

The Role of Edible Coatings in Enhancing the Quality of Local Lime Fruits During Cold Storage

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Abstract
Citrus fruits are exposed to numerous biotic and abiotic stresses, whether in the field, after harvest, or during storage, which affect their quality, reduce their resistance to pathogens, and shorten their shelf life. Local sour lemons are one type of citrus fruit affected by these factors; therefore, there has been a trend toward using certain edible coatings edible coatings to determine their effectiveness in enhancing fruit quality after harvest and during storage. Five treatments were applied: sodium alginate at concentrations of 1% and 3%, and chitosan at concentrations of 1% and 2%, in addition to a control treatment. The fruits in each treatment were immersed for ten minutes in the above solutions, then dried at room temperature and packed in 1-kg plastic bags perforated on both sides with 16 holes each, and stored at a temperature of 7 ±1 Celsius and a humidity of 85 – 90% for 20, 40, and 60 days. The results showed that the effect of high concentrations in the coatings used—particularly 2% chitosan—was significant, as it achieved the highest levels of total soluble solids (TSS), total acidity, and vitamin C, with juice percentages of 6.38, 6.19, 15.34, and 28.63, respectively, and the lowest rates of weight loss and microbial spoilage at 1.43 and 0.00, respectively. Meanwhile, the control treatment recorded the lowest levels of TSS, total acidity, vitamin C, and juice content at 6.33, 6.06, 14.90, and 26.72, respectively, and the highest rates of weight loss and microbial spoilage were 3.70 and 1.29, respectively, at the end of the 60-day storage period.

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Introduction

Among citrus fruits in Iraq, the local lemon (*Citrus limon*) attracts significant attention and ranks third in terms of production volume after oranges and bitter oranges, with a total of 5,638 metric tons (Directorate of Agricultural Statistics, 2021) [22]. The importance of this fruit stems from its rich content of nutrients, vitamins, and organic acids, as well as its versatility in uses—whether consumed fresh or utilized in the food industry, cosmetics, and perfumery (Al 1990 *et al*., and Khafaji) [8].

Citrus fruits are generally considered non-climacteric fruits, which means they have a low respiration rate, low ethylene production, and slow metabolic processes, thereby extending their shelf life after harvest (Al-Ani, 1985) [5]; (Samad *et al*., 2019) [57].

It is susceptible to infection by numerous pathogens, particularly the fungi Penicillium (both the green *Penicillium digitatum* and the blue *Penicillium italicum*) and Alternaria, as well as to physiological and mechanical damage—from harvesting through transportation, storage, marketing, and distribution—which negatively affects their quality and storability and results in significant economic losses (Al Jubouri, 2019) [7]. The use of chemical compounds as fungicides to control post-harvest fungal infections often leads to their accumulation, causing long-term health and environmental damage (Guynot *et al*., 2005) [29]

Therefore, there has been a shift toward using natural, environmentally friendly, and safe alternatives that help enhance the natural resistance of fruits and preserve their quality after harvest and during storage, due to their antioxidant, antifungal, and antibacterial properties. Previous studies have highlighted the role of food coatings in slowing down or delaying the and extending the shelf life of fruits and vegetables without affecting their nutritional value (Jitareerat *et al*., 2007) [35]. Thus, they can be considered a technical alternative for preserving fruit quality during cold storage (Raybaudi-Massili *et al*., 2016) [53].

The importance of edible coatings lies in their ability to form a barrier—a thin, semi-permeable layer surrounding the fruit's surface—that limits or reduces gas exchange between the fruit and the external environment (Nair *et al*., 2020) [46]. In some cases, they act as carriers for bioactive or antimicrobial substances and are typically classified according to the underlying biopolymer used; while coatings composed of polysaccharides such as alginates and chitosan regulate or modify the fruit's metabolism, thereby delaying ripening and senescence (Muqaddas *et al*., 2025) [45].

