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POSTHARVEST EDIBLE COATING TREATMENTS OF JOJOBA AND HIBISCUS OIL TO IMPROVING QUALITY AND STORABILITY OF HASS AVOCADO FRUITS DURING COLD STORAGE

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ABSTRACT

The edible coatings and films extend the postharvest life of fresh fruits. It is used to improve the' appearance of fruits and ensure their safety due to its environmentally friendly nature. The present study was conducted during the 2021 and 2022 seasons to investigate the effect of some edible coatings, such as oils of jojoba (Simmondsia Chinensis), Hibiscus (Hibiscus sabdariffa), or their mixture (1:1), on the quality and storability of avocado fruits cv. Hass. The fruits were stored under cold storage conditions (5 ± 1°C/ and 85 - 90% RH/ 6 weeks) compared with untreated fruits (control). The initial contamination of toxigenic fungi was determined for the collected avocado fruits. Also, the ability of treated fruits to resist fungal contamination was evaluated using a simulated experimental study. The results showed that all edible coating treatments cleared better physical and chemical properties during storage than untreated fruits (control). Avocado fruits coated with hibiscus extract resulted in the highest fruit firmness, vitamin C content, chlorophyll content, the least titratable acidity, and negligible phenol content. The Jojoba treatment showed the highest soluble solid content and chlorophyll b content. Generally, edible coatings with jojoba oil and hibiscus extract and their mix (1:1) can be recommended to preserve the fruit quality and extend avocado fruits' storage life.

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INTRODUCTION

Avocado (*Persea americana*) is a popular subtropical fruit consumed and produced in Central America, Mexico, and even central Chile. The global importance of the avocado fruit increased from being an insignificant crop to becoming one of the most important tropical fruits (Saidi *et al.,* 2021). Avocado is commonly referred to as a superfood due to its unique nutritional and phytochemical composition, including protein source, good fatty acids such as oleic, palmitic, linoleic, palmitoleic acids, trace amount of stearic acid, vitamins A, B, C, E, K, fiber sources, and high antioxidants (Bhuyan *et al.,* 2019).

Hass avocado cultivar is the foremost imperative in the cultivated region, geographical distribution, and consumption (Lu *et al.,* 2009). Among the distinctive cultivars of avocados commercially developed worldwide, 'Hass' is the most

overwhelming due to its nutty flavor and valuable properties. Hass avocados account for 80% to 95% of harvested avocados worldwide, making them the most essential commercialized cultivar (Garcia and Davidov-Pardo, 2020). Most of the research on postharvest decay and disorders affecting avocado fruit quality during storage and marketing is dedicated to the Hass avocado due to its incredible nutritional value and consumer demand.

Postharvest operations are promising approaches for regulating food safety and security. Various technologies have recently emerged to preserve fresh produce and extend its shelf life. However, consumers demand chemical-free fresh products with excellent quality and nutritional profiles. In this context, the edible coating of fresh produce seems to be a practical approach to mitigate safety production and quality issues (Khalid *et al.,* 2022).

The edible coating has recently been widely used to maintain fruit quality (Priya *et al.,* 2023). Edible coatings attract research attention as a practical natural approach for maintaining fresh agricultural produce quality and storability. Edible coatings are an environmentally friendly technology applied to many products to control moisture loss, gas exchange, or oxidation processes (Dhall, 2013). Edible coatings are defined as a thin layer covering the fruit and are made of biodegradable, edible components. These coatings protect products from mechanical, physical, chemical, and microbial damage, provide an aesthetic appearance and create a micro-modified atmosphere (Priya *et al.,* 2023).

Jojoba oil is the liquid oil produced from the seed of the jojoba plant. This oil appears as a clear golden liquid at room temperature with a slightly fatty odor, is very stable, does not become rancid or lose antioxidants even after long storage periods, and spreads well and absorbs well (Abd-Allah *et al.,* 2012). In addition, jojoba oil has antimicrobial, antiparasitic, and anti-inflammatory effects. Various extracts from jojoba seeds can be used as natural preservatives in food against the well-known causal agents of food-borne diseases and food spoilage (Umaiyal *et al.,* 2016). Zaghloul date palm fruits treated with JO at 5% combined with Arabic gum at 10% significantly recorded the highest responses, where it significantly mitigated the rise in decay incidence and reduced weight loss, and maintained high firmness, total phenol content, total flavonoids, total tannins, total sugars and antioxidant activity during cold storage. (Aboryia and Omar, 2020) .

Hibiscus or roselle (*Hibiscus sabdariffa* L.) is one of the most critical and famous medicinal plants. The calyx is rich in polysaccharides and pectin content; it is among the primary plant sources that can be used to make edible fruit coating (De los Santos-Santos *et al.,* 2020). Recently, Roselle application in edible coating reduced decay, microbial growth, anthocyanin degradation, and enzyme activities of blueberry while improving the total phenolic content (Yang *et al.,* 2019). Moreover, hibiscus mucilage (2%) as an edible coating for soursop fruits (*Annona muricata* L.) stored at 15°C showed the lowest titratable acidity and weight loss as well as increased vitamin C, total phenolic content, and antioxidant activity (De los Santos-Santos *et al.,* 2020). (Da-Costa-Rocha *et al.,* 2014). The hibiscus extract is antibacterial due to the antioxidant properties of some compounds, such as phenolic acids, anthocyanins, and carotenoids.

