Enhancement of storability and quality maintenance of carambola (*Averrhoa carambola* L.) fruit by using composite edible coating

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Abstract – Introduction. Our investigation aimed to examine the influence of eco-friendly edible coatings composed of sodium alginate, olive oil and green tea extract (GTE) on improving the shelf life and nutritional quality of carambola (*A. carambola* L.). **Materials and methods**. The combinations and concentrations of composite coatings tested were (2% sodium alginate + 0.1% olive oil) (T1), (2% sodium alginate + 0.2% olive oil) (T2) and (2% sodium alginate + 0.1% olive oil + 0.25% GTE) (T3), while the untreated fruit served as control (T4) and were stored at (25 ± 5) °C and (65 ± 5)% RH. All the stored fruit were subjected to physico-chemical and biochemical analysis at regular intervals of 4 days up to 16 days of their storage period. **Results and discussion**. Weight loss and decay occurrence were least in the fruit treated with T1 and T2 as compared with those of T3 and uncoated fruit (T4). The contents of total soluble solids, total sugars and changes in pigments were found to be least in fruit treated with T1 followed by those treated with T2 and T3. The addition of GTE (T3) to treated fruit during the storage helped enhance the antioxidants such as total phenols and ascorbic acid. **Conclusion**. The composite edible coatings tested in our study enhanced the shelf life of coated carambola fruit, *i.e.*, thirteen days for T1, sixteen days for T2, fourteen days for T3 and twelve days for control or untreated fruit (T4); the nutritional quality of carambola was enhanced with the treatment of edible coating containing GTE.

India / *Averrhoa carambola* / fruits / keeping quality / edible films / nutritive value / weight loss / pH / dry matter content / antioxidants / chlorophylls / carotenoids

Renforcement de la durée de stockage et du maintien de la qualité de la carambole (*Averrhoa carambola* L.) grâce à un enrobage composite comestible.

Résumé – Introduction. Notre expérimentation a cherché à étudier l'influence, sur l'amélioration de la durée de vie et de la qualité nutritionnelle de la carambole (*A. carambola* L.), de revêtements écologiques comestibles composés d'alginate de sodium, d'huile d'olive et d'extrait de thé vert (ETV). **Matériel et méthodes**. Les combinaisons et les concentrations des revêtements composites testés ont été de (2 % d'alginate de sodium + 0,1 % d'huile d'olive) (T1), (2 % d'alginate de sodium + 0,2 % d'huile d'olive) (T2), (2 % d'alginate de sodium + 0,1 % d'huile d'olive + 0,25 % ETV) (T3) ; des fruits non traités ont servi de témoin (T4) et ont été conservés à (25 ± 5) °C et (65 ± 5) % HR. Tous les fruits stockés ont été soumis à une analyse biochimique et physico-chimique à intervalles réguliers de 4 jours pendant 16 jours de stockage. **Résultats et discussion**. La perte de poids et la présence de dégradations ont été moindres dans les fruits ayant subi les traitements T1 et T2 par rapport à ceux ayant été soumis à T3 et aux fruits sans enrobage (T4). Les teneurs en matières solides solubles totales, sucres totaux et les changements de pigmentation se sont révélés être moindres dans les fruits soumis à T1, suivis par ceux de T2 et T3. L'addition d'ETV (T3) pour l'enrobage des fruits traités et entreposés a aidé à améliorer les antioxydants comme les phénols totaux et l'acide ascorbique. **Conclusion**. Les revêtements composites comestibles testés dans notre étude ont amélioré la durée de vie des caramboles enrobées ; elle a été de treize jours pour les fruits soumis à T1, seize jours pour ceux de T2, quatorze jours pour T3 par rapport à la durée de vie des fruits non enrobés (douze jours pour T4). La qualité nutritionnelle des caramboles a été améliorée dans le cas d'un enrobage comestible contenant de l'extrait de thé vert.

Inde / *Averrhoa carambola* / fruits / aptitude à la conservation / film comestible / valeur nutritive / perte de poids / pH / teneur en matière sèche / antioxydant / chlorophylle / caroténoïde

1. Introduction

Edible films and coatings composed of naturally obtained polymers such as polysaccharides, as well as proteins, are considered as good oxygen barriers due to their tightly packed and ordered hydrogen-bonded network structure [1]. The quality of the film/coating depends on cohesiveness, which is related to the chemical nature and structure of the polymer used, the presence of additives such as cross-linking agents and the ambient conditions during film formation. The major drawbacks of such films/coatings are their relatively low water resistance and poor vapor barrier properties resulting from their hydrophilic nature [2]. Thus, composite films are designed to achieve a synergistic effect of the combined features of pure components, even though, as with synthetic polymers, mechanical and barrier properties of composite biofilms strongly depend on the characteristics of the constituting polymers and their compatibility [3].

