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The Effect of Xanthan-based Edible Coatings Enriched with Oleic Acid on the Storage Quality and Antioxidant Properties of Sapodilla (*Manilkara zapota*) Fruit

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Abstract

The sapodilla fruit has a limited shelf life due to its perishability and rapid moisture loss. The application of edible coatings has attracted much interest because they are effective in prolonging the shelf life of fruits. This study aims to evaluate the effectiveness of an edible coating made from xanthan gum (XG) (0.1% and 0.2%) combined with oleic acid (Ol) (1%) in prolonging the shelf life of sapodilla fruit at 8 ± 1 ºc and a relative humidity (RH) of 85-90%. Weight loss was significantly reduced in the treated fruits, with the minimum weight loss observed in the Xan 0.2% + Ol treatment. Except for the Ol treatment, the other treatments showed a higher level of firmness compared to the control. At the end of the experiment, the treatments significantly reduced fruit respiration. The treated fruits also showed significantly increased antioxidant capacity and higher levels of ascorbic acid compared to the control. The lowest TSS (22.8%) level was noted in the Xan 0.2 + Ol treatment. Moreover, the results showed that fruit treated with Xan 0.1% + Ol coating exhibited higher activity in the superoxide dismutase (SOD), catalase (CAT), and ascorbate peroxidase (APX) enzymes compared to the fruit treated with Xan 0.2 + Ol coating and the control samples. In general, fruits treated with Xan 0.2 + Ol and Xan 0.1% + Ol demonstrated the highest overall quality compared to the control and other treatments. Therefore, the application of these treatments is recommended for maintaining the quality of sapodilla fruit.

Keywords: Coatings, Oleic acid, Sapodilla, Storage, Xanthan

Introduction

Sapodilla, *Manilkara zapota*, is the most well-known and the most widely used fruit of the Sapotaceae family. Sapodilla is a rich source of nutrients (carbohydrates, organic acids, proteins, amino acids), minerals (potassium, calcium, iron), and includes numerous bioactive compounds primarily composed of allergitannins, galotannins, phenolic acids, and flavonoids. Due to its rich phytochemical profile in both edible and non-edible parts, Sapodilla has various medicinal potential through different biological activities. Due to its perishability and quick moisture loss, the fruit of Sapodilla has a short shelf life, but post-harvest technologies can enhance fruit storage to some extent. There are several methods for preserving and improving the post-harvest life of fruits and vegetables, among which the use of biodegradable films and coatings is very promising (Khalil *et al*., 2020). Since the edible coating is made from natural

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materials, it is safe and suitable for human consumption (Paidari *et al*., 2021). Furthermore, edible coatings have many advantages, including the ability to form a semi-permeable barrier against gases and water vapor, help maintain firmness, add gloss to coated fruits while improving market acceptability, enhancing mechanical properties, and preventing the loss of volatile compounds (Galus & Kadzi´nska, 2015). Xanthan gum is an extracellular high molecular weight polysaccharide produced by *Xanthomonas campestris* bacteria and is one of the most important commercial microbial hydrocolloids used in the food industry as a thickening and stabilizing agent (Zheng *et al.*, 2019). Xanthan gum-based edible coating is a long-chain polymeric substance containing polymeric functional groups that exhibit unique properties under specific conditions, which can improve the mechanical properties of biodegradable materials. Xanthan can improve the tensile behavior of starch layers without reducing their water absorption capacity and water vapor permeability (Sapper *et al.*, 2019). Gelatin-carboxymethyl cellulose (CMC) films with xanthan gum showed improved physical and mechanical properties (Nur Hazirah *et al.*, 2016). A composite film of nanocapsules/xanthan gum can prolong the storage of freshly cut apples by reducing the initial respiration rate (Galindo-P´erez *et al.*, 2015). Lipid-based coatings (oleic acid) hinder moisture transfer due to their relatively low polarity. Therefore, a new approach is proposed to increase the shelf life of perishable fruits with minimal processing (Md. Sharif *et al*., 2017; Mladenoska *et al*., 2012; Karunanayake *et al.*, 2020; Mitelut *et al*., 2021). The content of oleic acid has been demonstrated to serve as an emulsifying agent and a base for preserving fruits (Butar-Butar *et al.*, 2021). In a study by Setianingsih *et al*. (2023), a combination of palmitic, stearic, and oleic acids was employed in an emulsion, leading to enhanced appearance and prolonged shelf life of orange fruits.