Therefore, this study aimed to explore the effects of two different coating systems (golden jojoba, hibiscus seed oils, and their mix [1:1]) as loading active ingredients of a nanoemulsion coating film used for preserving fruit quality and extending the storage life of Hass avocado under cold storage.

MATERIALS AND METHODS

Fruits

Avocado fruit cv. Hass was obtained from a private orchard (Salmya) in Nubaria, Al-Beheira governorate, Egypt. Fruits were harvested at the maturity stage (on 1st November of 2021 and 2022 seasons) from 15-year-old trees with similar growth, vigor, and subjected to the common horticultural treatments. Then, the fruits were transferred to the postharvest laboratory at the Horticultural Crops Technology Department, National Research Centre, Dokki, Egypt. On arrival, undamaged fruits free from apparent pathogen infection and similar shape, color, and firmness were selected, washed under tap water, air dried, and coated with some natural products.

Microbial evaluation of avocado fruits

The fruits were gently washed using double-distilled water, then immersed in a sodium hypochlorite solution (3%) for 2 minutes to suppress the fungi load (Galsurker *et al.,* 2020). Lately, it has been washed using sterile water and dried with sterile filter paper before coating.

Fungi isolation

Fungal isolates from the Avocado samples were purified using a single-spore isolation technique (Noman *et al.,* 2018). The microscopic observations of each fungal strain were compared first to those of Dr. Fungus. The isolated fungi from the avocado samples were identified morphologically compared to previous reports. The identification procedure began by determining the genus of the fungi based on morphological characteristics using the reports by (Domsch *et al.,* 2007; Samuels *et al.,* 2002; Dijksterhuis and Samson, 2007; Samson, *et al.,* 2010)**.**

Preparation of oil coarse for film loading material

Three types of coating films were prepared to be applied to fresh avocado fruit preservation. The fruits emerged in a plastic container full of a film solution. Firstly, the oil coarse solutions for jojoba, hibiscus, and their mix (1:1) were prepared individually by mixing oil with tween 80 at a ratio of 2:1 using a magnetic stirrer (20±1 °C/600 rpm/ 2h). The resulting oil coarse will be utilized for film loading, the following coating formula.

Formulation of coating film materials

Three formulas were prepared for application in the fruit coating; these formulas were prepared using the mixtures in the following manner:

1- Solution (A): 200 mL of double distilled water used for dissolve sodium alginate (2%, in 100 mL) + chitosan low molecular weight (3%, in 100 mL) + jojoba coarse oil (3% v/v of total emulsion), where the glycerol (1%; v/v) was added to the final solution mix.
2- Solution (B): 200 mL of double distilled water used for dissolving whey protein concentrate (10%; 100 mL) + chitosan high molecular weight (3%; in 100mL),

where coarse hibiscus oil (3%, v/v of total emulsion) was loaded to the emulsion, followed by glycerol (1%; v/v).

3- Solution (C): 200 mL of double-distilled water used to dissolve Maltodextrin (10%; in 100 mL) + gelatin, low molecular weight (10 %; in 100 mL) + gum Arabic (1%) + Span 40 (0.1%). The loaded coarse oil of Jojoba and hibiscus (3% oil coarse mix; 1:1) was prepared by stirring the oil mix with Tween 80, where the glycerol (1%; v/v) was added to the final solution mix.

Film formation is utilized in fruit coating

The contents of each film were dissolved in double-distilled water individually; they were mixed in equal quantities in the sequence order. After adding all materials for each film type (A, B, or C), magnetic stirring was performed at 50 ~ 60ºC for two hours until completely dissolved. For the film (A), jojoba oil, which was prepared as a coarse oil with tween 80, was dropwise added after the complete dissolving of chitosan to be encapsulated, where chitosan solution was prepared according to the method described before (Ibrahim *et al*., 2023), stirred for homogenizing well using a mechanical stirrer (1500 rpm/2h/22 C), and followed by adding of sodium alginate solution during stirring for another same period. At the final step of each composite preparation for (A, B, or C emulsions), the components of each film were mixed using an Ultra-Turrax homogenizer T18 basic (IKA, Wilmington, USA), operating at a speed of 18,000 rpm for 7 minutes. The solution was treated using ultra-sonication at 160 W power, 20 kHz frequency, and with 50 % pulse (Sonic Ruptor 400, OMNI International Homogenizer for nanoparticle formation (Na *et al*., 2011).

Avocado fruit coating process

The collected avocado fruits were coated using prepared formulas and divided into four groups (G). The fruits of G1 were considered the control group, which were washed with double-distilled water; the fruits of G2 were coated using solution A of the film; the fruits of G3 were coated using solution B; and the fruits of G4 were coated using solution C. The fruits were dried using a stainless-steel net rack with wide pores. The groups were then stored individually in polypropylene containers for storage and the following evaluations.