Sodium alginate is a compound used as a natural polysaccharide coating consisting of D-mannuronic and L-guluronic acids, which are derived from alginic acid salts found in brown seaweed (Dhall, 2013) [21]. Polysaccharide-based coatings have demonstrated the ability to form strong membranes from aqueous colloidal materials, as they are hydrophilic biopolymers. Their colloidal properties have facilitated their use in thickening, forming suspensions and gels, and stabilizing emulsions (Chien *et al*., 2007) [19], where they were successfully applied to apples and peaches (Maftoonazad *et al*., 2008) [41]. Other studies have confirmed that the use of edible coatings extended the shelf life of peach and nectarine slices (Ferrari and Sarantoulos, 2013) [27], reduced fruit spoilage and metabolic activity during storage, and preserved their total soluble solids (TSS) content (Chiabrando and Giacalone, 2016) [17].

Chitosan is a polysaccharide polymer classified as the second most abundant biopolymer after cellulose. It is obtained from a wide range of natural sources, such as the exoskeletons of crustaceans and insects and the cell walls of fungi. It is characterized by its biodegradability and lack of toxicity, and it has no systemic or local effects on living tissues (2003, Rudrapatnam, Farooq Ahmed) [55], (Tolaimate *et al*., 2000) [63], Bal, 2013) [11], Chitosan is used as a coating on the surface of fruits, forming a semi-permeable membrane that limits gas exchange between the fruit and the external environment to control fungal infections and limit their development (Elieh-Ali-Komi *et al*., 2016) [24]) It stimulates the enzyme chitinase, which is one of the defense enzymes, and is also used commercially in the food, medical, and pharmaceutical industries (Hadrami *et al*., 2010; Zhang *et al*., 2011; El) [23, 65].

Chien and Chou (2006) [18] noted that treating citrus fruits with a chitosan solution led to an increase in total soluble solids and a reduction in weight loss during 42 days of storage at 13°C. This was also demonstrated in studies conducted by Peticcione *et al*., (2015) [49] and Chiabrando and Giacalone (2016) [17] demonstrated the role of chitosan in delaying changes in the characteristics of three strawberry varieties by reducing weight loss and preserving the fruit's total soluble solids, titratable acidity, and ascorbic acid content compared to untreated fruits, due to lower metabolic activity of the fruits during storage.

Kumar *et al*. (2017) [38] observed that the use of 1% chitosan reduced weight loss and damage in jujube fruits during storage. AlJubouri (2019) [7] in her study on sweet lemons treated with 10 g/L chitosan that there was an increase in the percentage of juice, TSS, and ascorbic acid content in the fruit juice, as well as a decrease in spoilage at the end of the 90-day storage period. (Adiletta *et al*., 2022) [3] noted that coating pears with chitosan reduced weight loss and slowed changes in TSS and acidity levels, which delayed ripening and extended the storage period compared to untreated fruit; therefore, it can be considered a promising alternative and an effective technique for improving fruit quality.

The goal of postharvest management is to extend the shelf life of fruits by implementing sustainable, environmentally friendly, and low-cost strategies to enhance postharvest fruit quality. Although edible coatings are widely used on many types of fruit as a postharvest preservation technique, studies focusing on local lemons are somewhat limited; therefore, this study was conducted to evaluate these coatings and their effect on certain physical and chemical properties of the fruit under refrigerated storage conditions.

Materials and Methods

The study was conducted during the 2022 season on local sour lemons to determine the effect of certain edible coatings on the fruit's qualitative and chemical characteristics during storage. The fruits were harvested manually at the commercial maturity stage from a private orchard in Karbala Governorate. The total soluble solids content was 6.5%, the total acidity was 6.33%, and the vitamin C content was 15.5 mg/100 mL. The fruits were transported to the Graduate Studies Laboratory in the Department of Horticulture and Landscape Architecture at the College of Agriculture, Al-Qasim Green University. Fruits that were uniform in color and size and free of damage were selected, washed with water, left to air-dry, and then randomly divided into five groups. Each group was assigned one of the following treatments, with the first treatment being:

1. Control (Distil water)
2. sodium alginate%1
3. sodium alginate %3
4. chitosan %1
5. chitosan %2

The Second Factor Was Three Storage Periods (20, 40, and 60 Days)

