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Quality Assessment of Local Apples (*Malus Domestica*) Packaged and Treated with Chitosan During Refrigerated Storage

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Abstract: This study was conducted in a refrigerated warehouse in Salah al-Din Governorate after harvesting uniform apples (in terms of shape and size) free from any damage from an orchard in Balad District on August 7, 2024. The apples were stored for six months under controlled temperature and humidity. The aim of the study was to evaluate the performance of chitosan and the different types of packaging used with the Ibrahimi apple variety during the storage period. Data were recorded on December 7, 2024, the results, after statistical analysis, indicated that using chitosan at a concentration of (2) ml.L-1 resulted in a significant increase in most of the studied traits compared to the control treatment. Vacuum-sealed polyethylene packaging significantly outperformed other packaging methods in sugar content, TSS, percentage of dry matter, acidity, and protein. The interaction between chitosan at a concentration of 2 ml.L-1 and vacuum-sealed polyethylene packaging yielded the best results for most of the studied traits. Proline content was unaffected by the study factors and their interaction.

Keywords: Chitosan, Polyethylene , TSS, protein.

Introduction

Apple (*Malus domestica*) is one of the most economically and nutritionally important temperate fruit crops worldwide, owing to its high content of dietary fiber, bioactive compounds, and consumer-acceptable sensory properties. However, apples are highly perishable commodities due to their continuous physiological and biochemical activities after harvest, particularly respiration and transpiration processes, which accelerate postharvest quality deterioration. Postharvest losses in apples are mainly attributed to moisture loss, increased metabolic activity, enzymatic degradation, and microbial development, all of which negatively affect firmness, weight, and overall fruit quality during storage [1]. Post-harvest technologies are among the most important sustainability technologies for maintaining crop quality. In recent years, materials made from natural biopolymers have been used to wrap crops in order to preserve them for long periods so that they remain edible. Chitosan is one of

these materials used in treating crops after harvest and during cold storage, and it has received extensive studies. This is due to the ability of these materials (chitosan) to biodegrade, as well as their effective activity against microbes that may infect crops after harvest. It reduces respiration rates and water loss from fruits, which means preserving the quality of stored fruits and delaying their aging during the cold storage period [2], [3]. Packaging systems used to preserve agricultural products after harvesting play a crucial role in maintaining their quality. Polyethylene is one such packaging material, as it helps balance the internal gaseous environment by increasing the concentration of carbon dioxide and decreasing the concentration of oxygen. This, in turn, inhibits microbial growth by reducing respiration. Maintaining the quality of agricultural products after harvest can be achieved by combining the use of natural biopolymers with various packaging systems. This process extends the storage period for crops after harvesting and when stored in refrigerated warehouses. [4], [5].

Materials and Methods

Experimental Site and Plant Material

This experiment was carried out in one of the refrigerated warehouses in Salah al-Din Governorate after the ripe apple fruits (local Ibrahim variety) that were free of defects and disease and were uniform in shape and size were collected from one of the orchards in Balad District on 7/8/2024, and the storage process continued until 7/12/2024 after controlling both the temperature and humidity.

Experimental Design

The experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications under a factorial arrangement.

Factor A: Chitosan (Antitranspirant treatment)

- Control (0 ml L⁻¹)
- Chitosan dipping solution (2 ml L⁻¹)

Factor B: Packaging type

- Paper packaging
- Polyethylene packaging with vacuum sealing
- Polyethylene packaging without vacuum sealing

Experimental Procedure

Uniform fruits were selected and immersed in chitosan solution according to treatments. Fruits were then air-dried at room temperature to form a coating layer. Treated fruits were packed in standardized cardboard boxes and stored in a cold room under controlled environmental conditions throughout the storage period.