Preparation of fungal spore suspension

The spore suspension of *Aspergillus flavus* ITEM 698 was prepared according to the methodology of (Shehata *et al.,* 2019). Briefly, the fungal spores were suspended in sterile 0.1% (v/v) Tween 80 and then diluted with yeast extract sucrose broth (YESB) to achieve a concentration of 1.21×10^6 spores/mL as determined by the microscopic counts of spores on a hemocytometer slide. An appropriate dilution of the fungal spore inoculation was dispensed on the molten soft YESD (0.75% agar) to achieve a final mold spore concentration of 1.37×10^3 spores/mL for the spot assay.

Simulated experiment for fruit infection

A milliliter of spore suspension containing 1.37 10^3 spores was swabbed on the coated fruits in a control presence to test each film's resistance to fungal contamination. The fungal load of the fruits was tested every two days for their increment. The fungal count was read on days 1, 3, 5, 7, and 9 of inoculation. The lower fungal count loads on the fruits represent the higher antifungal film properties.

Evaluation of the fruit quality characteristics regarding the coating process

Avocado fruits of experimental groups were evaluated for the quality and stability of their characteristics during the cold storage period of the evaluation. The evaluated parameters were classified as the following tests:

1. Fruit Firmness

Fruit firmness was measured using an Ametek pressure tester. The firmness of two fruits from each replicate was measured at two opposite points on the equator of each fruit. The results were expressed in Ib/inch^2 (AOAC, 1990).

2. Total soluble solid

The total soluble solids percentage (TSS %) was calculated using a T/C hand refractometer Instrone, Brix readings 0-30 ranges (Model 10430, Bausch and Lomb Co. Calif., USA), and expressed as a percentage.

3. Total acidity

Titratable acidity percentage was expressed as oleic acid and determined by titration against 0.1 sodium hydroxide using phenolphthalein as an indicator as described in (AOAC, 1990).

4. Ascorbic acid content

Ascorbic acid content (VC, mg/100 ml juice) was determined using 2, 6 dichlorophenol indophenols' titration method as described in (AOAC, 1990).

5. Chlorophyll and Total carotenoid content

Chlorophyll and Total carotenoid content (mg/g FW): The concentrations of chlorophyll and carotenoids in avocado pulp (three duplicates) were analyzed spectrophotometrically using the method of (Wellburn, 1994). Using a spectrophotometer, Jenway 6715UV-Vis, the absorbance of the extract was measured at 663 nm for chlorophyll A, 646 nm for chlorophyll B, and 470 nm for total carotenoids (USA).

6. Total phenol content

Total phenol content (TPC, mg /100 g FW) was measured using the Folin–Ciocalteu test, which was modified slightly by (AOAC, 1990). Five milliliters of diluted Folin–Ciocalteau reagent were combined with one milliliter of extract (1:10). After 6 minutes, 4 mL of Na_2CO_3 (20%) was added to the mixture, which was allowed at room temperature for 2 hours before the absorbance against the reagent blank was measured with a UV-Visible spectrophotometer at 760 nm. Gallic acid equivalents/100 g of fruit were used to calculate total phenolic content (wet base). All the tests were carried out in duplicate.

7. **Polyphenol oxidase enzyme activity**

Polyphenol oxidase enzyme activity (PPO, Unit/g/FW): (Soliva *et al*., 2001) reported a method for determining the activity of polyphenol oxidase (PPO). 5g of mesocarp was homogenized for one minute in 15 ml of a 50 mM phosphate buffer for each treatment (pH 6.5). The mixture was centrifuged for 30 minutes at 4°C at 12000 rpm, with the supernatant utilized as the enzyme extract. The substrate consisted of 500µl of 20 mM catechol, 900µl of 50 mM phosphate buffer (pH 6.5), and 100µl of enzyme extract. A 500µl of 10% trichloroacetic acid (TCA) was poured

into the blank. The reaction was stopped by adding 500µl of 10% TCA to the mixture and incubating it for 20 minutes at 25°C. The absorbance was measured at 410nm with a spectrophotometer. The reaction was halted by adding 500µl of the TCA (10%). A spectrophotometer Jenway 6715UV-Vis was used to measure the absorbance at 410nm (USA). After a reaction time of 100 µl of extract, the PPO activity was observed as a rise in absorbance.

Statistical analysis

An ANOVA of the data was conducted using the InfoStat statistical package, version 2011; the replicate was considered the random variable. Means multiple comparisons were conducted using the Duncan test at $p \leq 0.05$. A statistical analysis of the data was carried out according to (Snedecor and Cochran, 1994).

RESULTS AND DISCUSSION

Natural fungal contamination of avocado fruit

The natural contamination of Avocado fruits by toxigenic fungi reflects the presence of seven fungal genera as *Aspergillus flavus*; *Aspergillus niger*; *Alternaria alternate*; *Fusarium solani*; *Fusarium moniliform*; *Penicillium expansum*; *Rhizopus sp*. These results indicate the natural contamination of avocado fruits in the stage of the preharvest section. Regarding these results, a fruit treatment that can significantly reduce the toxigenic fungal load is required to prevent more contamination during the following handling steps (Table 1).