The sodium alginate coating was prepared by adding the required concentration of sodium alginate powder to distilled water and heating the solution while stirring until dissolved, with the addition of 0.25% glycerin as a plasticizer, followed by cooling the solution to room temperature according to the method described by Belay *et al*. (2022) [13]. The chitosan solution (w/v) was prepared by dissolving the required concentration in 100 mL of acetic acid according to the method described by Ghasemnezhad *et al*. (2010) [28]. The fruits were immersed in the solutions designated for each treatment for 10 minutes, then left to dry at room temperature, after which they were placed in kg polyethylene bags perforated on both sides with 16 holes (8 holes on each side) and stored for 20, 40, and 60 days at a temperature of 7 ± 1°C and relative humidity of 90–85%.

Characteristics Studied: Measurements were taken periodically during the storage periods and included

Percentage of weight loss: Calculated using the following equation

Weight Loss *%* = Initial fruit weight – Fruit weight after a specific period / Total fruit weight × 100

Percentage of Microbial Deterioration: Calculated using the following equation
Microbial Deterioration *%* = Weight of spoiled fruit / Total fruit weight × 100
Percentage of juice: calculated using the following equation
Juice *%* = Juice weight / Fruit weight × 100

Percentage of Total Soluble Solids (T.S.S.): The percentage of total soluble solids in the fruit juice was determined using a handheld refractometer

Percentage of Total Acidity (TA): Determined as described by Rangana (1977) by titrating a specific volume of filtered fruit juice with 0.1 N standard NaOH using a phenolphthalein indicator, assuming citric acid is the predominant acid. Calculated using the following equation:

Total Acidity *%* = Volume of NaOH × 0.1N × equivalent weight of the predominant acid × 100 / Volume of juice × 1000

Vitamin C Content of The Juice (ascorbic acid, mg/100 mL of juice): The amount of vitamin C was determined using a spectrophotometer at a wavelength of 520 nanometers according to the method of Omaye *et al*. (1979).

Statistical Analysis
A factorial experiment was conducted using a completely randomized design (CRD) with 5×3×3 factorial layout and three replicates, with 1 kg per replicate. The data were analyzed using the GenStat statistical software, and differences between means were compared using the Least Significant Difference (LSD) test at a 0.05% significance level (Alsahuoky & Waheeb, 1990).

Results and Discussion
Percentage of Weight Loss
Weight loss is an important characteristic that must be monitored during storage, as it plays a significant role in evaluating storage efficiency and fruit quality, as well as determining storability. The data in Table 1 show significant differences among the treatments in the percentage rates of weight loss for local sour lemons. All treatments reduced this percentage, particularly the chitosan treatment, where both concentrations (2% and 1%) achieved the lowest rate of 1.43%, 1.72%, respectively, whereas this rate rose to 3.70% in the control treatment. A statistically significant and gradual increase in these rates was observed as the storage period continued, reaching a maximum of 3.69% after 60 days of storage, compared to the first storage period of 20 days, which recorded the lowest rate of 1.16%. On the other hand, the combined treatment of 2% chitosan and the first 20-day storage period reduced the percentage to 0.76%, while it rose to 6.32% when the control treatment was combined with the 60-day storage period.
Weight loss is due to the difference in water vapor pressure between the fruit and the surrounding air, which is typically reduced by the layer of epidermal cells and the cuticle. Differences in the ability of various coatings to reduce weight loss can be attributed to variations in the water vapor permeability of the polysaccharides that make up the edible coating (Chein *et al*., 2007) [19]. This variation is linked to the effect of these coatings on the surface properties of the fruit (Poverenov *et al*., 2014) [50], and the selection of the appropriate formulation significantly influences their effectiveness (Chiabrando and Giacalone, 2016) [17]. These compounds function by reducing weight loss through the formation of a barrier or thin film surrounding the fruit peel and creating a controlled atmosphere around the fruit that minimizes water loss, the transport of dissolved substances, and gas diffusion, thereby preserving the fruit's moisture content (Raybaudi-Massili *et al*., 2016) [53], 2017 Mahaoud *et al*., (Sowmyashree *et al*., 2021) [61], Chitosan plays a key role in reducing weight loss during storage by softening the fruit peel and sealing the stomata; this barrier serves as a means of controlling respiration and transpiration rates, thereby modulating physiological processes within the fruit and preserving its freshness (Modesti *et al*., 2019) [44]. These results are consistent with the study conducted by (Brasil *et al*., 2012) [14] (Poverenov *et al*., 2014) [50] using sodium and chitosan on nectarines, and when a chitosan coating was applied to grapes by (Alwan *et al*., 2024) [10] and Muqaddas *et al*., 2025) [45] on jujube fruits.
The gradual decrease in fruit weight that accompanies the prolongation of the storage period is attributed to ongoing physiological processes within the fruit, including transpiration, respiration, and the consumption of part of the nutrient reserves (Alani, 1985; Shieikov, 1988) [5, 58]. These results are consistent with the study conducted by Petriccione *et al*. (2015) [49] on sweet cherries, the study by Mahmoud *et al*. (2017) [42] on oranges, Abdel Gayed *et al*.(2017 [2] on peaches, Al-Jubouri (2019) [7] on sweet lemons, and Al-Asady (2020) [6] on persimmons.