In the recent past, a great number of research efforts have been focused on edible and biodegradable films/coatings with good water and oxygen barrier properties. These research efforts have helped to develop composite coatings or bilayer coatings such as integrating proteins, polysaccharides and/or lipids together to improve the efficiency and functionality of the coatings. Taking these facts into consideration, the composite coatings of sodium alginate, olive oil and green tea were selected for our study.

Alginates are the principal biomacromolecule extracted from brown seaweed. They are sodium salts of alginic acid, which is a linear (1→4) linked polyuronic acid containing poly-β-D-manopyranosyluronic acid (M) blocks and poly-α-L-gulo pyranosyluronic acid (G) blocks containing both polyuronic acids. According to Campos *et al.*, alginates form strong and quite brittle films with poor water resistance [4]; further, they opined that lipids with low polarity can be added to reduce the brittleness of the film and to improve the film-forming properties. One such lipid component is olive oil, which is composed of 56.3–86.5% monounsaturated fatty acids (MUFA), mainly of the mixed triglyceride esters of oleic acid and palmitic acid and other fatty acids, along with traces of squalene (up to 0.7%) and sterols (about 0.2% phytosterol and tocosterols). It is a vegetable oil and extensively consumed due to its nutritional value and its organoleptic characteristics. It is also rich in tocopherols and phenolic substances which act as antioxidants. Green tea is used as an additive in the coating material to enhance the antioxidant capacity of the coating because it is an excellent source of polyphenols, which are natural antioxidants that can be used as alternatives to synthetic antioxidants, as they are typically less harmful than synthetic ones, and appears to have an equivalent effect upon the inhibition of oxidation [5, 6].

Carambola (*Averrhoa carambola* L.), commonly known as star fruit, belongs to the Oxalidaceae family; it is a good source of potassium and antioxidants such as carotenoids and ascorbic acid. As consumers have become more familiar with carambola, its commercial acreage and production have increased throughout the tropical and subtropical world. However, the carambola has a high degree of perishability and therefore cannot be stored for a long period after harvesting, because, as Jhalegar *et al.* opined, after harvesting and during handling, storage or transportation, several physiological and biochemical changes take place in the fruit which lead to fruit softening and senescence [7]. Therefore, our work aimed to evaluate, for carambola, the potential of composite coatings based on sodium alginate and olive oil for improving its shelf life and nutritional quality.

2. Materials and methods

2.1. Fruit material

Carambola berries of a sweet variety were harvested at the slightly under-ripe commercial stage from an agricultural farm, Rainbow, located near Valasan village in Anand district, Gujarat (India), on December 2011. After bringing these fruit to the research laboratory, they were graded to obtain homogeneous batches based on uniform color and size, free from physical injuries and visual defects. Then all the fruit were washed thoroughly with water, surface-disinfected with 2% sodium hypochlorite for 10 min and air-dried.

2.2. Preparation of coating emulsions

Composite coating solutions of 2% (w/v) sodium alginate (Himedia, India) and olive oil were prepared by initial dispersion of the sodium alginate in hot water at 80 °C [8]. After complete solubilization of the sodium alginate, olive oil was added separately at two different concentrations (0.1% and 0.2%, w/v). Once the emulsion was prepared, 0.25% green tea extract was incorporated to formulate the third coating solution. Preparation of green tea extract was carried out by heating 0.25 g fresh leaves in distilled water at 80 °C for 10 min followed by filtration of it to obtain a clear solution [6].

2.3. Coating applications

Fruit were dipped in the following edible coating treatments for 5 min: T1, sodium alginate 2% + olive oil 0.1%; T2, sodium alginate 2% + olive oil 0.2%; T3, sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%, while the fruit treated with water for the same duration of time were considered as a control set (T4). All the treated fruit were allowed to dry at room temperature for 10 min. After setting a thin layer of edible coating on the surface of treated samples, all the control and treated fruit samples were stored in a storage room at room temperature, (25 ± 5) °C and (65 ± 5)% RH, which allowed them to ripen. The following analyses were carried out at (0, 4, 8, 12 and 16) days of storage to evaluate the effect of different concentrations of edible coating components on the postharvest shelf life and nutritional quality.

2.4. Weight loss percentage

Carambola fruit were weighed at the beginning of the experiment just after coating and air drying, and thereafter on every 4th day during the storage period. Weight loss was expressed as the percentage loss of the initial total weight calculated by considering the difference between the initial weight and final weight of the carambola fruit divided by their initial weight [9].

2.5. Storage life

The shelf life of carambola fruit in our study was calculated by counting the days required for them to reach the last stage of ripening, but up to the stage when they remained still acceptable for marketing.

2.6. pH and total soluble solids of the samples

The pH of the carambola fruit samples was determined through the AOAC method [9], whereas the total soluble solids (TSS) content of the fruit was determined by using a refractometer (Atago Co., Tokyo, Japan). A homogeneous sample was prepared by crushing 1 g of fruit sample in a mortar and pestlemortar and pestle with 10 mL water. After centrifuging, the pH was measured by a digital pH meter. For the measurement of TSS, a few drops of same supernatant were placed on the prism of the refractometer and a direct reading was taken.

