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Preserving the quality of fruits and enhancing the storability of cucumbers by postharvest treatments

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ABSTRACT

Cucumber fruit (*Cucumus sativus*, L.) Merage F1 hybrid was harvested at the appropriate stage of marketing maturity in 2021 and 2022 seasons to study the influence of some postharvest treatments (sodium alginate 2%, chitosan 0.5%, pomegranate peel extract (PPE) 10%, sodium alginate + PPE, and chitosan + PPE) compared with untreated fruits as a control on preserving quality and enhancing storability for cucumbers during storage at 10°C and 90-95 % relative humidity for 16 days. According to the results, all postharvest treatments were superior to untreated fruits in terms of reducing weight loss, change of color, loss of firmness, and maintaining total soluble solids, total chlorophyll, and total phenolic contents, as well as the overall appearance of fruits during storage periods. However, chitosan + PPE or sodium alginate + PPE treatments were the best treatments for maintaining the overall quality attributes of cucumber fruits. Furthermore, the chitosan + PPE treatment gave the best results in slowing the rate of weight loss (1.09 & 1.21%), retaining green color (L* and h°), maintaining fruit firmness (6.80 & 5.98 kg/cm^2), total soluble solids (3.87 & 3.63%), total chlorophyll (57.71 & 56.32 mg/100 g fresh weight), and total phenolic (6.62 & 6.28 mg/g dry weight), and giving an excellent appearance of fruits without decay for 16 days.

Keywords: *Cucumus sativus*, edible coatings, agro-industrial wastes, quality, postharvest life

INTRODUCTION

More than 90% of the cucumber (*Cucumus sativus*, L.) vegetable is water, which has a substantial impact on the fruit's quality throughout storage, transportation, and marketing (Smith *et al*., 2006). Because cucumbers are considered fast perishable crops, their fruit quality declined significantly after harvest due to water loss, skin shrinkage, and a loss of their vibrant green color, which limited their shelf life after harvest (Al-Juhaimi *et al*., 2012). During postharvest handling, the cucumber tends to have some physicochemical changes, microbial populations, and desiccation, which influence the appearance and lower the nutrients. The moisture loss resulting from the transpiration process leads to wilting, shrinkage, softening, and acceleration of senescence (Khojah *et al*., 2021). Therefore, it was suggested to use some postharvest treatments (chitosan, sodium alginate, and pomegranate peel extract) in addition to refrigeration to maintain quality and improve the storability of cucumber fruits.

Chitosan is a carbohydrate polymer with a high molecular weight that is created by the deacetylation of chitin. Chitosan is naturally biodegradable in addition to its antimicrobial and antioxidant characteristics (Edirisinghe *et al*., 2014). It is commonly used as a semipermeable coating in preserving fruits and vegetables to regulate the internal atmosphere and reduce transpiration and respiration, thus extending the postharvest life (Varasteh *et al*., 2017). Results of various experiments demonstrated that the use of chitosan was beneficial in retarding the ripening of strawberries (Martìnez *et al*., 2018) and tomatoes (Sucharitha *et al*., 2018), in addition to maintaining the fruit quality and increasing the storability of cucumbers (Saad, 2019).

Alginate is a natural polysaccharide that is derived from brown seaweed belonging to the Phaeophycean family. Alginate is a coating substance that has been shown to retard ripening and preserve fruit quality, and its effectiveness can be enhanced by combining it with antioxidant or antimicrobial agents (Benavides *et al*., 2012). It is widely applied to improve the storability of various horticultural crops by decreasing drought, respiration, and microbial degradation and enhancing mechanical characteristics (Parreidt *et al*., 2018), reducing weight loss, maintaining the firmness of fruits and overall quality properties, extending the shelf life of strawberries (Guerreiro *et al*., 2015 and Peretto *et al*., 2017), and delaying the ripening of tomatoes (Zapata *et al*., 2008).

Recently, the focus has been on using organic materials like agro-industrial wastes to biologically control plant diseases. The peel of pomegranates is regarded as a good example of this category, and it is approximately 50% of the total weight of the fruit. (Al-Said *et al*., 2009). Additionally, it includes bioactive substances such as phenolic and flavonoid compounds (Ismail *et al*., 2012), which have antifungal, antibacterial, and antioxidant properties (Malviya *et al*., 2014). With edible coatings, pomegranate peel, a natural antioxidant, can be employed to prevent microbial development and maintain biological processes. This is probably caused by the presence of bioactive molecules that prevent bacterial development (Nair *et al*., 2018a; Saxena *et al*., 2020).

Previous studies indicated that the application of chitosan or alginate coating combined with pomegranate peel extract significantly inhibited microbial growth, maintained quality properties, and extended the postharvest life of bell peppers (Nair *et al*., 2018a and Kumar *et al*., 2021), and proved effective in preserving the quality of guavas (Nair *et al*., 2018b).

The present research investigated the effects of chitosan, alginate, and pomegranate peel extract (PPE) separately and chitosan or alginate in combination with PPE on the quality of cucumber fruits during storage at 10°C and 90-95% relative humidity for 16 days.

MATERIALS AND METHODS

Cucumber fruits (*Cucumus sativus*, L.) Merage F1 hybrid were harvested at the proper marketing maturity stage from a private farm in Abu Rawash, Giza Governorate, during the winter season on 17th and 19th of January in 2021 and 2022 seasons, respectively. The cucumber fruits were transported to the laboratory of the Postharvest and Handling of Vegetable Crops Research Department, Horticulture Research Institute, Agricultural Research Center, Giza. Fruits healthy and free from any defects or diseases and uniform in length, diameter, weight, and color were selected for the storage experiment.

Preparation of chitosan solution: 0.5% (w/v) of chitosan powder (Technogene Co.) and 0.5% of citric acid solution were dissolved in distilled water, and this solution was homogenized using a magnetic stirrer at room temperature (Kumar *et al*., 2019).

Preparation of sodium alginate solution: 2% (w/v) of sodium alginate powder (Technogene Co.) was dissolved in distilled hot water at 45°C. The alginate solution was cooled and then 10% glycerol was added to this solution as a plasticizer and a stabilizer (Nair *et al*., 2018b).

Pomegranate peel extract (PPE) preparation: Pomegranate fruits were bought at a neighborhood store and manually peeled. The pomegranate peel was powdered after drying at 50°C. To get the crude extract, the powder was first dissolved in ethanol (1:20 w/v), which was then extracted for four hours at 40°C in a water bath (Eleryan and EL-Metwally, 2020). The approximate chemical composition of pomegranate peel extracts is shown in Table 1.

Table 1. Pomegranate peel extract's approximate chemical composition

Total phenolic content (mg/g)	Total flavonoid content (mg/g)	Antioxidant capacity (µg/ml)	Fat (%)	Ash (%)	Protein (%)	Fiber (%)	Total carbohydrate
148.25	62.89	13.71	0.68	4.11	7.62	16.35	56.12

Analytical methods:

Total phenolic content was measured as stated by Singleton *et al*. (1999), total flavonoid content was determined according to Matyuschenko and Stepanova (2003), antioxidant activity was determined according to Yen and Duh (1994), and fat, ash, fiber, protein, and total carbohydrate were determined using the AOAC method (2016).

Cucumber fruits were dipped in sodium alginate 2% for 2 min, chitosan 0.5% for 2 min., pomegranate peel extract (PPE) 10% for 2 min., sodium alginate 2% + pomegranate peel extract 10% for 2 min., solution of chitosan 0.5% + pomegranate peel extract 10% for 2 min., and distilled water as a control (untreated fruits). After removing water from fruits surface, the fruits from each treatment were packed in sealed polypropylene bags (30 µm thickness, 25×30 cm size), and each bag contained 3 fruits represented as one replicate. Twelve replicates were prepared for each treatment. All treatments were stored at 10°C and 90-95 % relative humidity for 16 days. The experimental design was a completely randomized design with three replicates. Three replicates from each treatment were taken at random and examined immediately after harvest and after 4, 8, 12 and 16 days at 10°C for the following properties.