Quality Attributes and Analytical Methods

The following physicochemical and biochemical parameters were evaluated:

- **Weight loss (%)**: determined according to AOAC [6].
- **Firmness (N)**: measured using a penetrometer [3].
- **Total Soluble Solids (TSS, °Brix)**: measured using a digital refractometer [6].
- **Titrateable Acidity (TA) and pH**: determined by titration with 0.1 N NaOH and pH meter [6].
- **Dry matter (%)**: determined by oven drying at 70 ± 2°C to constant weight [6].
- **Proline content**: determined according to Bates et al. using ninhydrin method [7].
- **Total phenolic content**: determined using Folin–Ciocalteu method, expressed as mg GAE/100 g FW [8].

Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) appropriate for RCBD factorial design. Mean comparisons were performed using Duncan at $p \leq 0.05$.

Results and Discussion:

Average sugar content (%):

Table (1) shows the significant superiority of the chitosan treatment at a concentration of (2) ml.L⁻¹ over the control treatment (0) ml.L⁻¹ in the average sugar content of apple fruits, as the

percentage reached (9.392 and 10.413)% respectively, which demonstrates the positive role of chitosan in improving the sugar content of fruits. This may be attributed to the ability of this compound to reduce moisture loss from fruits, thus helping them maintain their quality during the storage period [9].

The highest percentage of sugars was achieved when wrapping with polyethylene without vacuum, reaching (10.506)%, compared to the rest of the treatments, which reached (9.485) and (9.716)% respectively. Perhaps the reason for this is that wrapping in this way (polyethylene without vacuum) provides the best conditions for preserving the physiological characteristics of the fruits, which reduces their deterioration during the storage process .

The interaction results indicate that the chitosan treatment at a concentration of 2 mL.L⁻¹ combined with vacuum-sealed polyethylene packaging resulted in the highest percentage of sugars in the apples, reaching 11.263%, significantly surpassing all other treatments. The lowest percentage, 9.193%, was observed in the control treatment (0 mL.L⁻¹) combined with paper wrapping. These results demonstrate the role of chitosan in vacuum-sealed polyethylene in improving the sugar content of the fruit.

Table 1. Effect of chitosan and packaging type on average sugar content (%).

Values followed by the same letter are not significantly different from each other at a

Treats	Paper packaging	Polyethylene packaging with vacuum sealing	Polyethylene packaging without vacuum sealing	Effect Chitosan
Chitosan 0 mL.L ⁻¹	9.193 c	9.233 c	9.750 bc	9.392 b
Chitosan 2 mL.L ⁻¹	9.776 bc	10.200 b	11.263 a	10.413 a
Effect				
Polyethylene packaging	9.485 b	9.716 b	10.506 a	

probability level of 0.05.

Total Soluble Solids (TSS):

Table (2) clearly shows the effect of both chitosan and different types of packaging on the average total solids characteristic of the Ibrahimi apple variety, which is usually measured in Brix° using a refractometer. The results indicate that the chitosan treatment with a concentration of (2 mL.L⁻¹) is significantly superior to the control treatment (0 mL.L⁻¹) in the average total solids, which reached (8.1555 and 10.2888) Brix° respectively. These results show that chitosan has a clear role in maintaining the total solids content of apple fruits. This may be attributed to the fact that this substance reduces both the respiration rate and moisture, as well as delaying decomposition processes during storage [2].

The results also indicate a significant and gradual increase in the average total solids content of the apples with different packaging types. Paper packaging achieved the lowest value for this characteristic (8.483 Brix°) compared to polyethylene packaging with vacuum and polyethylene packaging without vacuum, which reached (9.033) and (10.150) Brix°, respectively. This may be attributed to the fact that using polyethylene reduces water loss from the apples, thus preserving their total solids content .

The results show that the interaction between the chitosan treatment (2 mL L⁻¹) and polyethylene packaging without vacuuming resulted in the highest value of total solids in the apple fruits, reaching (11,500) Brix°, and thus significantly surpassed the rest of the interactions. The lowest value was (7,600) Brix° when the interaction between the control treatment (0 mL L⁻¹) and paper packaging of the fruits occurred.