2.7. Biochemical analysis

The procedures cited by Thimmaiah [10] were followed for the determination of reducing sugars and non-reducing sugars with dinitro-salicylic acid, while total sugars were estimated by using the anthron method. The quantitative analysis of ascorbic acid was carried out by using 2,4-dinitrophenyl hydrazine, as per the method of Roe [11]. Extraction and estimation of total phenols were carried out by using the FCR method cited by Thimmaiah [10]. Extractions and estimations of total chlorophylls and total carotenoids were carried out by following the method of Wang *et al.* [12].

2.8. Statistical analysis

Our data were statistically analyzed by using SPSS 17 software. All analyses performed

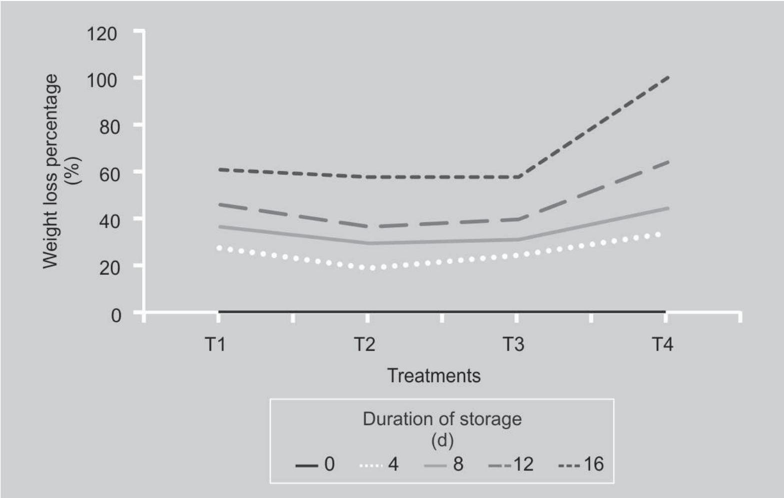

Figure 1.
Effect of composite edible coatings on weight loss percentage in carambola fruit during storage at (25 ± 5) °C and according to three treatments using composite edible coating: T1 (sodium alginate 2% + olive oil 0.1%), T2 (sodium alginate 2% + olive oil 0.2%), T3 (sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%) and T4 (control with no coating).

were carried out in triplicate. The mean and standard deviation (SD) were calculated. The statistical significance of the data was assessed by one-way analysis of variance and the LSD test. Mean comparisons were performed using the HSD of Tukey's test to examine if differences between treatments and storage time were significant at $P < 0.05$. The overall least significance difference (LSD; $p \leq 0.05$) was calculated and used to detect significant differences among all the treatments and control set [13].

3. Results and discussion

The results of our study regarding the influence of the composite coatings on physicochemical and biochemical attributes of coated as well as uncoated carambola fruits are presented below.

3.1. Effect on weight loss

Progressive weight loss was observed in all the treated as well as untreated fruit during the storage of carambola fruit (*figure 1*). Our results suggest that throughout the storage period the weight loss percentage in the fruit of the control set was found to be higher as compared with that of treated fruits. On the 16th day of the storage period, it was observed that the fruit treated with (2% sodium alginate + 0.2% olive oil) (T2) and (2% sodium alginate + 0.2% olive oil + 0.25% green tea extract) (T3) had significantly less weight loss (57.99%) than that of the fruit treated with (sodium alginate 2% + olive oil 0.1%) (T1) (60.99%). This indicates that the treatment with a higher concentration of olive oil could reduce the weight loss more efficiently than the lower concentration, because low polarity of lipid can rectify the brittleness of the film and makes a physical barrier that reduces the water loss from the fruit surface. In view of this, Perez-Gago *et al.* stated that composite coatings of polysaccharide-lipid are known to increase water barrier efficacy with increased lipid content and, in turn, more reduction of weight loss could be achieved [14]. This is also supported by Maqbool *et al.*, who opined that the reduction in weight loss was probably due to the effects of the composite coating, which served as a semi-permeable barrier against oxygen, carbon dioxide and moisture, thus reducing respiration, water loss and oxidation reactions [15].

3.2. Effect on pH and total soluble solids

The values of pH and total soluble solids (TSS) increased significantly ($p < 0.05$) in both treated as well as untreated fruit as the storage time increased (*table I*). According to Pesis *et al.* [16], the increase in pH of fruit may be due to the breakdown of acids in the respiration process during storage, which is influenced by the oxygen uptake and carbon dioxide evolved. In fresh fruit, the metabolic process continues even after harvesting. On the 12th day of the storage period, the lowest pH (4.22) was found in the fruit treated with T2, followed by a pH of 4.84 found in T3 and a pH of 5.00 found in T1. At the end of the storage period, the highest value of pH was recorded in control fruit, *i.e.*, 5.09. This suggests that the composite coating with a higher lipid concentration is more efficient at reducing the respiration rate by reducing organic acid uptake in the respiration process. It is well known that the lower the respiration rate by means of postharvest applications, the lower the use of organic acids in the enzymatic reactions of respiration [13, 17].