The percentage of weight loss was calculated using the following equation: Weight loss percentage = ((Initial weight of fruits – weight of fruits at sampling date) / Initial weight of fruits) × 100. The general appearance was graded on a scale from 9 to 1, with 9 being excellent, 7 being good, 5 being fair, 3 being poor, and 1 being unsalable; fruits rated (5 or lower) were judged unmarketable. It was noted for shrivelling, wilting, color change, decay, and any other observable deterioration, as stated by Kader *et al*. (2002). The decay was graded on a scale of 1 to 5, with 1 indicating no decay, 2 indicating slight decay, 3 indicating moderate decay, 4 indicating severe decay, and 5 indicating extreme decay. It was documented for all the damaged or rotten fruits caused by fungus or bacteria, as specified by Wang and Qi (1997). The firmness of skin was measured using a hand pressure tester (Italian model) and expressed in kg/cm^2 (Abbott, 1999). A refractometer was used to determine the TSS, which stands for the total soluble solids percentage (AOAC, 1990). A Minolta CR-400 Chroma Meter was utilized to get readings for the brightness (L*) and hue angle (h°) of the color found on the outside surface (Minolta Co., Ltd., Osaka, Japan). Lightness, on the other hand, was used to express gloss, while hue angle was used to communicate skin color. During the entirety of each data observation, three readings were collected from each cucumber fruit in a variety of postures (McGuire, 1992). The AOAC method (1990) was utilized in order to provide an accurate reading of the skin's total chlorophyll content. Ten milliliters of acetone with 80 percent concentration were used to extract one gram of the sample. After the samples had been filtered, an absorbance spectrophotometer was used to measure the chlorophyll a and chlorophyll b absorbance wavelengths at 662 and 645 nanometers, respectively. According to Singleton and colleagues' findings, the total phenolic content of the pulp was determined (1999). After being dried, the samples were then milled into a powder. In 10 milliliters of ethanol with a concentration of 95%, 0.5 grams of the powder were extracted. Following filtering, one milliliter of the extract was combined with one milliliter of Folin-Ciocalteu reagent and two milliliters of sodium carbonate at a concentration of seven-point five percent. The tubes were then left to sit for thirty minutes while the blue color developed. To determine the sample concentrations, a spectrophotometer set at 750 nm was utilized.

Statistical analysis:
Using the MSTATC program, a statistical analysis of the data was performed to calculate the means, variance, and standard error. The LSD value at the 5% level was calculated to estimate mean separations (Snedecor and Cochran, 1980).

RESULTS

Weight loss (%)

As can be observed in Figure 1, the weight loss % of cucumbers increased considerably as the storage duration was extended in both seasons. When compared with untreated fruits, all of the treatments that were applied indicated a much-reduced percentage of weight loss during storage. Furthermore, chitosan plus pomegranate peel extract (PPE) and sodium alginate plus PPE were the best treatments for reducing the percentage of weight loss, with no significant differences between them. The chitosan-alone treatment was the second best in this regard, followed by the sodium alginate-alone treatment, which was the least effective in this regard. Both the pomegranate peel extract treatment and the untreated fruits resulted in the greatest percentage of weight reduction; nevertheless, there were significant disparities between the two groups. Throughout both seasons, there was a significant amount of interaction between all of the treatments and all of the storage periods. In addition, the treatments with chitosan + PPE and sodium alginate + PPE had the lowest values of weight loss for 16 days of storage (1.09 & 1.21 percent) and (1.14 & 1.26 percent), respectively, with no significant differences between them. On the other hand, untreated fruits recorded the highest values of weight loss (4.01 & 4.19 percent) during the same period.

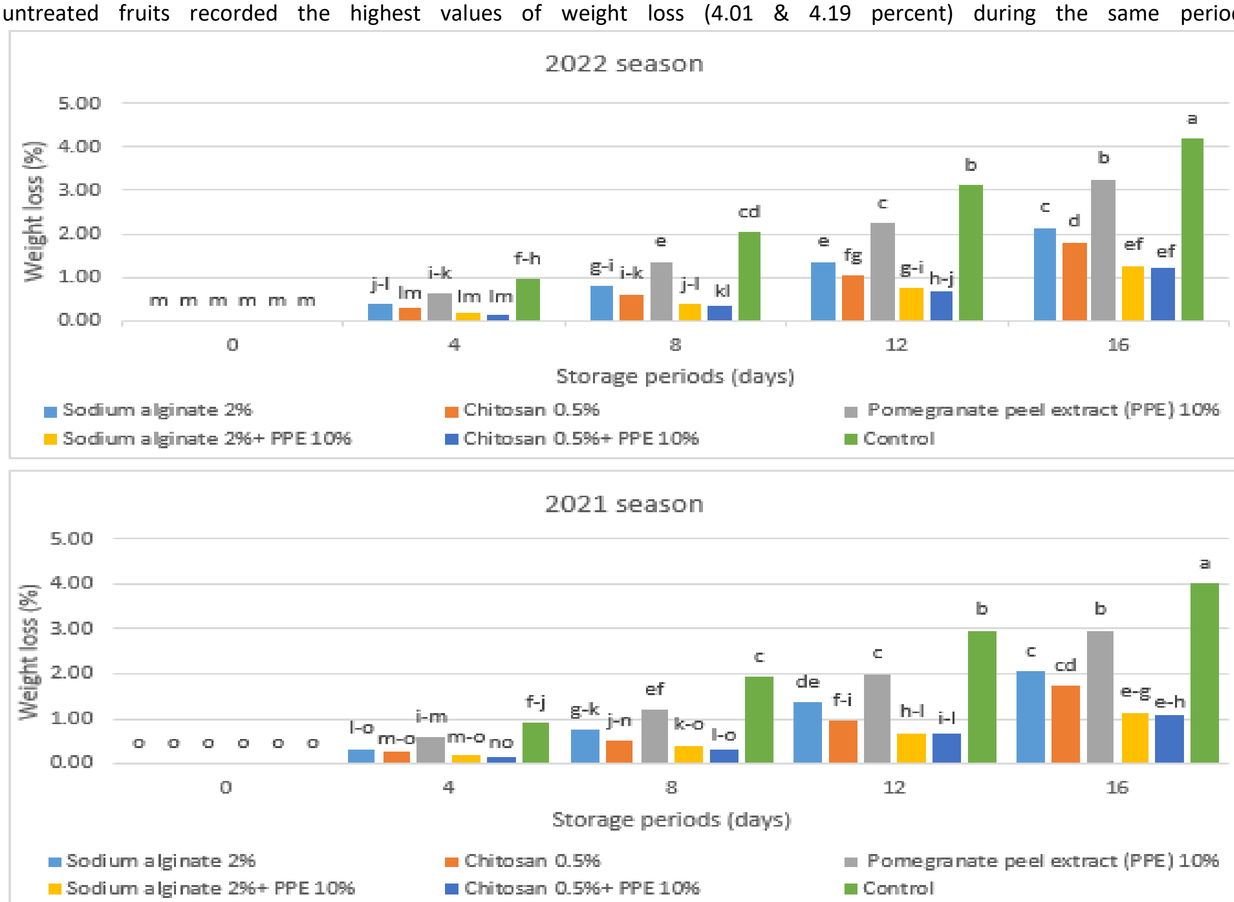


Fig. 1. The impact of postharvest treatments on the proportion of weight loss of cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.

General appearance (GA)

As can be observed in Figure 2, there was a considerable decrease in the GA of cucumber fruits with an extension of the storage time in both seasons. When compared to the treatment that served as a control, the overall degradation in appearance was significantly mitigated by each of the treatments that were applied. In addition, neither the chitosan + PPE nor the sodium alginate + PPE treatments substantially varied from one another in terms of keeping their GA. In addition, these treatments resulted in the fruits having the best appearance and recording the highest score in GA. The treatments by chitosan alone or sodium alginate alone came in second place in this regard, with no significant differences between them in the first season. PPE treatment was the least successful for maintaining the GA of cucumber fruits, whereas untreated cucumbers received the lowest score possible in this regard. There was a significant amount of interaction between all of the treatments and all of the storage periods. Chitosan + PPE treatment gave an excellent appearance and didn't show any changes in this appearance until the end of the storage duration (8.33) in both seasons, while sodium alginate + PPE treatment gave a good appearance during the same storage period (7.00) in both seasons. While chitosan or sodium alginate treatments alone provided a good appearance until 12 days of storage and then deteriorated to a fair appearance after 16 days, in contrast, untreated fruits showed an unsalable appearance after 16 days of storage (1.67 and 1.00) in both seasons, respectively.