Table (1): Toxigenic fungal contamination of collected avocado fruit

Fungi isolate	*Aspergillus flavus*	*Aspergillus niger*	*Alternaria alternata*	*Fusarium solani*	*Fusarium moniliform*	*Penicillium expansum*	*Rhizopus sp.*	Total count
Count (Log CFU/mL)	1.05±0.02	0.88±0.02	0.34±0.01	0.27±0.01	0.42±0.04	0.12±0.0.1	0.56±0.05	4.88±1.26

The results were expressed as mean±SD (n=5; $P \leq 0.05$).
Fungal contamination was calculated in (Log CFU/mL).

Simulated fungal contamination experiment

Avocado fruits of the control and coated groups were inoculated by *Aspergillus flavus* ITEM 698, where the results reflect the power of applied films to reduce the fungal count during the storage period (Table 2). The result regarding the coated fruits using the film's solution (A) represented the best impact against the inoculation of *Aspergillus* toxigenic contamination. In the second order, fruits of avocado, which are coated using film solution (B), were shown to reduce the *Aspergillus* contamination positively but with a lower level of film (A) efficacy. Compared to the control, coated avocado fruits by the film (C) which containing the oils mix was effective in fungal reduction.

Fruit firmness (Ib\inch^2)

Results in Table (3) showed a gradual and significant decrease in avocado fruit firmness with increasing the cold storage period at 5^0C in all coated treatments, including untreated fruits (control) during the average of two seasons. Hibiscus extract recorded the highest fruit firmness for the treatments, followed insignificantly by jojoba extract compared to the other treatments. As for cold storage, periods came

sequentially, with zero time being the highest, followed by the first week, through the second week, and until the sixth week, which was the lowest in fruit firmness.

Table (2): reduction of toxigenic fungi of inoculated avocado fruits (control and coated treatments) in a simulated experiment.

Incubation time	G1 Control	G2 inoculated	G3 inoculated	G4 inoculated
0	$1.19 \times 10^3 \pm 0.057$	$1.19 \times 10^3 \pm 0.114$	$1.19 \times 10^3 \pm 0.072$	$1.19 \times 10^3 \pm 0.012$
1	$1.96 \times 10^3 \pm 0.044$	$1.24 \times 10^3 \pm 0.017$	$1.27 \times 10^3 \pm 0.026$	$1.19 \times 10^3 \pm 0.014$
3	$1.74 \times 10^4 \pm 0.077$	$4.57 \times 10^3 \pm 0.073$	$5.8 * 10^3 \pm 0.031$	$6.8 \times 10^3 \pm 0.011$
5	$2.3 \times 10^4 + 0.186$	$7.82 \times 10^3 + 0.022$	$9.3 \times 10^3 + 0.022$	$9 \times 10^3 + 0.016$
7	$2.65 \times 10^5 + 0.141$	$1.2 \times 10^4 + 0.027$	$1.37 \times 10^4 + 0.016$	$1.64 \times 10^5 + 0.034$
9	$7.13 \times 10^6 + 0.081$	$1.5 \times 10^4 + 0.073$	$1.65 \times 10^4 + 0.011$	$2.49 \times 10^6 + 0.122$

The results were expressed as mean±SD (n=5; $P \leq 0.05$).
G1: the control group was just washed with double distilled water G2: Hass- fruit coated with a film containing jojoba oil; G3: Has -fruit coated with a film containing roselle seed oil; G4: Has -fruit coated with a film containing a mix of jojoba and roselle seed oils.

In the interaction between treatments and periods, all treatments in zero time achieved the highest fruit firmness, followed by the H and JH treatments after one week of cold storage, then the JO treatment after one week of storage. The lowest fruit firmness was observed in the control treatment at the fifth and sixth weeks.

Table (3): Firmness (Ib\inch^2) of avocado fruits affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons).

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Conrol	
zero	30.00 a	30.00 a	30.00 a	30.00 a	30.00 a
1st	29.00 ab	30.00 a	29.67 a	28.00 abc	29.17 a
2nd	27.67 a-d	29.00 ab	26.00 c-f	24.67 e-h	26.83 b
3rd	26.00 c-f	27.00 b-e	25.00 e-h	23.67 f-i	25.4c2
4th	24.67 e=h	25.33 d-g	23.00 g-j	21.00jk	23.50 d
5th	22.93 g-j	22.50 h-k	21.37ijk	20.00 kl	21.70 e
6th	21.07 jk	20.00 kl	20.67jkl	18.33 l	20.02 f
Mean	25.91 ab	26.26 a	25.10 b	23.67 c	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % probability level. Control = Tap water, JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus.

Total soluble solids percentage (TSS**, %)**

Data in Table (4) show the effect of coating avocado fruits cv. Hass by jojoba, hibiscus, and their mixture (JH) extracts after six weeks under cold storage on total soluble solids percentage (TSS %) as the average of two seasons. As for dipping treatments, jojoba extract significantly increased the average TSS% of fruit compared to the other treatments. No significant effect was detected concerning the impact of hibiscus, JH, and control treatments on TSS%. Regarding storage periods, the TSS% gradually decreased significantly over time, reaching a storage period of six weeks. Concerning the interaction between dipping treatments and cold storage periods, the zero time showed the highest TSS% in all treatments, followed by jojoba then

hibiscus after one week. The lowest TSS% appeared in control, JH, and hibiscus, respectively, after six weeks of cold storage.