Table I.
Changes in pH and total soluble solids of carambola fruit during 16 days of storage, according to three treatments using composite edible coating.

a) pH

Treatments		Day 0	Day 4	Day 8	Day 12	Day 16
T1	Sodium alginate 2% + olive oil 0.1%	3.34 ± 0.18 a	3.91 ± 0.01 b	4.95 ± 0.01 b	5.00 ± 0.02 b	5.95 ± 0.01 a
T2	Sodium alginate 2% + olive oil 0.2%	3.34 ± 0.18 a	3.53 ± 0.01 c	4.09 ± 0.01 d	4.22 ± 0.03 d	5.72 ± 0.02 c
T3	Sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%	3.34 ± 0.18 a	3.89 ± 0.03 b	4.72 ± 0.01 c	4.84 ± 0.02 c	5.81 ± 0.02 b
T4	Control (no coating)	3.34 ± 0.18 a	4.42 ± 0.01 a	4.99 ± 0.03 a	5.09 ± 0.01 a	–

b) Total soluble solids (mg·g^{-1} fresh weight)

Treatments		Day 0	Day 4	Day 8	Day 12	Day 16
T1	Sodium alginate 2% + olive oil 0.1%	0.63 ± 0.06 a	1.13 ± 0.0 b	1.20 ± 0.0 b	1.50 ± 0.0 b	1.53 ± 0.1 ab
T2	Sodium alginate 2% + olive oil 0.2%	0.63 ± 0.06 a	0.80 ± 0.0 c	0.90 ± 0.0 d	1.00 ± 0.0 d	1.23 ± 0.1 b
T3	Sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%	0.63 ± 0.06 a	1.10 ± 0.0 b	1.17 ± 0.0 c	1.37 ± 0.1 c	1.50 ± 0.0 a
T4	Control (no coating)	0.63 ± 0.06 a	1.23 ± 0.0 a	1.30 ± 0.0 a	1.80 ± 0.0 a	–

Different letters in the same column indicate significantly different data at $p \leq 0.05$.

Aguiar *et al.* also noted that a variety of coating materials have been investigated due to their ability to modify the internal fruit atmosphere, slowing down respiration and, therefore, ripening and senescence [18].

On the 12th day of the storage period, the TSS content was found to be the highest (1.8%) in the untreated fruit; it was observed to be the lowest in fruit treated with T2 (1%), followed by T3 (1.37%) and T1 (1.5%). The highest amount of TSS is probably due to the higher accumulation of hexose sugar during ripening [19]. Increase in the TSS content indicates conversion of polysaccharides present in fruits into soluble sugars by the action of various hydrolyzing enzymes [20]. Throughout the storage period, the TSS content of treated fruits was lower as compared with that of untreated fruit. A similar result was reported by Mastromatteo *et al.* [21]. These authors reported higher accumulation of TSS in control fruits in minimally processed kiwi fruit coated with alginate, as compared with that of the other treatments. An edible coating provides a semi-permeable barrier which is proficient at prolonging storability by reducing oxygen, carbon dioxide (CO_2), moisture and solute movement, thereby reducing respiration, water loss and oxidation reaction rates [22, 23]. A low respiration rate decelerates the synthesis and utilization of metabolites, resulting in lower TSS due to the slower change from carbohydrates to sugars. Uncoated (control) fruit was observed to have the highest TSS. The TSS was found to be reduced with calcium-treated fruit, which was probably due to the slowing down of respiratory and metabolic activity, thereby delaying the ripening process [24, 25]. According to Nurul Hanani *et al.*, it is important to decrease the amount of carbon dioxide escaping from internal tissues of fruits to control their ripening [26]. They found that a coating slowed down the rise in carbon dioxide throughout the storage time of star fruits.

3.3. Effect on reducing sugars, non-reducing sugars and total sugars

A significant ($p < 0.05$) increase was observed in the content of reducing sugars, non-reducing sugars and total sugars of carambola fruit throughout its storage period