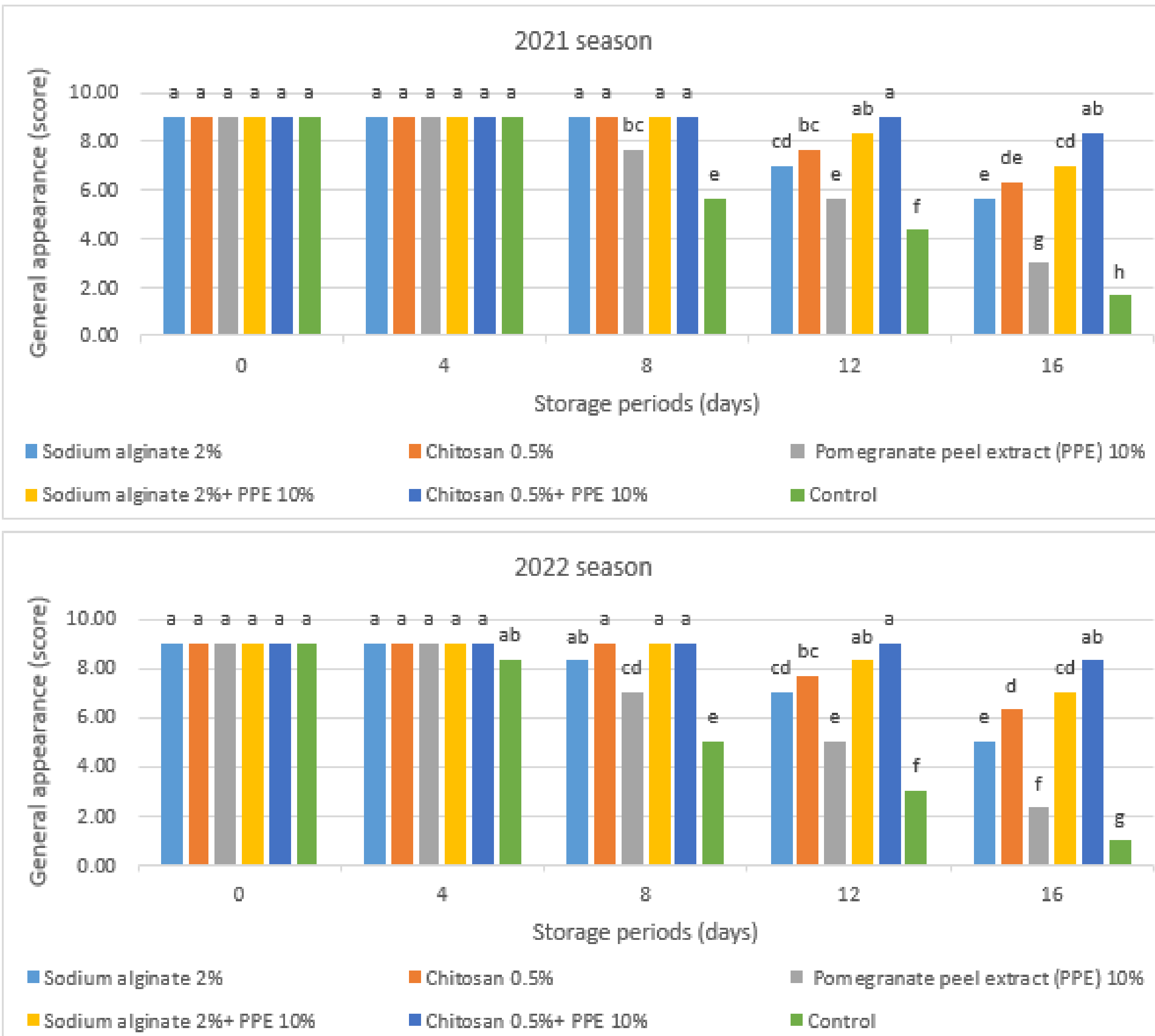


Fig. 2. The impact of postharvest treatments on the general appearance (score) of cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.

Decay

As shown in Fig. 3, the decay score of cucumbers increased significantly with increasing storage duration in both seasons. All treatments performed significantly better in decreasing the decay score and thus prolonging the storage period when compared with the control fruits. Moreover, chitosan + PPE, sodium alginate + PPE, or chitosan alone treatments didn't show any decay until the end of the storage time, with no significant differences between them in both seasons, while sodium alginate alone or PPE treatments decreased the occurrence of decay, with significant differences between them. On the other hand, the highest score of decay was recorded in untreated fruit after 16 days of storage in both seasons.

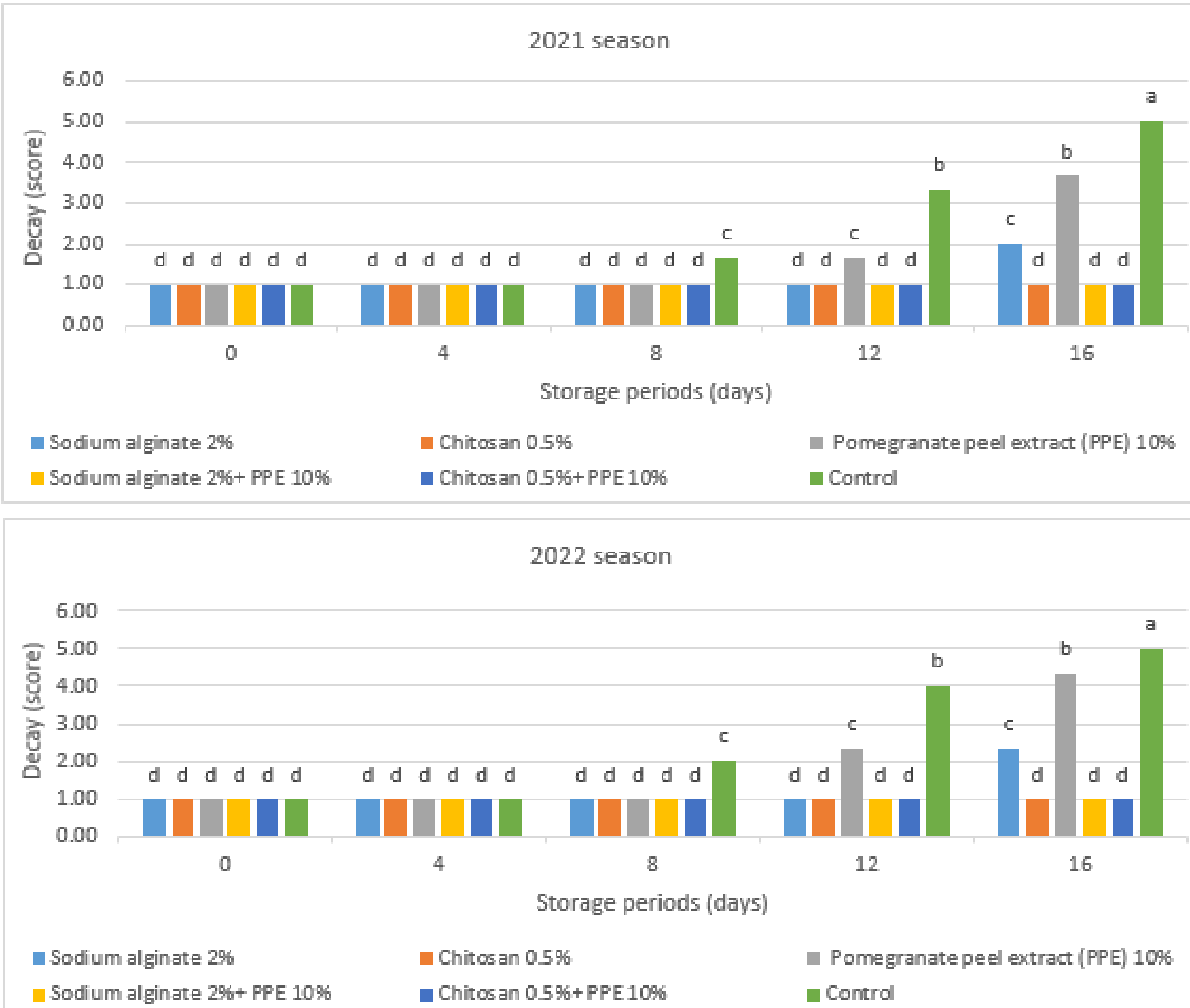


Fig. 3. The impact of postharvest treatments on the degree of decay (score) of cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.