Table (4): Total soluble solids percentage (%) of avocado fruit affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons)

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Conrol	
zero	1.8 a	1.80 a	1.80 a	1.80 a	1.8 a
1st	1.65 a	1.43 b	1.37 bc	1.33 bc	1.45 b
2nd	1.37 bc	1.33 bc	1.26 cd	1.23cd	1.30 c
3rd	1.35 bc	1.15 de	1.13 de	1.027 ef	1.17 d
4th	1.20 cd	0.84 ghi	0.98 efg	0.91 fgh	0.98 e
5th	1.15 de	0.70 ijk	0.80 hi	0.77 hij	0.85 f
6th	1.10 de	0.53 k	0.60 jk	0.68ijk	0.73 g
Mean	1.37 a	1.11 b	1.13 b	1.11 b	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % level of probability. Control = Tap water, JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus.

Titratable acidity (TA, %)

Regarding titratable acidity percentage in fruit, results in Table (5) show that jojoba extract significantly increased fruit titratable acidity compared to JH and the rest of the treatments. Also, TA decreased significantly over time in terms of storage period. All treatments gave the highest TA at zero time, and jojoba after one week of cold storage. The least TA appeared after six weeks of cold storage for control treatment.

Table (5): Titratable acidity (TA, %) of avocado fruits affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons)

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Conrol	
zero	4.11 a	4.11 a	4.11 a	4.11 a	4.11 a
1st	4.11 a	3.24 bc	2.88 cd	2.12 e	2.91 b
2nd	2.15 e	1.86 ef	2.62 d	1.97 ef	2.15 c
3rd	2.03 ef	1.35ghi	2.12 e	1.69 fgh	1.79 d
4th	1.75 efg	1.05 ijk	1.13 ij	1.30 hi	1.31 e
5th	1.18 ij	0.65 klm	0.79 jkl	1.04 ijk	0.92 f
6th	0.79 jkl	0.45 lm	0.39 lm	0.28 m	0.48 g
Mean	2.2 a	1.82 c	2.01 b	1.79 c	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % level of probability. Control = Tap water, JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus.

Ascorbic acid content (mg\100 g FW)

The lowest vitamin C content was seen in the control treatment, while the highest content was obtained by JH, hibiscus, and jojoba, respectively, (Table 6). Fruit vitamin C content was significantly observed to be high at zero time, then decreased thoroughly in the sixth week, which was the lowest. The interaction between treatments and cold storage periods illustrated the superiority of all treatments at zero time in vitamin C content, followed by hibiscus, JH, and jojoba after one week of storage, respectively. There were no apparent differences between the treatments in the last three weeks of cold storage, but the control group had the lowest values of vitamin C.

Table (6): Ascorbic acid content (mg100 g^{-1} FW) of avocado fruits affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons)

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Conrol	
zero	39.50 a	39.50 a	39.50 a	39.50 a	39.50 a
1st	36.00 ab	39.00 a	39.00 a	31.00 cde	36.25 b
2nd	29.30 def	33.60 bc	33.00 bcd	28.25 ef	31.04 c
3rd	27.90 ef	29.30 def	29.30 def	26.20 f	28.18 d
4th	14.40 g	14.80 g	15.00 g	13.10 g	14.33 e
5th	13.90 g	13.80 g	14.60 g	12.00 g	13.58 e
6th	13.70 g	13.50 g	14.00 g	11.33 g	13.13 e
Mean	24.96 a	26.21 a	26.34 a	23.06 b	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % level of probability. Control = Tap water, JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus.

Total phenols content (mg100 g^{-1} FW)

Table (7) illustrated that the control treatment gave the highest value of fruit total phenols content, followed by JH, jojoba, and hibiscus extracts, respectively. Fruit total phenols content decreased over time, starting from zero time to the sixth week. All treatments recorded the highest fruit content of total phenols at zero time.

Fruits total chlorophyll (mg/g FW)

According to the treatments in Table (8), the fruit chlorophyll of H was the highest in chlorophyll A, followed by the JO treatment, then JH and control. Concerning periods of storage, as with all previous parameters, the zero time significantly recorded the highest content of chlorophyll A, followed by all storage time respectively. Regarding dipping treatments and cold storage periods, no apparent differences were observed between treatments and periods at zero time, which were the superior among all treatments. The lowest chlorophyll A values were noticed in the control fruits after six weeks of cold storage.

Table (7): Total phenols content (mg/100 g FW) of avocado fruits affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons)

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Conrol	
zero	191.54 a	191.54 a	191.54 a	191.54 a	191.54 a
1st	171.04 d	171.34 d	174.22 c	184.45 b	175.26 b
2nd	132.13 g	104.1 j	143.54 f	153.68 e	133.36 c
3rd	106.78 i	89.51 m	121.35 h	133.44 g	112.77 d
4th	90.49 lm	62.70 p	91.22 l	94.51 k	84.73 e
5th	66.30 o	58.34 q	77.46 n	66.88 o	67.25 f
6th	39.76 s	49.72 r	57.32 q	65.50 o	53.07 g
Mean	114.01 c	103.89 d	122.38 b	127.14 a	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % level of probability. Control = Tap water, JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus

Table (8): Chlorophyll A content (mg g^{-1} FW) of avocado fruits affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons)

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Control	
zero	0.9583 a	0.9583 a	0.9583 a	0.9583 a	0.9583 a
1st	0.8765 c	0.8895 b	0.8565 d	0.8342 e	0.8642 b
2nd	0.7908 f	0.8334 e	0.749 g	0.7324 h	0.7764 c
3rd	0.6778 i	0.7552 g	0.6671 ij	0.6438 k	0.686 d
4th	0.5943 l	0.657 j	0.5716 m	0.4731 o	0.574 e
5th	0.4509 p	0.6045 l	0.4791 o	0.3604 r	0.4737 f
6th	0.3594 r	0.523 n	0.378 q	0.3296 s	0.3975 g
Mean	0.6726 b	0.7459 a	0.6657 c	0.6188 d	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % level of probability. Control = Tap water, JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus

The first treatment significantly outperformed all treatments in fruit content of chlorophyll B, followed by hibiscus, JH, and control, respectively. The longer the storage period, the lower fruit content of chlorophyll B; this is evident in Table (9) regarding storage periods. The highest results after zero time were for the first treatment (JO), while the lowest fruit chlorophyll B content was noticed in JH treatment after six weeks of cold storage.

Data in Table (10) showed that the third and first treatments respectively outperformed fruits' total chlorophyll content, while the control treatment was the least. Since the sum of both chlorophyll A and B equals the total chlorophyll, so we found that fruits' total chlorophyll content behaved in the same direction concerning both chlorophyll A and B, where the fruit content of total chlorophyll gradually decreased over time until reaching six weeks of cold storage.

Table (9): Chlorophyll B content (mg g-1 FW) of avocado fruits affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons)

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Control	
zero	0.8285 a	0.8285 a	0.8285 a	0.8285 a	0.8285 a
1st	0.7968 ab	0.749 abc	0.7324 a-d	0.5785 e-h	0.7142 b
2nd	0.7156 a-d	0.6798 b-e	0.621 d-g	0.6147 d-h	0.6578 b
3rd	0.6489 c-f	0.5527 fgh	0.5716 e-h	0.529 f-i	0.5755 c
4th	0.5057 ghi	0.5397 fgh	0.4909 hij	0.4087 ijk	0.4863 d
5th	0.3794 jkl	0.379 jkl	0.3594 klm	0.2383 mno	0.339 e
6th	0.2808 lmn	0.2763 lmn	0.2124 no	0.1381 o	0.2269 f
Mean	0.5937 a	0.5721 ab	0.5452 b	0.4765 c	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % level of probability. Control = Tap water, JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus

It was observed that the highest values of total chlorophyll after zero time were for the third treatment after two weeks of storage, followed by the first treatment after one week of storage. Conversely, the control treatment recorded the lowest values after 6th weeks of storage.

Table (10): Total chlorophyll content (mg g^{-1} FW) of avocado fruits affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons)

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Control	
zero	1.7868 a	1.7868 a	1.7868 a	1.7868 a	1.7868 a
1st	1.6438 ab	1.5743 abc	1.5671 abc	1.3651 bcd	1.5376 b
2nd	1.5191 abc	1.3651 bcd	1.6591 ab	1.2585 cde	1.4504 b
3rd	1.046 def	0.9747 e-h	1.0073 efg	0.9583 e-h	0.9966 c
4th	0.9583 e-h	0.8333 f-i	0.9942 e-h	0.7527 f-i	0.8846 c
5th	0.7908 f-i	0.6438 hi	0.8285 f-i	0.529 i	0.698 d
6th	0.6778 ghi	0.5943 i	0.6943 ghi	0.4934 i	0.615 d
Mean	1.2032 a	1.1103 ab	1.2196 a	1.0205 b	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % level of probability. Control = Tap water,JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus

Fruits total carotenoids content

The third treatment achieved the highest value of fruit carotene content, while there were no apparent differences between the first and second treatments. Still, the lowest results were obtained by control. Fruits carotene content decreased significantly over time until the end of the sixth week Table (11).

All treatments at zero time and the third treatment after one week of cold storage achieved the highest results concerning the fruit's carotene content. At the same time, the lowest results were for the control treatments after six weeks of cold storage.

Table (11): Total carotenoid content (mg g^{-1} FW) of avocado fruits affected by some edible coating treatments under cold storage at 5 ±1°C and 85-90% RH (average of two seasons)

Storage weeks	Treatments				Mean of storage
	JO	H	JH	Control	
zero	1.345 a	1.345 a	1.345 a	1.345 a	1.345 a
1st	1.2338 ab	1.1965 ab	1.3236 a	1.1469 bc	1.2252 b
2nd	1.0982 bcd	0.9942 cd	1.2336 ab	0.8285 ef	1.0386 c
3rd	0.7527 fg	0.7285 fg	0.9583 de	0.6147 gh	0.7635 d
4th	0.4976 hij	0.529 hi	0.7775 f	0.3961 ijk	0.55 e
5th	0.342 klm	0.3818 i-l	0.536 hi	0.3844 i-l	0.411 f
6th	0.323 klm	0.2353 lm	0.3555 j-m	0.212 m	0.2814 g
Mean	0.7989 b	0.7729 b	0.9328 a	0.7039 c	

Similar letters for the means of each factor and interaction indicate a non-significant difference at a 5 % level of probability. Control = Tap water; JO= Jojoba oil, H= Hibiscus and JH= Jojoba + Hibiscus

Edible coatings are gaining traction for extending the shelf life and maintaining the post-harvest quality of fresh fruits and fresh-cut produce. This study demonstrates that a coating comprising jojoba oil, Arabic gum, and hibiscus extract effectively preserves fruit freshness and quality, consistent with previous research highlighting the benefits of edible coatings in reducing moisture loss, delaying ripening, and minimizing microbial decay (El-wahed and Naser, 2023; Aboryia and Omar, 2020).