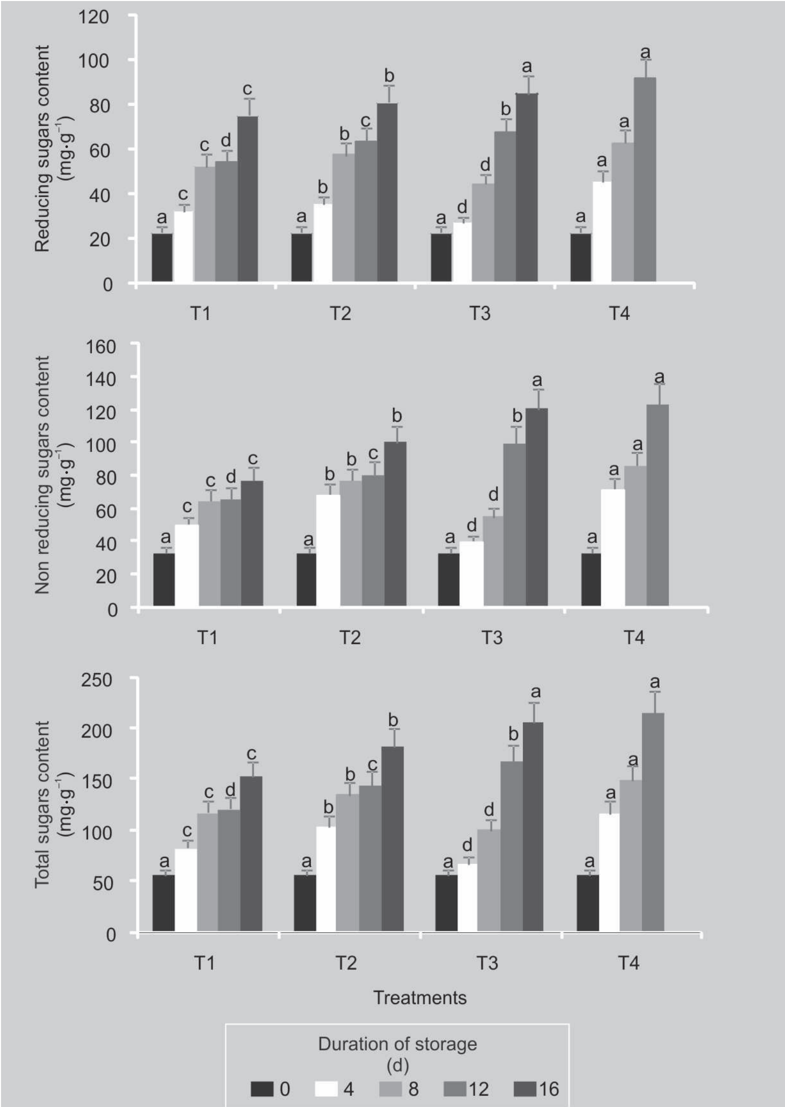

Figure 2.
Effect of composite edible coatings on reducing sugars, non-reducing sugars and total sugar contents in carambola fruit during storage at (25 ± 5) °C and according to three treatments using composite edible coating: T1 (sodium alginate 2% + olive oil 0.1%), T2 (sodium alginate 2% + olive oil 0.2%), T3 (sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%) and T4 (control with no coating). Different letters on the bars mean significantly different at $p \leq 0.05$.

in both the treated and the control set (*figure 2*).

Reducing sugar content was 22.4 $mg \cdot g^{-1}$ at day 0 but subsequently, in control fruit, it increased gradually and reached 45.09 $mg \cdot g^{-1}$ on the 4th day, 62.43 $mg \cdot g^{-1}$ on the 8th day and 90.52 $mg \cdot g^{-1}$ on the 12th day of the storage period. In all the treated fruit, the levels of reducing sugars were lower in comparison with those of untreated fruit. At the end of the storage period, the carambola fruit treated with (sodium alginate 2% + olive oil 0.1%) (T1) showed the lowest value of reducing sugar, that suggests a decline in the rate of the metabolism due to the impact of the composite coating. Wills and Rigney opined that the maximum amount of reducing sugars in untreated control fruits might be due to rapid conversion of starch to sugars as a result of moisture loss and decrease in acidity by physiological changes during storage [27]. On the 12th day of storage, the lowest value of non-reducing sugar was found in the order of fruit treated with T1 (65.95 $mg \cdot g^{-1}$), T2 (80.64 $mg \cdot g^{-1}$) and T3 (99.94 $mg \cdot g^{-1}$), and the highest in the control fruit (123.7 $mg \cdot g^{-1}$). At the end of the storage, the total sugar content was also found to be the highest in the control fruit (214.6 $mg \cdot g^{-1}$). According to Maqbool *et al.*, an increase in reducing sugar was correlated with the enzymatic conversion of starch to reducing sugar and also the conversion of some non-reducing sugars to reducing sugars through the process of inversion [15].

3.4. Effect on ascorbic acids

The ascorbic acid of fruit is one of the most important nutrient quality parameters. Various parameters such as water loss, cell wall damage, oxygen level, temperature and humidity have been reported to affect the stability or breakdown of the ascorbic acid structure of fruits during their postharvest storage [17, 28]. Initially at day 0, the value of ascorbic acid was 130.2 $mg \cdot g^{-1}$ (*table II*). After that, this value decreased significantly ($p \leq 0.05$) in all the treated as well as untreated fruits. On the 12th day of the storage period, fruit treated with T3 containing green tea extract showed the highest ascorbic acid content (82.22 $mg \cdot g^{-1}$), followed by T2 (77.11 $mg \cdot g^{-1}$) and T1 (68 $mg \cdot g^{-1}$), whereas the lowest amount (62.89 $mg \cdot g^{-1}$) occurred in untreated fruit. These results indicate that the composite coating comprising green tea extract and a higher concentration of olive oil could help in improving the antioxidant power in terms of ascorbic acid enhancement and reduce the loss of ascorbic acid by reducing gaseous exchange, because, according to Yaw *et al.*, autoxidation of ascorbic acid occurs spontaneously when it combines with oxygen in the air [29]. Togrul *et al.* stated that coatings

Table II.
Changes in ascorbic acid and total phenols of carambola fruit during 16 days of storage, according to three treatments using composite edible coating.