Table 2. Effect of chitosan and packaging type on Total Soluble Solids.

Values followed by the same letter are not significantly different from each other at a probability level of 0.05.

Treats	Paper packaging	Polyethylene packaging with vacuum sealing	Polyethylene packaging without vacuum sealing	Effect Chitosan
Chitosan 0 ml.L ⁻¹	7.600 f	8.066 e	8.800 d	8.1555 b
Chitosan 2 ml.L ⁻¹	9.366 c	10.000 b	11.500 a	10.2888 a
Effect Polyethylene packaging	8.483 c	9.033 b	10.150 a	

Dry matter (%):

The results in Table (3) show that the use of chitosan at a concentration of (2 ml.L⁻¹) achieved a significant increase in the percentage of dry matter of apple fruits, as the percentage reached (13.910)%, compared to the control treatment (0 ml.L⁻¹), which recorded the lowest percentage of dry matter (12.372)%. This means that adding chitosan preserves the dry matter by reducing the respiration process and moisture loss during the fruit storage process [10].

The difference in packaging type was accompanied by a difference in the percentage of dry matter. Polyethylene packaging without vacuum achieved the highest percentage of dry matter at 13.953%, significantly surpassing both paper packaging and polyethylene packaging with vacuum, which yielded percentages of 12.390% and 13.080%, respectively. This may be attributed to the fact that polyethylene packaging with vacuum reduces water loss, thus preserving the components of the apples, compared to those wrapped in paper.

The results of the interaction between the two factors show that the highest percentage of dry matter was achieved in the interaction between the chitosan treatment at a concentration of (2 ml L⁻¹) and polyethylene packaging without vacuum sealing, reaching (14.496)%. The lowest percentage was achieved in the interaction between the control treatment (0 ml L⁻¹) and paper packaging, reaching (11.293)%.

Table 3. Effect of chitosan and packaging type on Dry matter (%).

Values followed by the same letter are not significantly different from each other at a probability level of 0.05.

Treats	Paper packaging	Polyethylene packaging with vacuum sealing	Polyethylene packaging without vacuum sealing	Effect Chitosan
Chitosan 0 ml.L ⁻¹	11.293 d	12.413 c	13.410 b	12.372 b
Chitosan 2 ml.L ⁻¹	13.486 b	13.746 b	14.496 a	13.910 a
Effect Polyethylene packaging	12.390 c	13.080 b	13.953 a	

Acidity (pH):

The results in Table (4) indicate a clear and significant effect of the chitosan treatment at a concentration of (2 ml.L⁻¹) compared to the control treatment (0 ml.L⁻¹) on the average acidity of the Ibrahimi apple variety. The pH values reached (0.678 and 0.792) for the two treatments, respectively. This may be attributed to the fact that chitosan may reduce the respiration rate during storage, thus helping to preserve the organic acid content of the apples. [11].

The difference in packaging material for apples resulted in a difference in the average pH, which reached (0.815) when using polyethylene packaging without vacuum, thus significantly exceeding the paper packaging and polyethylene packaging with vacuum, where the pH reached (0.668) and (0.723) respectively. This may be attributed to the variation in limiting gas exchange with the different packaging material, which contributed to reducing the physiological changes in apples during storage and maintaining pH levels .

The interaction between the chitosan treatment at a concentration of (2 ml.L⁻¹) and polyethylene packaging without vacuum resulted in the highest pH value, which reached (0.815), and thus significantly surpassed all other interactions. The lowest pH value was achieved in the interaction between the control treatment (0 ml.L⁻¹) and the paper packaging of apple fruits, which reached (0.596).

Table 4. Effect of chitosan and packaging type on Acidity (pH).

Values followed by the same letter are not significantly different from each other at a probability level of 0.05.