Numerous studies have investigated the effectiveness of coatings in preserving the quality of various fruits during storage. These studies have consistently shown positive results. For instance, in a study conducted by Wani *et al.* (2021), it was found that the use of Arabic gum, carrageenan, and xanthan gum combined with lemon grass essential oil proved to be effective in maintaining the quality parameters of strawberries during storage. This coating treatment demonstrated superior results compared to the control, indicating its potential for extending the shelf life and preserving the quality of strawberries. In another study, guava fruits were coated with a mixture of Arabic gum (10%), oleic acid (1%), and cinnamon oil (1%). This coating significantly delayed browning development in guava compared to other treatments, while preserving fruit firmness and reducing weight loss. Additionally, it prevented lipid peroxidation and electrolyte leakage at the end of the storage period, indicating its effectiveness in maintaining fruit quality (Vargas *et al*., 2006). Previous studies have extensively explored the use of fruit coatings; however, this research introduces an innovative approach by utilizing a combination of xanthan gum and oleic acid to preserve the quality of sapodilla fruits. To the best of our knowledge, there is no previous report on the application of this compound for maintaining the quality of sapodilla fruit. Therefore, this research represents the first investigation to assess the effects of xanthan gum and its combination with oleic acid on the shelf life of sapodilla.

Materials and Methods

Fruit Treatment and Edible Coating Preparation

For this study, mature stage fruits of the Alano variety of Sapodilla (Chico) were harvested from the Minab Agricultural Research Station. Immediately after harvest, the fruits were transported to the physiology laboratory. Healthy and uniform fruits were carefully selected for the experiment. The selected fruits were subjected to various experimental treatments, which included the application of edible coatings comprising xanthan gum at concentrations of 0.1% and

0.2%, along with oleic acid at a concentration of 1.0%. Following the application of the coatings, the treated fruits were stored at 8±1 ^{o}c and a relative humidity of 90-85% for 10, 30, 20, and 40 days.

Weight Loss

The weight loss of the fruits was measured using a digital scale by weighing each individual fruit on the first day and at regular intervals (every 10 days). The percentage of weight loss was calculated using the following formula (Juhaimi *et al*., 2012).

Weight loss (%) = [(Fruit initial weight-fruit weight at each sampling time)/Fruit initial weight] ×100

Firmness

The firmness of the fruits was measured at two points in the middle section (without the peel). Two points on the surface of each fruit were selected and the firmness was reported in N (Juhaimi *et al*., 2012).

Respiration

A specific weight of fruit was placed in a plastic container. The initial CO_2 level (D1) was measured during the first instance, and again after 20 minutes (D2), using a respirometer device called the STEP Respiratory Sensor. The respiration rate was expressed in mL/kg.h according to the following formula (Xing *et al*., 2008).

RCO_2 = (D2− D1) × 10^6 × Volume of container ⁄ (Time × Fruit weight)

Total Antioxidant Activity

The antioxidant activity was calculated based on the method described by Brand-Williams *et al*. (1995), and the absorbance of the samples was measured using a microplate reader at 517 nanometers. The antioxidant activity was then calculated using the following formula.

Antioxidant activity (%)= [1 - (Abs sample/ (Abs control)] × 100

Soluble Solids Content

The soluble solids content of the fruit juice was measured in terms of the Brix^{o} using a digital refractometer (DBR95, Taiwan).

Ascorbic Acid Content

The ascorbic acid content was measured using a spectrophotometer (O'Grady *et al*., 2014). The absorbance of the samples was read at 510 nanometers using a microplate reader instrument (Epoch, Bio Tek® Instruments, VT, USA).

Catalase

The measurement of catalase activity in the samples was performed using the method described by Chance & Maehly (1955). The absorbance at 240 nanometers was read using a UV-Visible spectrophotometer model UNICO 2150 for a duration of one minute.

Ascorbate Peroxidase (APX)

The enzyme activity was measured using the method described by Nakano & Asada (1981). The activity of this enzyme was measured at 290 nanometers for a duration of two minutes using a spectrophotometer. The enzyme activity was then calculated in terms of units per gram of fresh weight (U/g FW min) of the flesh or peel.

Superoxide Dismutase (SOD)

The SOD activity was measured using the method described by Giannopolitis & Ries (1977). The absorbance of the samples was read at 560 nanometers using a spectrophotometer. The activity of this enzyme was expressed as units per gram of fresh weight (U/g FW).