Treatments		Day 0	Day 4	Day 8	Day 12	Day 16
a) Ascorbic acid ($mg \cdot g^{-1}$ fresh weight)						
T1	Sodium alginate 2% + olive oil 0.1%	130.2 ± 2.04 a	97.33 ± 2.40 b	74.22 ± 2.69 c	68.00 ± 2.67 c	48.00 ± 1.76 b
T2	Sodium alginate 2% + olive oil 0.2%	130.2 ± 2.04 a	99.56 ± 4.02 b	78.44 ± 1.02 b	77.11 ± 0.38 b	56.00 ± 1.76 ab
T3	Sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%	130.2 ± 2.04 a	120.0 ± 8.67 a	93.78 ± 3.15 a	82.22 ± 2.04 a	58.00 ± 2.67 a
T4	Control (no coating)	130.2 ± 2.04 a	77.56 ± 2.69 c	70.22 ± 1.68 d	62.89 ± 1.01 d	–
b) Total phenols ($mg \cdot g^{-1}$ fresh weight)						
Treatments		Day 0	Day 4	Day 8	Day 12	Day 16
T1	Sodium alginate 2% + olive oil 0.1%	1.553 ± 0.05 a	2.472 ± 0.02 c	2.071 ± 0.01 c	1.392 ± 0.01 c	1.007 ± 0.01 c
T2	Sodium alginate 2% + olive oil 0.2%	1.553 ± 0.05 a	2.622 ± 0.08 b	2.135 ± 0.03 b	1.754 ± 0.02 b	1.486 ± 0.03 b
T3	Sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%	1.553 ± 0.05 a	2.913 ± 0.02 a	2.381 ± 0.04 a	1.804 ± 0.01 a	1.563 ± 0.01 a
T4	Control (no coating)	1.553 ± 0.05 a	2.168 ± 0.03 d	0.981 ± 0.11 d	0.545 ± 0.02 d	–

Different letters in the same column indicate significantly different data at $p \leq 0.05$.

serve as a protective layer and control the permeability of O_2 and CO_2, thus decreasing the autoxidation potential of fruit [30]. These results are in accordance with the findings of Zhu *et al.*, who reported that the use of edible coatings of different types of polysaccharides significantly reduced the loss of vitamin C in mango [31].

3.5. Effect on total phenols

Phenolic compounds are closely associated with the sensory and nutritional quality of foods. These phenolic compounds contribute directly or indirectly to desirable or undesirable aroma and taste. Phenolic compounds are thus good antioxidants and substrates for oxidative browning [32]. Phenolic compounds are widely distributed in plants, and have gained much attention due to their antioxidant activities and free radical-scavenging abilities, which potentially have beneficial implications for human health [33].

Our results regarding the phenolic content of carambola fruit studied during its postharvest storage show that, during four days of the storage period, the phenol contents increased significantly ($p \leq 0.05$) in both treated as well as untreated fruit (*table II*). Subsequently, these values continued to increase in all treated fruit but, on the 8th day of the storage period, these values were found to have decreased, *i.e.*, 2.071 $mg \cdot g^{-1}$ for fruit of T1, 2.135 $mg \cdot g^{-1}$ for fruit of T2 and 2.381 $mg \cdot g^{-1}$ for fruit of T3. In the control set, the level of phenols was found to have declined (0.981 $mg \cdot g^{-1}$). At the end of the storage, the highest value of total phenols (1.804 $mg \cdot g^{-1}$) was found in fruit treated with T3 (sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%) followed by those treated with T2 (1.754 $mg \cdot g^{-1}$), then those treated with T3 (1.392 $mg \cdot g^{-1}$); the lowest value was found in control fruit (0.545 $mg \cdot g^{-1}$). This suggests that the composite coating comprising sodium alginate, olive oil and green tea extract as an additive helps in enhancement of phenolic contents. Ali *et al.* reported a low amount of total phenolic content or a sharp decline of it in untreated control tomato fruit as compared with that treated with Arabic gum [34]. Several studies have demonstrated that green tea extract, which contains polyphenols and catechins, has