Table 1: Effect of edible coatings, storage periods, and their interactions on the percentage of weight loss in local sour lemons

Treatment	Storage Periods (Day)			Average Transactions
	20	40	60	
Control	1.37	3.41	6.32	3.70
Sodium alginate *%1*	1.26	1.81	4.41	2.49
Sodium alginate *%3*	1.18	1.52	3.06	1.92
Chitosan *%1*	1.21	1.28	2.68	1.72
Chitosan *%2*	0.76	1.57	1.97	1.43
Average Storage Periods	1.16	1.92	3.69	
L.S.D	Treatment 0.475	Interference 0.823	Storage Periods 0.368	

Percentage of Damage

The data in Table 2 showed that local sour lemons were not susceptible to microbial damage when treated with 3% sodium gene, 1% and 2% chitosan, whereas the control treatment recorded the highest rate of 1.29%. The spoilage rate also increased gradually from 0.23% after 20 days to 0.44% after 60 days of storage, On the other hand, we observed a positive effect of the interaction treatments between 1% sodium gene treatment and the first 20-day period in preventing spoilage; the same was true for all interaction treatments between 3% sodium gene treatment and 1% chitosan and 2% chitosan with the three storage periods, as damage was recorded at 0.0%, while the highest damage rate of 1.49% occurred when the control treatment was combined with the 60-day storage period. It is worth noting that the fungus *Penicillium digitatum* was identified as the primary cause of the damage. The high rate of spoilage during the final stages of storage is due to the continued vital processes within the fruits—including transpiration and evaporation—as well as the consumption of most stored nutrients through respiration, their passage through the ripening stage, and their entry into the senescence stage, which consequently reduces their resistance to microbial infection. However, the use of edible coatings has contributed positively to reducing spoilage rates and limiting the development and spread of infection, as these coatings act as disinfectants, possess antifungal and antibacterial properties, reduce the metabolic activity of the fruits (Campos *et al*., 2011) [15], preserve their quality, and extend their shelf life (Brasil *et al*., 2012) [14] and (Salvia-Trujillo *et al*., 2015) [56]. The role of chitosan treatment in preventing fruit damage is highlighted by its ability to inhibit microbial growth, as it contains positively charged amino groups that bind to the negative charges on the surface of microbial cells, causing a change in cell membrane permeability and disrupting osmosis, which results in the inhibition of microbial growth (Hadwiger *et al*., 1986) [31]. Chitosan also induces the enzyme chitinase, which is one of the defense enzymes that stimulates the production of antimicrobial substances (Hadwiger *et al*., 1986) [31]. microbes (Hadwiger *et al*., 1986) [31]. Chitosan also induces the enzyme chitinase—one of the defense enzymes—which stimulates the hydrolysis of chitin in the fungal cell wall, thereby inhibiting fungal growth (Hu and Zou, 1998) [32] and (Bal, 2013) [11] Therefore, chitosan can be considered an alternative to synthetic pesticides, as it has a dual mechanism of action: it inhibits the progression of fungal infections and stimulates the host tissue's response and resistance (Bautista-Banos *et al*., 2006) [12] and (Romanazzi, 2010) [54]. These results are consistent with a study by Ahmed *et al*. (2018) [4] on grapefruit, Al-Jubouri (2019) [7] on sweet lemons, and Khan *et al*. (2023) [36] on peaches when using sodium-based coatings.