Jojoba oil, previously shown to enhance the storage stability of fresh produce in whey protein-based coatings (Galus *et al*., 2022), likely acts as a semi-permeable barrier due to its hydrophobic nature, regulating gas exchange and reducing respiration. Our findings corroborate this, as jojoba oil significantly improved texture and color retention in coated fruits. Arabic gum's film-forming properties and ability to prevent moisture loss are well-documented (Emam *et al*., 2021). Consistent with studies on pomegranates and plums (Maklad, 2015), our results show that Arabic gum coatings reduce weight loss and improve fruit firmness during storage. Edible coatings based on carboxymethyl cellulose and gum Arabic improved Acid Lime fruit quality and shelf life (Beheiry *et al.,* 2023; Hasanin *et al.,* 2025).

Hibiscus extract, rich in phenolic compounds, offers antioxidant and antimicrobial potential. While its use in edible films is limited, its ability to inhibit microbial spoilage aligns with findings on other plant-based extracts (Ngcobo and Fawole, 2023). The hibiscus-enriched coatings in this study-maintained fruit sensory attributes, suggesting its viability as a natural preservative. Compared to lipid-based coatings that enhance the storage stability of pears and citrus fruits (Cruz *et al*., 2015; Elnagar *et al*., 2021), our results indicate a synergistic effect of jojoba oil, Arabic gum, and hibiscus extract in improving fruit quality and shelf life.

Another investigation was optimized coating concentrations, evaluated efficacy on diverse fruits, and explore incorporating other bioactive compounds to further enhance functionality (Aguirre-Joya *et al*., 2016).

The findings of this study outperform those published by (De los Santos-Santos *et al.,* 2020) and (González *et al.,* 2014), who coated soursop fruits with hibiscus mucilage, candelilla wax, and beeswax. According to (Yashoda *et al*., 2006), the reduction of total sugars, starch, and cellulose during ripening, which results in

the production of oligosaccharides and monosaccharides that give the fruit its texture and flavor, is responsible for changes in the TSS concentration for climacteric fruits. The results of our investigation do not agree with those that appeared with (Tarabih and El-Metwally, 2014) which show that the percentage of TSS in Washington navel orange coated with jojoba oil increased with storage, as their justification for that was an increase in the hydrolysis of polysaccharides and concentration of juice due to dehydration.

The total phenolic content of blueberries was recently increased by using Roselle extract as an edible coating, inhibiting microbial growth, anthocyanin degradation, and enzyme activity (Yang *et al.,* 2019). In addition, hibiscus mucilage (2%), used as an edible coating for soursop fruits (*Annona muricata* L.) kept at 15°C, demonstrated the lowest titratable acidity and weight loss as well as a rise in vitamin C, total phenolic content, and antioxidant activity (De los Santos-Santos *et al.,* 2020).

(De los Santos-Santos *et al*., 2020) also concluded that a coating made of hibiscus and roselle mucilage (2%) improved the vitamin C content of soursop fruits. Due to the coatings' ability to suppress polyphenol oxidase, the coated fruits' delayed loss of firmness may be strongly related to their healthy cellular membranes and slow down the fruit's softening process (Zhao *et al.,* 2019).

According to (Lima *et al*., 2004) and (Etienne *et al*., 2013), titratable acidity falls near the end of storage, indicating that organic acids are utilized as substrates in the respiration process.

Firmness: Increased respiration rate and ethylene generation at the start of ripening are characteristic of climacteric fruits like avocados. During the climacteric peak, avocados release significantly more ethylene (80–100 µl kg^{-1} h^{-1} at 20°C) than other climacteric fruits (Pedreschi *et al.,* 2019). According to (Moya-León, *et al.,* 2019), the deterioration of cell walls and loss of connectivity of pectins and hemicelluloses as a result of solubilization and enzymatic depolymerization are to blame for the loss of firmness in climacteric fruits such as avocado.

These findings concur with those of (Yaman and Bayoındırlı, 2002), who discovered that the reaction of the degradation of protections (insoluble form) into more soluble pectin components might be used to define the maintenance of firmness. When the fruit ripens, pectinesterase and polygalacturonase enzyme activity rise, causing a polymerization or shortening of the chain length of pectic compounds. As a liquid wax, jojoba oil may prevent moisture loss and inhibit pectin-degrading enzyme activity, which is directly connected to the softening of fruit by slowing the flow of metabolic processes during senescence (Zhou *et al.,* 2007; El-Nagdi 2017). Our findings corroborate those of (Khaliq *et al.,* 2015) and (Saleh *et al.,* 2019), who found that edible coating may help to support firmness. In the current experiment, the jojoba and hibiscus extract-treated fruits displayed higher firmness values than the untreated fruits, which may be attributable to the edible coating's thick layer, which created a favorable environment around the fruit surface and slowed down the breakdown of the cell wall enzymes and changes in pectin materials.