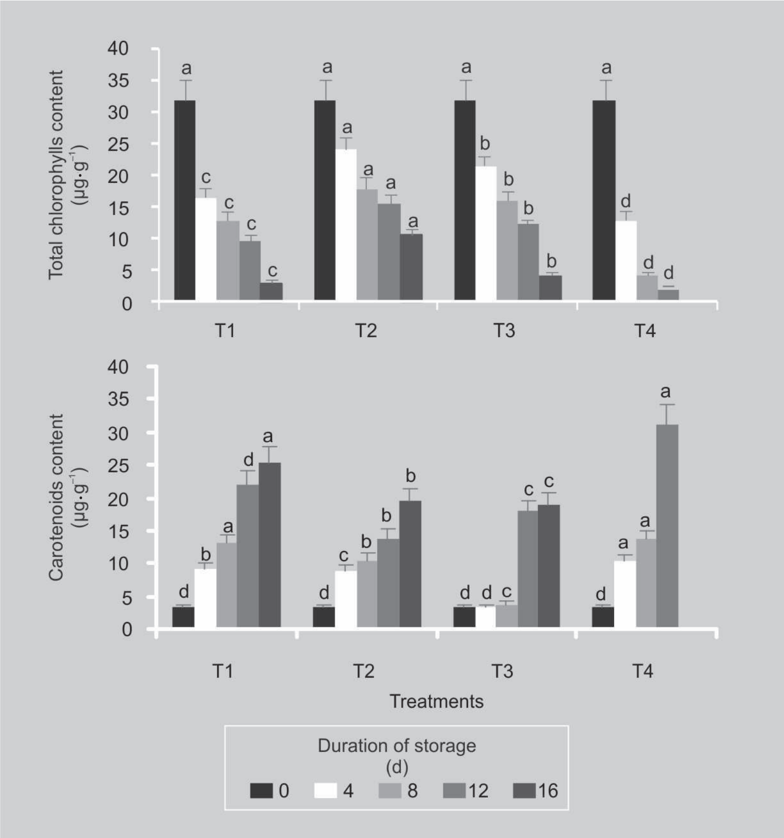

Figure 3.
Effect of composite edible coatings on total chlorophyll and carotenoid contents in carambola fruit during storage at (25 ± 5) °C and according to three treatments using composite edible coating: T1 (sodium alginate 2% + olive oil 0.1%), T2 (sodium alginate 2% + olive oil 0.2%), T3 (sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%) and T4 (control with no coating). Different letters on the bars mean significantly different at $p \leq 0.05$.

antibacterial activity, antiviral action and radical scavenging action [35, 36].

3.6. Effect on total chlorophylls and carotenoids

According to Tucker *et al.*, the color of the fruit changes during fruit ripening from green to yellow due to chlorophyll degradation and carotenoid synthesis [37].

Our data regarding the total chlorophylls and carotenoids show that initially the value of total chlorophyll was 32 $\mu g \cdot g^{-1}$ and that it decreased gradually throughout the storage period in both the treated as well as untreated fruit (significant at $p < 0.05$) (*figure 3*). At the end of the storage period, at 12 days, the highest chlorophyll content (15.3 $\mu g \cdot g^{-1}$) was retained by the fruit of the T2 treatment, followed by those of T3 (12.2 $\mu g \cdot g^{-1}$) and T1 (9.4 $\mu g \cdot g^{-1}$), whereas in the control fruit it was very minimal, *i.e.*, 1.5 $\mu g \cdot g^{-1}$.

These results indicate that the composite coating can reduce the gaseous exchange and lowers the availability of oxygen, thereby reducing the activity of chlorophyllase enzyme. During storage, the color of the carambola fruit changes from green to yellow, which indicates that the chlorophylls are degraded and the carotenoids are synthesized.

At day 0, the content of carotenoids was 3.3 $\mu g \cdot g^{-1}$ and this content gradually increased during the storage period (*figure 3*). At the end of the storage, the highest content of carotenoids was found in fruits of the control set and the lowest one in the treated fruits, *i.e.*, 21.89 $\mu g \cdot g^{-1}$ for fruit of T1, 13.78 $\mu g \cdot g^{-1}$ for fruit of T2 and 17.86 $\mu g \cdot g^{-1}$ for fruit of T3. This suggests that the composite coating can help in reducing the synthesis of carotenoids, which delays ripening and senescence and extends the shelf life of the fruit. The delay in the ripening of the coated fruit may be due to the modified internal atmosphere in the coated fruit that reduces the degradation of chlorophylls and/or the biosynthesis of carotenoids [38]. Retention of skin color in coated fruit was a result of the modified atmosphere created by coatings around the fruit. It has been reported that the presence of CO_2 prevented degradation of chlorophyll [39, 40].