Fruit firmness

As shown in Fig. 4, cucumber fruit firmness decreased considerably with increasing storage durations in both seasons. All applied treatments of cucumber fruits were firmer than the untreated fruits during cold storage periods. Furthermore, chitosan + PPE or sodium alginate + PPE treatments had the highest fruit firmness values during cold storage, with significant differences between them, followed by chitosan and sodium alginate alone treatments, with significant differences between them. The PPE treatment was less effective in this regard, while untreated fruits recorded the lowest fruit firmness values. The interaction between all treatments and all storage durations was significant in both seasons. Cucumber fruits treated with chitosan + PPE and sodium alginate + PPE had the highest fruit firmness values after 16 days of storage (6.80 & 5.98 kg/cm^2) and (6.65 & 5.63 kg/cm^2), respectively, with significant differences between them in the second season only, while untreated fruits had the lowest fruit firmness values during the same period (4.81 & 4.03 kg/cm²) in both seasons, respectively.

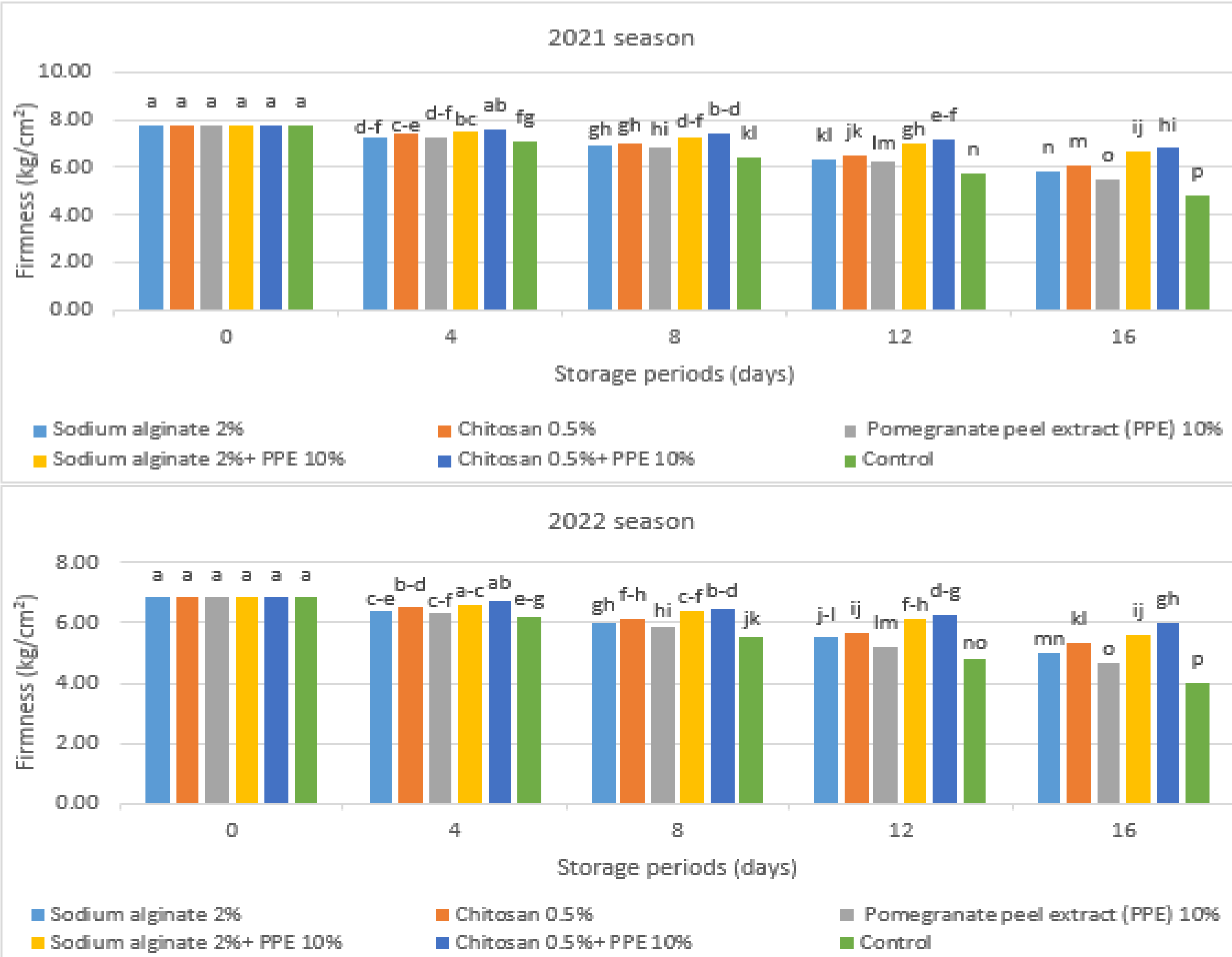


Fig. 4. The impact of postharvest treatments on the firmness (kg/cm²) of cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.

Total soluble solids

Data in Fig. 5 indicate that cucumber fruits decreased significantly in total soluble solids (TSS) percentage with increasing storage periods in both seasons. All applied treatments considerably reduced the TSS loss compared with the control treatment during all storage durations. Furthermore, cucumber fruits treated with chitosan + PPE retained more TSS content, followed by sodium alginate + PPE treatment, with significant differences between them. PPE treatment was the least effective treatment in this regard, while untreated fruits gave the lowest value of TSS. In both seasons, the interaction between all treatments and all storage periods was significant. Cucumbers treated with chitosan + PPE or sodium alginate + PPE had the higher values of TSS % after 16 days of storage (3.87 & 3.63%) and (3.67 & 3.37%), respectively, with significant differences between them, followed by chitosan (3.13 & 3.00%) or sodium alginate alone treatments (3.00 & 2.77%) in both seasons, respectively, with no significant differences between them in the first season, while untreated fruits showed the lowest values of TSS % during the same period (2.53 & 2.33%) in both seasons, respectively.