Table 2: Effect of edible coatings, storage periods, and their interactions on the percentage of spoilage in local sour lemons

Treatment	Storage Periods (Day)			Average Transactions
	20	**40**	**60**	
Control	1.15	1.23	1.49	1.29
Sodium alginate *%1*	0.0	0.47	0.73	0.40
Sodium alginate *%3*	0.0	0.0	0.0	0.0
Chitosan *%1*	0.0	0.0	0.0	0.0
Chitosan *%2*	0.0	0.0	0.0	0.0
Average Storage Periods	0.23	0.34	0.44	
	Treatment 0.055	Interference 0.096	Storage Periods 0.042	

Juice Content (Percentage): The data in Table 3 showed that the juice content of local sour lemons was significantly affected by the study factors, as the chitosan treatment at both concentrations (1% and 2%) achieved the highest juice content, at 28.28% and 28.63%, respectively. This was followed by the sodium alginate treatment at both concentrations (1% and 3%), which recorded 27.55% and 27.86%, respectively, while the juice content in the control treatment dropped to a low of 26.72%. Storage periods also had a significant effect, as the juice content decreased from 28.45% in the first storage period to 27.18% after 60 days. As for the interaction treatments, the 2% chitosan treatment combined with the first 20-day storage period retained the highest juice content at 28.94%, while it decreased to 25.02% when the control treatment was combined with the 60-day storage period. The quality of citrus fruits depends on many factors, including juice content, which is considered a key attribute given its importance in the food industry (Samad *et al*., 2019) [57]. Edible coatings helped preserve the fruit's juice content by forming a thin barrier around the fruit's surface that limits transpiration and evaporation, prevents the transfer of substances, slows metabolic activity, and maintains fruit quality (Vargas *et al*., 2008) [64].

Table 3: Effect of edible coatings, storage periods, and their interactions on the juice content (in percent) of local sour lemons

Treatment	Storage Periods (Day)			Average Transactions
	20	**40**	**60**	
Control	28.29	26.84	25.02	26.72
Sodium alginate *%1*	28.25	27.17	27.24	27.55
Sodium alginate *%3*	28.27	28.02	27.30	27.86
Chitosan *%1*	28.48	28.30	28.06	28.28
Chitosan *%2*	28.94	28.67	28.28	28.63
Average Storage Periods	28.45	27.90	27.18	
L.S.D	Treatment 0.318	Interference 0.551	Storage Periods 0.246	

Total Dissolved Solids (T.S.S.) Percentage

The data in Table 4 indicate that all edible coating treatments resulted in a gradual increase in the percentage of total dissolved solids (T.S.S.), particularly the 3% sodium alginate treatment and the 2% chitosan treatment, reaching 6.37% and 6.38%, respectively, while it decreased to 6.33% in the control treatment. A gradual increase in this percentage was also observed as the storage period continued, rising from 6.30% in the initial 20-day period to 6.41% after 60 days of storage. On the other hand, the 2% chitosan treatment outperformed the others during the final 60-day storage period by maintaining the highest T.S.S. content at 6.45%, compared to the combination of the 1% chitosan treatment and the initial 20-day storage period, which recorded the lowest T.S.S. content at 6.28%.