3.7. Effect on shelf life

The shelf life of the treated carambola fruits was longer than that of untreated fruits (*figure 4*). In our study, the shelf life of the fruits treated with T1 could be extended to 16 days, which is longer than the shelf life of fruits of all other treatments and the control set. Perhaps the incorporation of olive oil in the sodium alginate coating helped in reducing the rate of ripening in terms of respiration and metabolism. These results are similar to the results of Kittur *et al.*, who noted that polysaccharide-based coating formulations helped in reducing the rate of the metabolism to give prolonged storage life and extension to the shelf life of banana of 21 days and mango of 8 days longer than that of the control fruits [41]. Baraiya *et al.* also reported that the application of edible coatings such as carrageenan and CMC with a combination of cinnamon oil was found to be effective in extending the shelf life of tomato fruit in upholding and improving its nutritional quality [42]. Similar results were observed by Gol *et al.,* according to whom the shelf life of carambola fruit could be prolonged by using a composite coating of chitosan and gum arabic without affecting the nutritional quality [40].

4. Conclusion

Our results suggest that the application of a composite edible coating of sodium alginate and olive oil was effective in retarding the ripening behavior of carambola fruit without its excessive deterioration. A combination of sodium alginate and olive oil could form a better film than any single component. Moreover, a higher concentration of olive oil (0.2%) in sodium alginate exhibited more efficiency in delaying ripening than a lower concentration (0.1%). The composite coating was able to retard the rate of respiration and the metabolism, which helped in delaying the ripening and senescence process of fruit. The application of green tea extract was found to be effective in improving the level of phenolic compounds and ascorbic acid. Moreover, addition of olive oil strengthened the film-forming property of sodium alginate and helped to overcome setbacks such as fragility and brittleness of the film.

Thus, the experiment of using a composite edible coating on carambola fruit conducted here may be a useful and promising eco-friendly postharvest technique for enhancement of postharvest shelf life and quality maintenance of perishable fruits and vegetables.

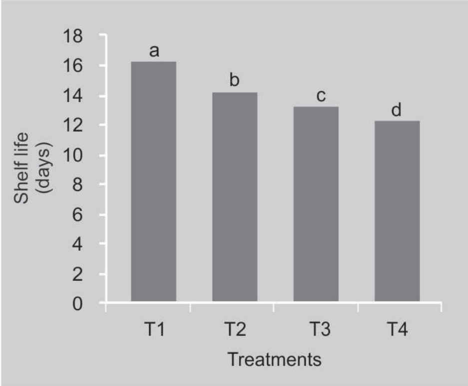

Figure 4.
Effect of composite edible coatings on shelf life in carambola fruit during storage at (25 ± 5) °C and according to three treatments using composite edible coating: T1 (sodium alginate 2% + olive oil 0.1%), T2 (sodium alginate 2% + olive oil 0.2%), T3 (sodium alginate 2% + olive oil 0.1% + green tea extract 0.25%) and T4 (control with no coating). Different letters on the bars mean significantly different at $p \leq 0.05$.

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Refuerzo de la duración de almacenamiento y del mantenimiento de la calidad de la carambola (*Averrhoa carambola* L.) gracias a un revestimiento compuesto comestible.

Resumen – **Introducción**. El objetivo de nuestro experimento fue el estudio de la influencia de revestimientos ecológicos comestibles, compuestos de alginato de sodio, de aceite de oliva y de extracto de té verde (ETV), en la mejora de la duración de vida y la calidad nutricional de la carambola (*A. carambola* L.). **Material y métodos**. Las combinaciones de los revestimientos compuestos testeados fueron de un (2 % de alginato de sodio + 0,1 % de aceite de oliva) (T1), (2 % de alginato de sodio + 0,2 % de aceite de oliva) (T2), (2 % de alginato de sodio + 0,1 % de aceite de oliva + 0,25 % ETV) (T3) ; los frutos no tratados sirvieron de testigo (T4) y se conservaron a (25 ± 5) °C y (65 ± 5) % HR. Todos los frutos almacenados se sometieron a un análisis bioquímico y físico-químico, en intervalos regulares de 4 días durante 16 días de almacenamiento. **Resultados y discusión**. La pérdida de peso y la presencia de degradaciones fueron menores en los frutos sometidos a los tratamientos T1 y T2 en relación con aquéllos sometidos a T3 y con los frutos sin revestimiento (T4). Los contenidos de materias sólidas solubles totales, azúcares totales y los cambios de pigmentación resultaron ser menores en los frutos sometidos a T1, seguidos por los de T2 y T3. El aporte de ETV (T3) en el revestimiento de los frutos tratados y almacenados contribuyó a mejorar los antioxidantes, como los fenoles totales y el ácido ascórbico. **Conclusión**. Los revestimientos compuestos comestibles testeados en nuestro estudio mejoraron la duración de vida de las carambolas revestidas; que fue de trece días para los frutos sometidos a T1, diez y seis días para los de T2, catorce días para T3, en relación con la duración de vida de los frutos no revestidos (doce días para T4). La calidad nutricional de las carambolas se mejoró en el caso de un revestimiento comestible con contenido de extracto de té verde.

India / *Averrhoa carambola* / frutas / aptitude para la conservación / film comestible / valor nutritivo / pérdida de peso / pH / contenido de materia seca / antioxidantes / clorofilas / carotenoides