Treats	Paper packaging	Polyethylene packaging with vacuum sealing	Polyethylene packaging without vacuum sealing	Effect Chitosan
Chitosan 0 ml.L ⁻¹	0.596 c	0.656 c	0.783 ab	0.678 b
Chitosan 2 ml.L ⁻¹	0.740 b	0.790 ab	0.846 a	0.792 a
Effect				
Polyethylene packaging	0.668 c	0.723 b	0.815 a	

Proline: (mg.g⁻¹)

Table (5) shows that treating apples with chitosan at a concentration of (2 ml.L⁻¹) had no significant effect on average proline compared to the control treatment (0 ml.L⁻¹). Proline levels were (1.032 and 1.023) (mg.g⁻¹) for the two treatments, respectively. Furthermore, the packaging material had no significant effect on this trait, and no significant interaction between the two factors was observed. This indicates that treating apples with chitosan and packaging materials did not cause any physiological changes in the fruit during storage.

Table 5. Effect of chitosan and packaging type on Proline: (mg.g⁻¹).

Treats	Paper packaging	Polyethylene packaging with vacuum sealing	Polyethylene packaging without vacuum sealing	Effect Chitosan
Chitosan 0 ml.L ⁻¹	1.040 a	1.050 a	1.006 a	1.032 a
Chitosan 2 ml.L ⁻¹	0.996 a	1.056 a	1.016 a	1.023 a

Effect			
Polyethylene packaging	1.018 a	1.053 a	1.011 a

Values followed by the same letter are not significantly different from each other at a probability level of 0.05.

Protein content (mg.g⁻¹):

Table 6 shows that treating apples with chitosan at a concentration of 2 ml.L⁻¹ resulted in a significant increase in the average protein content compared to the control treatment (0 ml.L⁻¹), reaching 0.399 and 0.509 mg.g⁻¹ for the two treatments, respectively. This may be attributed to the fact that adding chitosan helped maintain protein levels due to its effective role in reducing physiological deterioration, as well as its role in slowing down the decomposition process, or that it may have stimulated protein synthesis in apples during storage [12].

The two polyethylene packaging treatments, without vacuum and with vacuum, were significantly superior to the paper packaging treatment, with protein content in the three treatments reaching (0.405, 0.460, and 0.485) mg.g⁻¹ respectively. This may be attributed to polyethylene's ability to preserve the biological activity of apple fruits compared to paper packaging, in addition to polyethylene potentially reducing moisture loss during apple storage [13].

The results of the interaction between the two factors show that the chitosan treatment (2 ml.L⁻¹) and the three packaging materials (paper and polyethylene with and without vacuum) were significantly superior to the control treatment (0 ml.L⁻¹) and to the three packaging materials, respectively. The highest protein concentration was achieved in the interaction between the chitosan treatment (2 ml.L⁻¹) and the non-vacuum polyethylene packaging, reaching (0.526) mg.g⁻¹, while the interaction between the control treatment and the paper packaging resulted in the lowest protein concentration, which was (0.323) mg.g⁻¹ [14]. [15].

Table 6. Effect of chitosan and packaging type on Protein content (mg.g⁻¹).

Treats	Paper packaging	Polyethylene packaging with vacuum sealing	Polyethylene packaging without vacuum sealing	Effect Chitosan
Chitosan 0 ml.L ⁻¹	0.323 d	0.403 c	0.443 b	0.399 b
Chitosan 2 ml.L ⁻¹	0.486 a	0.516 a	0.526 a	0.509 a
Effect Polyethylene packaging	0.405 b	0.460 a	0.485 a	

Values followed by the same letter are not significantly different from each other at a probability level of 0.05.

Conclusion

The study showed that using chitosan at a concentration of (2) ml.L⁻¹ with appropriate packaging systems resulted in obtaining high-quality apples after harvesting and storing them for six months in refrigerated warehouses by reducing weight loss and maintaining the firmness of the apples. This integrated approach provides an effective and sustainable strategy for extending the shelf life of local apple cultivar "Ibrahim".

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