According to research by (Abd-Allah *et al.,* 2012), applying jojoba oil to persimmon fruits helped to postpone ripening and maintain fruit quality during cold storage.

(Tarabih and El-Metwally, 2014) revealed that a minimum percent of TA was found in fruit treated with boric acid at 1.0%+jojoba oil at 0.1%. Using organic acids in the respiration process may cause a reduction in acidity throughout storage.

The decline in ascorbic acid content varied from 36.36 to 34.16 mg after 45 days of shelf life at room temperature in both seasons and from 35.10 to 31.36 mg (Tarabih and El-Metwally, 2014). They also stated that ascorbic acid levels decreased gradually with boric acid treatment (1.0%) and jojoba oil (0.1%). Due to its oxidation during food processing and storage compared to other nutrients, ascorbic acid is a crucial nutritional quality criterion and is highly susceptible to deterioration (Veltman *et al.,* 2000). According to (Kerk and Feldman, 1995), ascorbic acid also has a role in the cell cycle and other significant enzymatic processes in plant tissues, such as ethylene production. (Jawandha *et al.,* 2012) similarly showed a progressive decline in acidity. (Rashida *et al.,* 1997) also concluded that fruit will ripen to their least acidic and highest quantities of sugar, ascorbic acid, soluble solids, and other nutrients.

CONCLUSIONS

This study highlights the effectiveness of a novel edible coating composed of jojoba oil, Arabic gum, and hibiscus extract in enhancing the shelf life and quality of fresh fruits and fresh-cut produce. The synergistic action of these natural ingredients contributes to reducing moisture loss, maintaining firmness, and preserving sensory attributes. Jojoba oil serves as a moisture barrier, Arabic gum enhances film-forming properties, and hibiscus extract provides antioxidant and antimicrobial benefits. Compared to existing edible coatings, this combination offers a sustainable and promising alternative for post-harvest preservation. Future investigations should focus on optimizing formulation ratios, exploring additional fruit varieties, and integrating other bioactive compounds to maximize functionality and commercial viability. These findings support the broader adoption of plant-based edible coatings as a natural and eco-friendly solution to extending fruit shelf life while maintaining nutritional and sensory qualities.

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CONFLICT OF INTEREST

There are no conflicts to declare.

تأثير بعض معاملات الطلاء الصالح للأكل من الجوجوبا والكركديه بعد الحصاد على تحسين جودة وقابلية تخزين ثمار الأفوكادو 'هاس' أثناء التخزين البارد

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الخلاصة

تعمل الطبقة والفيلم الصالحين للأكل على إطالة عمر الفاكهة الطازجة بعد الحصاد. يتم استخدامه لتحسين مظهر الفاكهة وتوفير سلامتها بطبيعته الصديقة للبيئة. أجريت الدراسة الحالية للتحقيق في تأثير بعض الطلاءات الصالحة للأكل مثل زيوت الجوجوبا (*Simmondsia Chinensis*) أو الكركديه (*Hibiscus sabdariffa*) أو خليطهما (1:1) على جودة وقابلية تخزين ثمار الأفوكادو صنف هاس. تم إجراء التقييم خلال موسمين متتاليين 2021 و2022، حيث تم تخزين الفاكهة في ظروف تخزين باردة (5 ± 1 درجة مئوية / و85 – 90٪ رطوبة نسبية / 6 أسابيع) مقارنة بالفاكهة غير المعالجة (المجموعة الضابطة). تم تحديد التلوث الأولي بالفطريات السامة لثمار الأفوكادو المجموعة. كما تم تقييم قدرة الفاكهة المعالجة على مقاومة التلوث الفطري باستخدام دراسة تجريبية محاكاة. تم تقييم تركيبة الأحماض الدهنية للزيوت المطبقة لشرح نشاط الفيلم. أظهرت النتائج أن جميع معاملات الطلاء الصالحة للأكل أظهرت خصائص فيزيائية وكيميائية أفضل أثناء التخزين مقارنة بالفواكه غير المعالجة (الشاهد). نتج عن ثمار الأفوكادو المغلفة بمستخلص الكركديه أعلى صلابة للثمار ومحتوى فيتامين سي ومحتوى الكلوروفيل وأقل حموضة قابلة للقياس ومحتوى ضئيل من الفينول. لاحظت معاملة الجوجوبا أعلى محتوى من المواد الصلبة الذائبة ومحتوى الكلوروفيل ب. بشكل عام، يمكن التوصية بالطلاء الصالح للأكل بزيت الجوجوبا ومستخلص الكركديه ومزيجهما (1:1) للحفاظ على جودة الثمار وإطالة عمر تخزين ثمار الأفوكادو.

الكلمات المفتاحية: ثمار الأفوكادو، طلاء صالح للأكل، زيت الجوجوبا، زيت الكركديه، التخزين البارد.

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