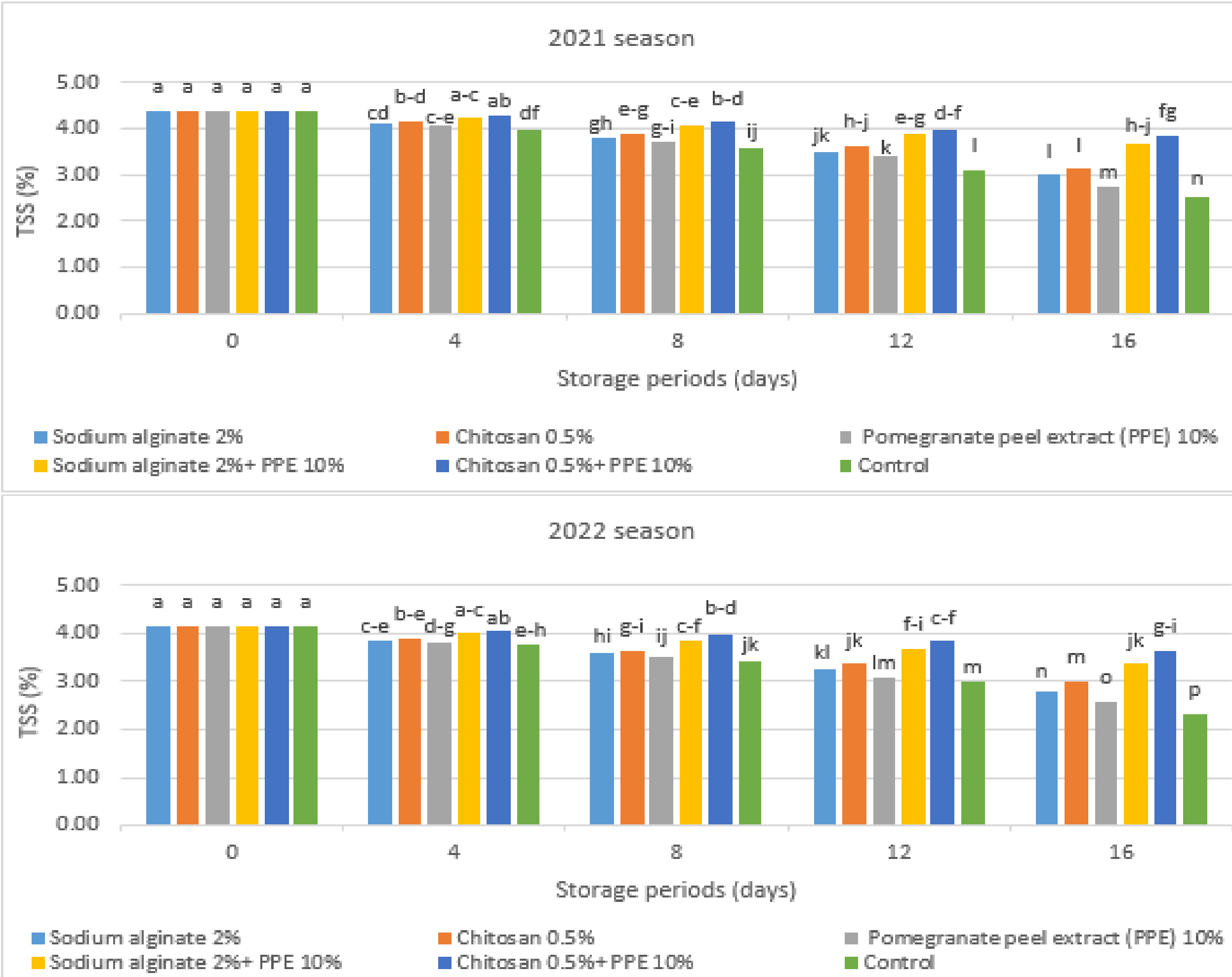


Fig. 5. The impact of postharvest treatments on the percentage **of** total soluble solid (TSS) in cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.

Color

As shown in Fig. 6&7, there was a significant reduction in color parameter values (L* and hue angle (h°)) and an obvious loss of lightness and a slight yellowness appeared on the surface of fruits with increasing storage time. However, all applied treatments show significantly higher values of L* and hº compared with the untreated control. Furthermore, chitosan + PPE or sodium alginate + PPE were the most effective treatments in preserving higher L* and h° values, indicating that lighter fruits (high L*) and retained green color (high h°) during storage periods with no significant differences between them, followed by chitosan and sodium alginate alone treatments, whereas untreated fruits had lower L* and h°, indicating that darker fruits (low L*) and less green color (low h°). In both seasons, the interaction between all treatments and all storage durations was substantial. After 16 days, chitosan + PPE or sodium alginate + PPE resulted in significantly higher L* and h° values with no significant differences between them, whereas the control treatment gave the lowest values in this regard during the same period.

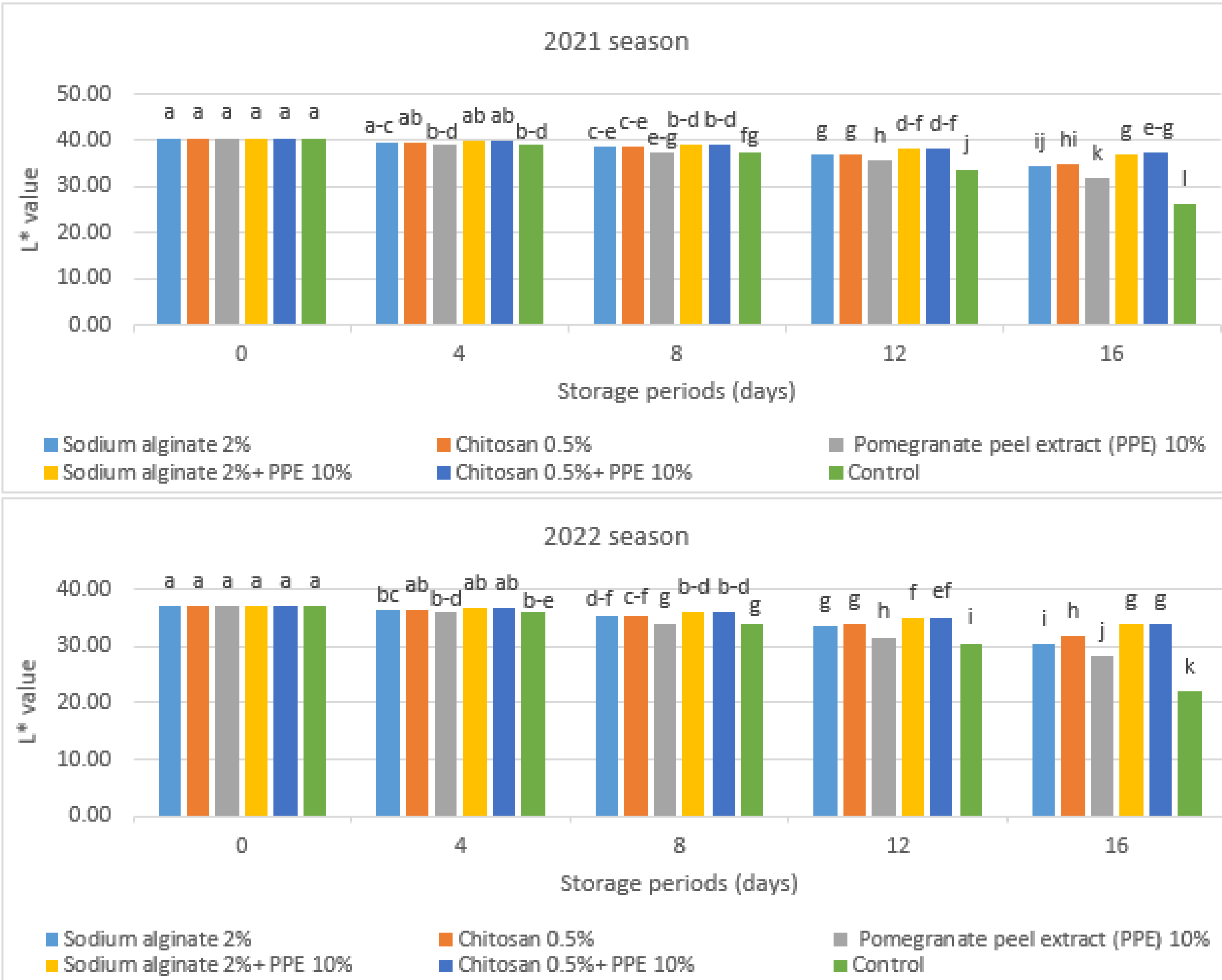
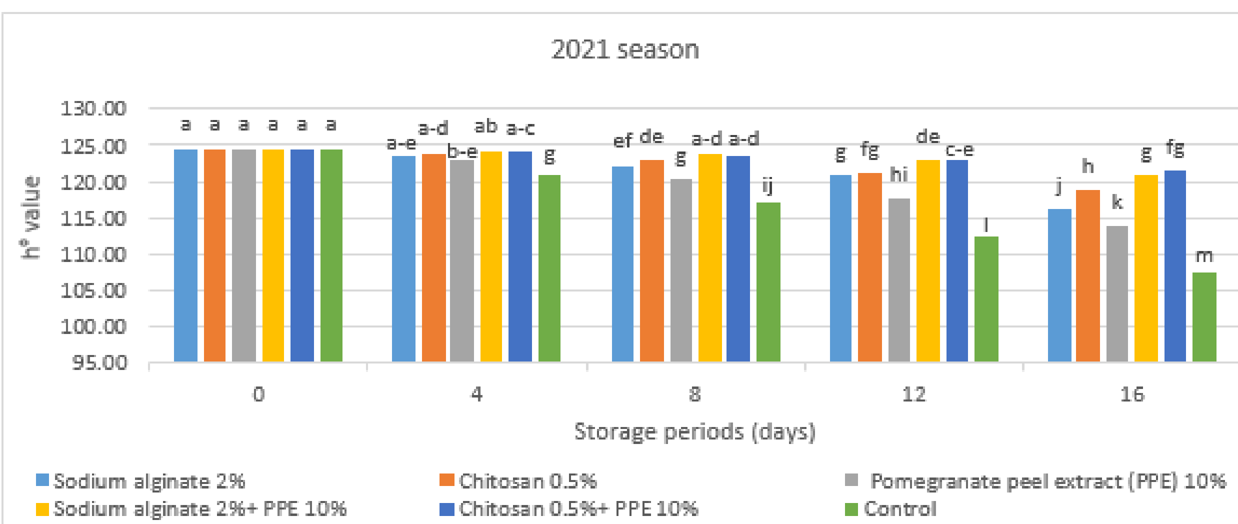


Fig. 6. The impact of postharvest treatments on the color (L* value) of cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.