Total soluble solids are among the most important factors influencing fruit flavor and nutritional value. Generally, these solids increase as the storage period continues due to changes in cell wall components and the breakdown of complex carbohydrates, as increased activity of carbohydrate-degrading enzymes leads to the breakdown of certain cell wall components and their conversion into soluble compounds and sugars, which indirectly results in an increase in TSS. It has been noted that the decrease in pectin, cellulose, and hemicellulose content during fruit ripening is accompanied by a clear increase in soluble solids, or may be attributed to the degradation of nitrogenous compounds, pectins, and mineral salts in the fruit, as well as to the increased activity of enzymes responsible for the breakdown of starch into soluble sugars (Abbasi *et al*., 2009) [1]. On the other hand, the gradual decrease in fruit weight and juice content during storage (Table 1 On the other hand, we note that treating the fruits with both coatings helped preserve their content of these substances by limiting oxygen access to the fruit surface, reducing the respiration rate, and maintaining membrane integrity (Sun *et al*., 2010) [62], which in turn had a positive effect by slowing and delaying the ripening and aging processes (Habibi *et al*., 2019 [30]; Liu *et al*., 2020 [40]). The decrease in T.S.S. as the storage period continued is attributed to the degradation of carbohydrates and pectin, moisture loss, and increased metabolic activity of the fruits (Lara *et al*., 2004) [39] and (Chouksey *et al*., 2013) [20]. These results are consistent with a study by Al-Jubouri (2019) [7] on local sweet lemons, Adiletta *et al*. (2022) [3] on pears, and Meena *et al*. (2024) [43] on squash.

Table 4: Effect of edible coatings, storage periods, and their interactions on the percentage of total soluble solids (T.S.S.) in local sour lemon fruits

Treatment	Storage Periods (Day)			Average Transactions
	20	**40**	**60**	
Control	6.30	6.34	6.37	6.33
Sodium alginate *%1*	6.32	6.37	6.41	6.37
Sodium alginate *%3*	6.30	6.35	6.42	6.36
Chitosan *%1*	6.28	6.35	6.43	6.35
Chitosan *%2*	6.30	6.39	6.45	6.38
Average Storage Periods	6.30	6.36	6.41	
L.S.D	Treatment 0.026	Interference 0.045	Storage Periods 0.020	

Percentage of Total Acidity

The data in Table 5 show that local sour lemons exhibited a gradual decrease in acidity levels in general and in the control treatment in particular; It is noted that this characteristic was significantly affected by the edible coating treatments, as the 1% and 2% chitosan treatments significantly outperformed the others by recording the highest total acidity percentage of 6.19% for both concentrations, whereas it decreased to 6.06% in the control treatment. The first storage period recorded the highest percentage at 6.25%, while it decreased to 6.06% at the end of the 60-day storage period. This percentage was also affected by the interaction between the 2% chitosan treatment and the first 20-day storage period, as well as the interaction between the control treatment and the same period, as both recorded the highest percentage. It reached 6.26%, while the combination of the control treatment and the 60-day storage period reduced the acidity to 5.86%.

Acidity is one of the key characteristics associated with fruit ripeness (Casquero and Guerra, 2009) [16] and is primarily attributed to several organic acids, including citric acid—which is predominant in citrus fruits—as well as malic acid. The concentration of these acids increases during fruit growth and development, reaching its peak at the ripening stage, then gradually decreases as ripening progresses until it disappears when the fruit enters the senescence stage (Alani, 1985) [5].

The positive effect of edible coatings on maintaining the acidity of the juice during storage is achieved by forming a thin, semi-permeable layer or film and creating a controlled atmospheric environment surrounding the fruit surface, which regulates gas exchange and inhibits respiration (Shiri *et al*., 2013) [59], reducing metabolic activity and lowering the consumption of organic acids—which are the first compounds consumed during respiration (Faust and Shear, 1972 [26]; Abdul Gayed *et al*., 2017) [2], and delays changes in chemical compounds—including acidity—and controls fruit quality (Adiletta *et al*., 2021).

On the other hand, the decrease in the percentage of acidity observed during the latter part of storage is attributed to physiological changes in the fruit as it ripens, which led to a change in the concentration of organic acids and a decrease in their levels as a result of their consumption during respiration (Hulme, 1970) [33] or perhaps to increased permeability of cell membranes, which allows for the oxidation of organic acids present in the cell vacuoles during respiration (Pareek, 2016) [48]. Elyatem and Kader (1984) [25] noted that the decrease in acidity at the end of the storage period is attributed to the fruits' inability to synthesize organic acids due to their passage from the ripening stage into the senescence stage.

