N., Sharma, S. C., & Kumar, S. (2022). Gum Arabic–A versatile natural gum: A review on production, processing, properties and applications. *Industrial Crops and Products*, *187*, 115304.

9.Kumar, Y., Roy, S., Devra, A., Dhiman, A., & Prabhakar, P. K. (2021). Ultrasonication of mayonnaise formulated with xanthan and guar gums: Rheological modeling, effects on optical properties and emulsion stability. *LWT*, *149*, 111632.

10.Zhang, X., Liu, J., Qian, C., Kan, J., & Jin, C. (2019). Effect of grafting method on the physical property and antioxidant potential of chitosan film functionalized with gallic acid. *Food hydrocolloids*, *89*, 1-10.

11.Gangadharan, G., Gupta, S., Kudipady, M. L., & Puttaiahgowda, Y. M. (2024). Gallic Acid-Based Polymers for Food Preservation: A Review. *ACS omega*, *9*(36), 37530-37547

12.Cui, H., Bai, M., Rashed, M. M., & Lin, L. (2018). The antibacterial activity of clove oil/chitosan nanoparticles embedded gelatin nanofibers against Escherichia coli O157: H7 biofilms on cucumber. *International journal of food microbiology, 266*, 69-78.

13.Mulla, M., Ahmed, J., Al-Attar, H., Castro-Aguirre, E., Arfat, Y. A., & Auras, R. (2017). Antimicrobial efficacy of clove essential oil infused into chemically modified LLDPE film for chicken meat packaging. *Food Control*, *73*, 663-671.

14.Mahdi, A. A., Mohammed, J. K., Al-Ansi, W., Ghaleb, A. D., Al-Maqtari, Q. A., Ma, M., ... & Wang, H. (2020). Microencapsulation of fingered citron extract with gum arabic, modified starch, whey protein, and maltodextrin using spray drying. *International journal of biological macromolecules*, *152*, 1125-1134.

15.Meena, M., Zehra, A., Swapnil, P., Dubey, M. K., Patel, C. B., & Upadhyay, R. S. (2017). Effect on lycopene, β-carotene, ascorbic acid, and phenolic content in tomato fruits infected by Alternaria alternata and its toxins (TeA, AOH, and AME). *Archives of Phytopathology and Plant Protection*, *50*(7-8), 317-329

16. El-Mesery, H. S., Adelusi, O. A., Ghashi, S., Njobeh, P. B., Hu, Z., & Kun, W. (2024). Effects of storage conditions and packaging materials on the postharvest quality of fresh Chinese tomatoes and the optimization of the tomatoes' physicochemical properties using machine learning techniques. *LWT*, *201*, 116280.

17.Gallardo, R. K., Ma, X., Colonna, A., Montero, M. L., & Ross, C. (2023). Consumers’ Preferences for Novel and Traditional Pear Cultivars: Evidence from Sensory Evaluation and Willingness-to-pay Elicitation. *Hortscience*, *58*(12), 1474-1483.

18.Wang, K., Handa, A. K., & Mattoo, A. K. (2017). Understanding and improving the shelf life of tomatoes. In *Achieving sustainable cultivation of tomatoes* (pp. 337-364). Burleigh Dodds Science Publishing.

19.Peralta-Ruiz, Y., Tovar, C. D. G., Sinning-Mangonez, A., Coronell, E. A., Marino, M. F., & Chaves-Lopez, C. (2020). Reduction of postharvest quality loss and microbiological decay of tomato “Chonto”(Solanum lycopersicum L.) using chitosan-e essential oil-based edible coatings under low-temperature storage. *Polymers*, *12*(8), 1822.

20.Brashlyanova, B., Zsivánovits, G., & Ganeva, D. (2014). The texture quality of tomatoes is affected by different storage temperatures and growth habits. *Emirates Journal of Food and Agriculture*, *26*(9), 750.

21.An, X., Li, Z., Zude-Sasse, M., Tchuenbou-Magaia, F., & Yang, Y. (2020). Characterization of textural failure mechanics of strawberry fruit. *Journal of Food Engineering*, *282*, 110016.

22.Li, Z., Lv, K., Wang, Y., Zhao, B., & Yang, Z. (2019). Multi-scale engineering properties of tomato fruits related to harvesting, simulation, and textural evaluation. *LWT-Food Science and Technology*, *61*(2), 444-451.