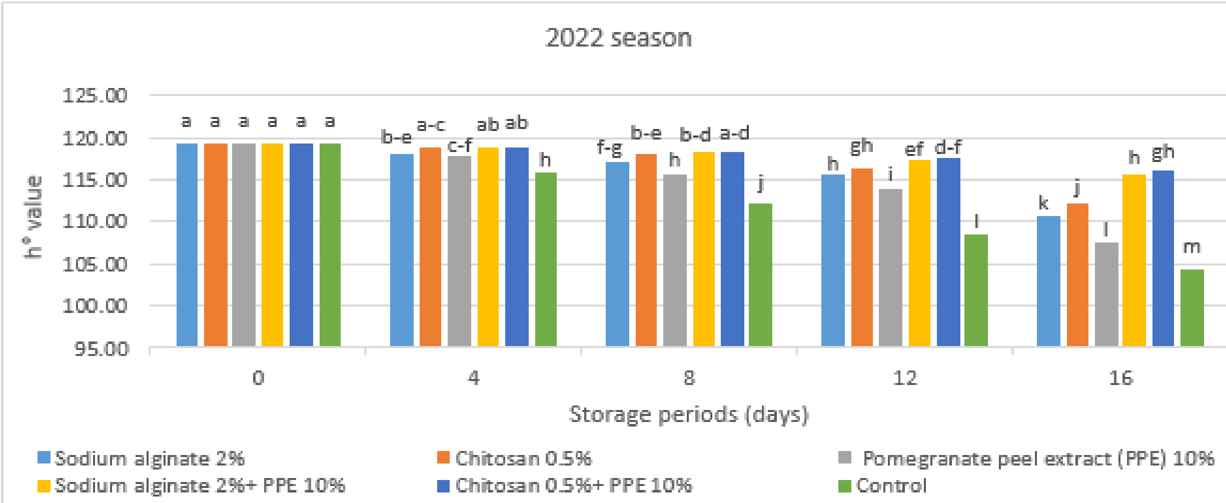
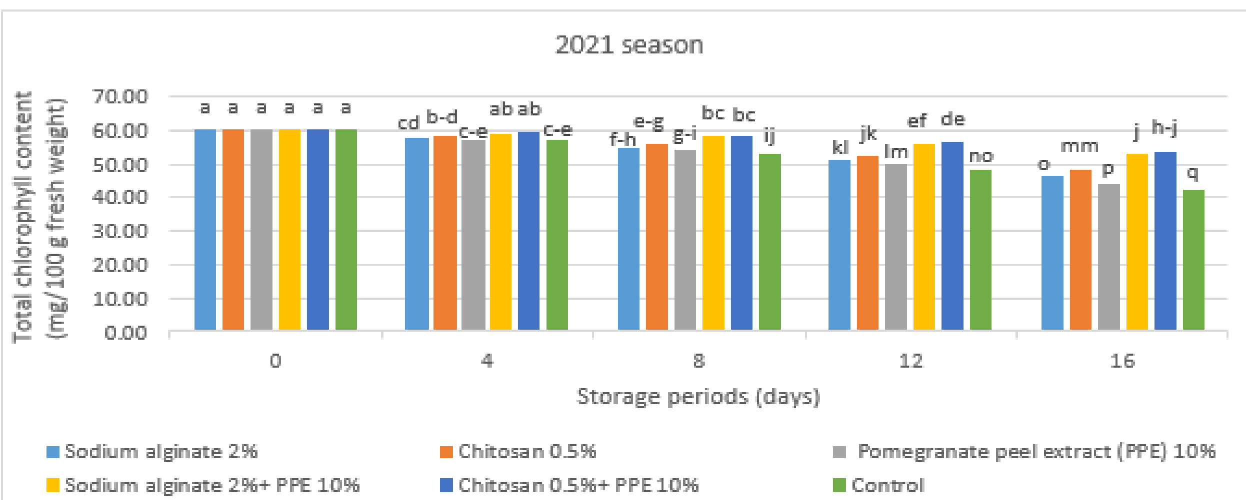


Fig. 7. The impact of postharvest treatments on the color (h° value) of cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.

Total chlorophyll content

As shown in Fig. 8, the total chlorophyll content of cucumber fruits decreased significantly as storage time increased. When compared to untreated fruits, all treatments significantly reduced total chlorophyll content loss during storage. Furthermore, chitosan + PPE or sodium alginate + PPE were the best treatments for decreasing total chlorophyll content loss during storage periods, with no significant differences, followed by chitosan and sodium alginate alone treatments, with significant differences, whereas the control treatment had the lowest total chlorophyll content values. In both seasons, the interaction between treatments and all storage durations was significant. After 16 days of storage, the chitosan + PPE and sodium alginate + PPE treatments had the highest total chlorophyll content (53.84 & 52.18 mg/100 g fresh weight) and (52.73 & 51.40 mg/100 g fresh weight), respectively, with no significant differences, while the control treatment had the lowest total chlorophyll content (42.34 & 38.01 mg/100 g fresh weight) in both seasons.



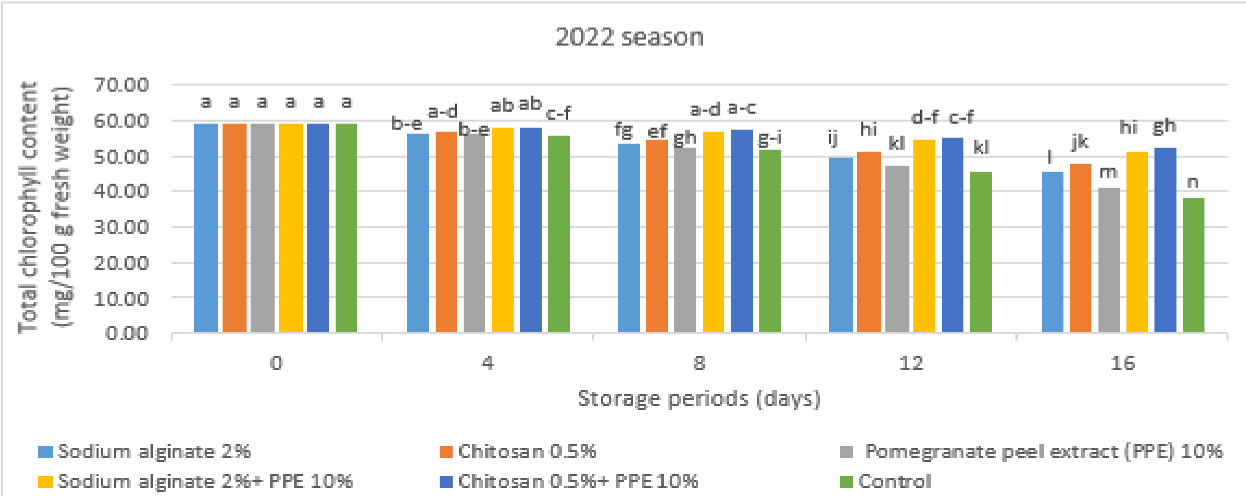
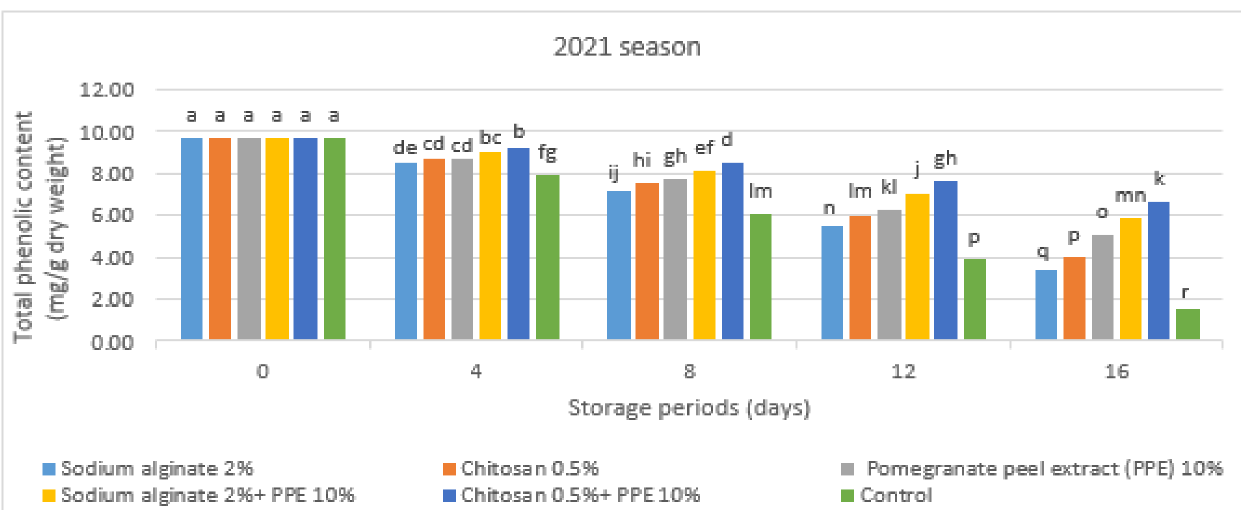


Fig. 8. The impact of postharvest treatments on the total chlorophyll content (mg/100 g fresh weight) of cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.