Table 5: Effect of edible coatings, storage periods, and their interactions on the percentage of total acidity in local sour lemons

Treatment	Storage Periods (Day)			Average Transactions
	20	40	60	
Control	6.26	6.08	5.86	6.06
Sodium alginate *%1*	6,23	6.13	6.06	6.14
Sodium alginate *%3*	6.25	6.16	6.10	6.17
Chitosan *%1*	6.25	6.18	6.16	6.19
Chitosan *%2*	6.26	6.19	6.13	6.19
Average Storage Periods	6.25	6.15	6,06	
L.S.D	Treatment 0.042	Interference 0.073	Storage Periods 0.033	

Vitamin C Content In Juice, In Mg Per 100 Ml $^{-1}$ Juice Sample

The data in Table 6 indicate that all treatments were statistically superior in preserving the maximum vitamin C content in juice made from local lemons compared to untreated fruit; in particular, the 2% chitosan treatment recorded the highest value of 15.34 mg per 100 mL per 100 mL of juice, while the control treatment recorded the lowest value of 14.90 mg per 100 mL of juice. This characteristic was also affected by storage periods, decreasing from 15.35 mg per 100 mL of juice during the first 20-day storage period to 14.96 mg per 100 mL -1 juice after 60 days of storage. On the other hand, the interaction between the 2% chitosan treatment and the 20-day storage period resulted in the juice retaining the highest vitamin C content of 15.43 mg/100 mL -1 juice, whereas the combination of the control treatment with a 60-day storage period caused it to decrease to 14.48 mg/100 mL-1 juice. Vitamin C is one of the water-soluble vitamins found naturally in fruits and vegetables and is an important indicator in assessing fruit quality (Khorshidi *et al*., 2011) [37] The higher concentration of vitamin C in fruits treated with edible coatings is attributed to the antioxidant properties of these coatings, which enhance the health benefits derived from consuming lemons (Siboza *et al*., 2014) [60], as well as the effect of these treatments in reducing respiration rates, delaying chemical changes, and modulating metabolic processes, thereby enhancing fruit quality and extending shelf life (Raybaudi-Massili *et al*., 2016 [53]; Adiletta *et al*., 2022 [3]; Muqaddas *et al*., 2025 [45]). As for the decrease in vitamin C content in the juice as the storage period continues, this is associated with the ripening process under long-term storage conditions (Habibi *et al*., 2019) [30] or may be due to physiological disturbances and weight loss, which led to oxidative reactions that reduced the fruit's vitamin content (Mahmoud *et al*., 2017) [42] or to oxidation caused by the enzymes ascorbase, phenolase, and peroxidase (Hussien *et al*., 1998) [34]; Gad, 2018). These results are consistent with the findings of Samad *et al*. (2019) [57] in their study on lemons and those of Al-Jubuori (2019) [7] on sweet lemons.

Table 6: Effect of edible coatings, storage periods, and their interactions on the vitamin C content of the juice in local sour lemons

Treatment	Storage Periods (Day)			Average Transactions
	20	40	60	
Control	15.27	14.95	14.48	14.90
Sodium alginate *%1*	15.31	15.13	15.01	15.15
Sodium alginate *%3*	15.40	15.18	15.01	15.19
Chitosan *%1*	15.34	15.18	15.03	15.18
Chitosan *%2*	15.43	15.34	15.26	15.34
Average Storage Periods	15.35	15.15	14,96	
L.S.D	Treatment 0.141	Interference 0.109	Storage Periods 0.244	

Conclusions

It can be concluded from this study that the use of edible coatings as postharvest treatments played a positive role in enhancing the quality of local limes after harvest and extending their shelf life, which lasted 60 days under refrigerated storage conditions, by delaying the development of indicators associated with fruit ripening, such as loss of acidity and vitamin C. They also proved effective in reducing weight loss, minimizing microbial damage, and preserving the fruit's juice content and total soluble solids, due to their antioxidant, antimicrobial, and antifungal properties, as well as their ability to reduce the fruit's metabolic activity of the fruit, slowing down biological processes, and delaying ripening and aging. We therefore recommend applying this method to various types of fruits and vegetables after harvest as a promising, environmentally friendly technique that is easy to use, readily available, and low-cost.

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