Total phenolic content

As seen in Fig. 9, the total phenolic content of cucumbers decreased significantly with increasing storage period. All applied treatments significantly decreased the loss of total phenolic content compared to control during storage. Furthermore, chitosan + PPE or sodium alginate + PPE were the best treatments for reducing the loss of total phenolic, with significant differences between them, followed by PPE, chitosan or alginate alone treatments with significant differences between them. The lowest values of total phenolics were obtained from untreated fruits. In both seasons, the interaction between all treatments and all storage periods was substantial. Chitosan + PPE and sodium alginate + PPE treatments showed the highest retention of total phenolic content in fruits for 16 days (6.62 & 6.28 mg/g dry weight) and (5.86 & 5.44 mg/g dry weight), respectively, with a significant difference between them, followed by PPE (5.12 & 4.24 mg/g dry weight), chitosan (4.05 & 3.74 mg/g dry weight) or alginate alone treatments (3.44 & 3.20 mg/g dry weight), respectively, with a significant difference between them. Whereas the control treatment had the lowest values during the same period (1.60 & 1.10 mg/g dry weight) in both seasons, respectively.



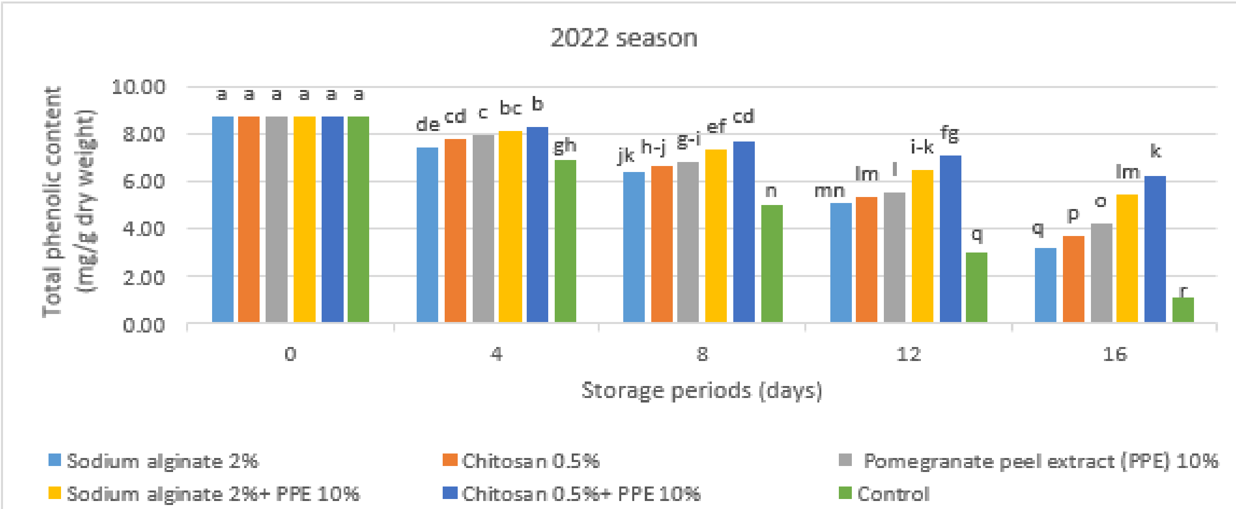


Fig. 9. The impact of postharvest treatments on the total phenolic content (mg/g dry weight) of cucumbers during storage durations in 2021 and 2022. When looking at the same kind of letter over the same amount of time, it becomes clear that there are no significant variations between the treatments at the level of 5 %.

DISCUSSION

The results of this study revealed that dipping cucumber fruits in sodium alginate 2%, chitosan 0.5%, pomegranate peel extract (PPE) 10%, sodium alginate + PPE, and chitosan + PPE significantly enhanced the storability and maintained the quality compared to the control treatment (untreated fruits). However, chitosan + PPE was the best treatment for reducing weight loss, maintaining firmness, green color (L* and h°), total soluble solids, total chlorophyll, and total phenolic contents, and giving fruits without any decay till the end of the storage period (16 days), followed by sodium alginate + PPE treatment. Moreover, cucumber fruits dipped in chitosan + PPE showed an excellent appearance without any changes in this appearance after 16 days of storage, while cucumber fruits dipped in sodium alginate + PPE showed a good appearance during the same period. These results were true in both seasons, and similar findings were confirmed by previous studies (Nair *et al*., 2018a&b and Kumar *et al*., 2021).

Chitosan and sodium alginate edible coatings act as semipermeable membranes on the surfaces of horticultural crops against O_2, CO_2, and moisture to limit the exchange of water and gases, thereby decreasing respiration rate, moisture loss, microbial rot of fruits, degradation by enzymes, preventing dehydration and fruit shrinkage, and inhibiting the production of ethylene, thus preserving the overall quality and extending the postharvest life of fruits (Tavassoli-Kafrani *et al*., 2016). Furthermore, edible coating has lower water vapor permeability and good elasticity, so it could be used as a preservative film for these fruits (Moraes *et al*., 2012). Also, the beneficial effects of edible coatings are due to their hygroscopic characteristics, which allow the creation of a water barrier between the fruit and the surrounding environment (Ru *et al*., 2020).

Previous studies have demonstrated that functional additive substances such as phenolics in PPE are added to polysaccharide-based edible coatings to improve their efficiency in maintaining quality and extending fruit postharvest life. Chitosan or alginate enriched with the functional compounds acts as an oxygen and water barrier, thereby decreasing respiration and preventing the production of reactive oxygen species (ROS). In addition, these functional additive compounds, primarily phenolics, work as antioxidants and shield fruits and vegetables from ROS damage. Furthermore, the addition of functional additives such as phenols in PEE to chitosan or alginate was most effective in preventing the degradation of sensory characteristics such as color, freshness, firmness, flavor, and overall acceptability, inhibiting microbe spoilage and weight of fruits extending their postharvest life, and maintaining chemical characteristics (Nair *et al*., 2020).

Furthermore, the reduction in percentage of weight loss and preservation of general appearance of fruits treated with chitosan or alginate and enriched with PPE during storage may be because the extract contains phenolic substances, and some main structural characteristics determine the link between phenolic compounds in the extract and the edible coatings, like the hydrogen and hydroxyl bonding groups available on phenolic compounds, along with their corresponding binding sites on edible coatings (Dobson *et al*., 2019). Phenolic substances interact with the polymer matrix of chitosan or alginate via hydrogen bonding, allowing for the slow and orderly release of these phenolic substances into the surrounding environment (Hosseini *et al*., 2009). The interaction between chitosan or alginate and the phenolic substances in PPE decreased the respiration rate and water loss and retained fruit weight and quality during storage (Nair *et al*., 2018a). This might be caused by the limited interactions of free-OH groups with water brought on by the creation of hydrogen bonding between phenolic substances and the lipid substances in the chitosan or alginate coatings (Sirk *et al*., 2008). As a result, adding phenols in PPE to chitosan or alginate significantly contributed to fruit quality preservation (Nair *et al*., 2020).

Chitosan or alginate reduced fruit rotting by increasing the ability to remove free radicals, and this may be due to their ability to increase the antioxidant enzyme activity and prevent the increasing oxidative enzyme activity during storage, thus improving tissue resistance to microbial invasion and reducing physiological deterioration (Nair *et al*., 2020). Furthermore, the molecular interactions between the negatively charged microbial cells and the positively charged amines on the structure of chitosan cause the membrane structure of the microbial cells to disintegrate, killing the microbe by allowing intracellular components and electrolytes to leak into the surrounding environment (Frazão *et al*., 2017). Moreover, PPE has a natural inhibitory effect on bacteria, fungi, and pathogens (Romeo *et al*., 2015). PPE contains antibacterial phenolic compounds. These substances can weaken microbial membranes, allowing them to enter cells and prevent protein synthesis, resulting in electrolyte leakage and the death of microorganism cells. They further impede the production of the lipids, RNA, and DNA that the microorganisms need to survive (Shan *et al*., 2007). Furthermore, the addition of plant extracts such as pomegranate peel extracts to edible coatings such as chitosan or alginate improved the efficiency of edible coatings in inhibiting the growth of fungal pathogens in fruits and reducing the microbial count (Nair *et al*., 2018a).

The reduction in firmness with increasing the storage period may be due to insoluble protopectin being converted into water-soluble pectin by the enzymes polygalacturonase and pectin methylesterase, which leads to the breakdown of the middle lamellae, reducing the hardness of cell walls, and softening fruits (Maftoonazad *et al*., 2008). The application of chitosan or alginate reduced softening and maintained firmness, which may be due to the membrane formed on the fruit surface that acts as an O_2 barrier, thus controlling the metabolic activities and inhibiting the polygalacturonase enzyme and pectin methylesterase enzyme activity responsible for the degradation of the cell wall, reducing softening of the fruit (Valero and Serrano, 2010), decreasing moisture loss from the fruit, and maintaining the firmness of fruits (Azarakhsh *et al*., 2014). Furthermore, pomegranate peel extract reduces the softening of fruits by inhibiting ethylene synthesis, decreasing respiration rate, and inhibiting oxidation enzyme activity responsible for cell wall degradation that leads to the softening of fruits. Also, PPE has been shown to significantly reduce fruit rot and softening due to its antibacterial and antifungal components (Nicosia *et al*., 2016).

The TSS content of non-climacteric fruits like cucumbers often decreases after postharvest. The explanation is that these fruits don't have or only have a small amount of starch while they are being harvested. So, the sugars in the fruits are used as a source of energy for the respiration process, and the content of TSS in fruits lowers during storage time (Nazoori *et al*., 2020). The beneficial effect of chitosan or alginate in maintaining TSS content of cucumber fruits might be because of the formation of a semipermeable membrane on the surface of fruit acting to modify the concentrations of O_2 and CO_2, hence reducing respiration rate and metabolic activities (Zapata *et al*., 2008), delaying senescence (Hong *et al*., 2012), which reduces the loss of TSS content during storage.

Color is one of the main visual quality criteria that influence whether or not consumers would accept fresh products. To assess the color change that happens in fruits across all storage periods, the color parameters L* (lightness) and h° (hue angle) were measured. The L* value represents the visual appearance of fruits by indicating the brightness or darkness of the fruit surface (Kumar *et al*., 2021), whereas the value of h° specifies a coordinate in a specified color space (Guerreiro *et al*., 2015). With increasing storage time, the color parameter values (L* and h°) of cucumber fruits declined dramatically, and an evident loss of lightness and a slight yellowness occurred on the surface of the fruits. A reduction in L* value indicates that the surface is darkening (Yousuf *et al*., 2018). Changes in hue angle values are thought to be a sign of senescence (Saad, 2019). This might be due to increased metabolic activity during storage, which causes chlorophyll to degrade and change fruit color (Mohammadi *et al*., 2016). Restrictive color changes in fruits treated with chitosan or alginate loaded with PPE may be related to gas and water barriers which reduce respiration rates, delay the ripening process, suppress oxidation and browning enzymatic reactions, and delay pigmentation (Nair *et al*., 2018a and Kumar *et al*., 2021).

Furthermore, the total chlorophyll content of cucumbers decreased with increasing storage time. This may be attributed to a gradual increase in the degradation of chlorophyll and the conversion of chloroplasts into chromoplasts caused by the activity of the chlorophyllase (Forney and Rij, 1991). The reduction in chlorophyll loss during storage in the fruits dipped in chitosan might be due to the semipermeable membrane formation that is responsible for the lower O_2 and higher CO_2 concentrations, thus decreasing the respiration rate, ethylene synthesis, and the activity of chlorophylls, which resulted in decreased degradation of chlorophyll (Olawuyi *et al*., 2019) and reducing the change of color (El-hamahmy *et al*., 2017).

Phenolic substances are secondary metabolites found in horticultural crops that have an antioxidant effect as they scavenge the free radicals caused by oxidative stress (Peretto *et al*., 2017). Also, they can influence the activity of some enzymes, promote auto-oxidation and the chelation of metal ions (Howard *et al*., 2003), and protect the cells of fruits and vegetables from damage (Toor and Savage, 2005). The reduction in total phenolic content of cucumber fruit during storage may be attributed to increased respiration rate, peroxidase (POD) enzyme, and polyphenol oxidase (PPO) enzyme activity (Chiabrando and Giacalone, 2015). The use of edible coating prevents the total phenolic loss of bell peppers during storage by reducing the oxidation of lipids and the activity of oxidation enzymes and inhibiting ethylene synthesis (Xing *et al*., 2011). It also modifies the internal atmosphere and leads to increased antioxidant activity and the accumulation of phenolic substances (Frusciante *et al*., 2007). Also, Kumar *et al*. (2021) found that the chitosan enriched with PPE had an effective influence on maintaining the phenolics in bell peppers during storage, which may be since chitosan creates a barrier against gases, losses of water, and enzymatic activity (Zam, 2019). Furthermore, the combination of the edible coating and PPE improves the phenolic activity and retains the phenolic content in the fruits (Nair *et al*., 2018a& b). Moreover, the increase in phenolic activity may be attributed to the pomegranate peel extract having a high content of natural antioxidants (Kumar *et al*., 2021).

CONCLUSION

It is clearly concluded that cucumber fruits treated with chitosan 0.5% + pomegranate peel extract 10% maintained the quality attributes and did not exhibit any changes in the appearance of the fruits for 16 days of storage at 10°C and 90–95% relative humidity.

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المحافظة على جودة الثمار وتحسين القدرة التخزينية للخيار بمعاملات ما بعد الحصاد

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تم حصاد ثمار الخيار (هجين ميراج) في المرحلة المناسبة من النضج التسويقى فى موسمي 2021 و 2022 لدراسة تأثير بعض معاملات ما بعد الحصاد (الجينات الصوديوم بنسبة 2٪ ، الشيتوزان بنسبة 0.5٪ ، مستخلص قشر الرمان (PPE) بنسبة 10٪ ، الجينات الصوديوم + PPE والشيتوزان + PPE) مقارنة بالثمار غير المعاملة فى المحافظة على جودة الثمار وتحسين القدرة التخزينية لثمار الخيار أثناء التخزين على 10 درجة مئوية و رطوبة نسبية 90-95٪ لمدة 16 يوم. وفقاً للنتائج، جميع معاملات ما بعد الحصاد تفوقت على الثمار غبر المعاملة من حيث تقليل الفقد فى الوزن، التغير فى اللون و الفقد فى الصلابة والمحافظة على نسبة المواد الصلبة الذائبة الكلية، المحتوى من الكلوروفيل الكلى والفينولات الكلية والمحافظة على المظهر العام للثمار خلال فترات التخزين. ومع ذلك، المعاملة بالشيتوزان + PPE أو الجينات الصوديوم + PPE كانت افضل المعاملات فى الحفاظ على جميع صفات الجودة لثمار الخيار. علاوة على ذلك، أعطت المعاملة بالشيتوزان + PPE أفضل النتائج فى إبطاء معدل الفقد فى الوزن (1.09 و 1.21 %)، الاحتفاظ باللون الاخضر للثمار (*L و °h)، المحافظة على صلابة الثمار (6.80 و 5.98 كجم/سم^2)، نسبة المواد الصلبة الذائبة الكلية (3.87 و 3.63%)، الكلوروفيل الكلي (57.71 و 56.32 ملجم/100جم وزن طازج) والفينولات الكلية (6.62 و 6.28 ملجم/جم وزن جاف)، وأعطت مظهراً ممتازً للثمار بدون أي تالف لمدة 16 يوم.

الكلمات المفتاحية: خيار ، الاغشية الصالحة للأكل ، مخلفات التصنيع الزراعى ، الجودة ، العمر بعد الحصاد