Results and Discussion

Weight Loss

The fruits covered with edible coatings exhibited lower weight loss compared to the control throughout the storage. At the end of the storage period, the Xan 0.2 % + Ol treatment had a significant reduction in fruit weight loss by 28.51% compared to the control (Fig. 1). Weight loss is an important indicator of fruit quality during the post-harvest stage and is influenced by transpiration due to differences in vapor pressure between the fruit and the environment (Yaman & Bayonidirli, 2002). It is also influenced by respiration and various physiological mechanisms (Juhaimi *et al*., 2012). The application of an edible coating composed of chitosan and essential oils helps minimize water loss in fruits by reducing the rate of water vapor transmission. This coating acts as a barrier, effectively blocking the escape of water vapor and inhibiting excessive transpiration. By regulating the loss of moisture, the coating helps maintain the fruit's water content and prevents dehydration. The reduction in water vapor transmission rate achieved through the coating contributes to the preservation of fruit quality and freshness (Widyastuti *et al*., 2023). Similar results were obtained in the study conducted by Kumar *et al*. (2021). They found that a bilayer edible coating consisting of xanthan gum and beeswax on tomato resulted in increased shelf life and improved resistance to water vapor transmission.

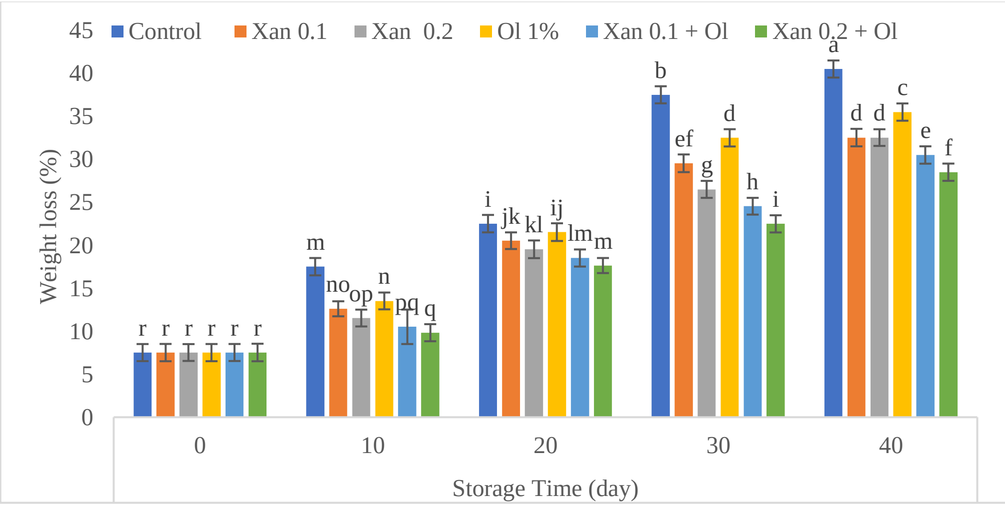


Fig. 1. The interaction effect between treatments (Control, Xanthan 0.1 %, Xanthan 0.2 %, Oleic acid 1%, Xanthan 0.1 % + Oleic acid 1 %, and Xanthan 0.2 % + Oleic acid 1 %) and storage periods on the weight loss of sapodilla fruit during four periods (10 days) of storage at 8 ± 1℃ and 85% relative humidity (RH)

The values represent mean ± SD from three replicates (n=3). Statistical analysis was performed using LSD test.

Firmness

Fruit firmness gradually decreased during storage (Fig. 2-A). The highest level of firmness was observed in the Xan 0.2 % + Ol and Xan 0.1 % + Ol treatments, respectively (Fig. 2-B). Fruit firmness is an important parameter in fresh horticultural products, and it decreases as the storage time increases. The loss of fruit firmness is concurrent with changes that occur in the cell wall structure. Pectin substances are responsible for the integrity of fruits. They are the main components of the middle lamella and predominantly form the initial cell wall structure. The effects of coatings on fruits and their storage conditions vary significantly, as evidenced by the considerable impact on fruit firmness. In the case of sapota fruits, the reduction in firmness can be attributed to several factors, including a decrease in cellular turgor pressure, the release of extracellular and vascular air, and the degradation and breakdown of cell walls (Shah *et al*., 2016). The addition of lipids to the polymer composition can increase the water repellency behavior of the coating and consequently reduce water permeability. Typically, the permeability values increase linearly with a decrease in the concentration of the essence (Sánchez-González *et al*., 2010). In this regard, Vargas *et al*. (2006) reported that the combination of oleic acid with chitosan coating resulted in decreased permeability and respiration rate due to surface solid density.

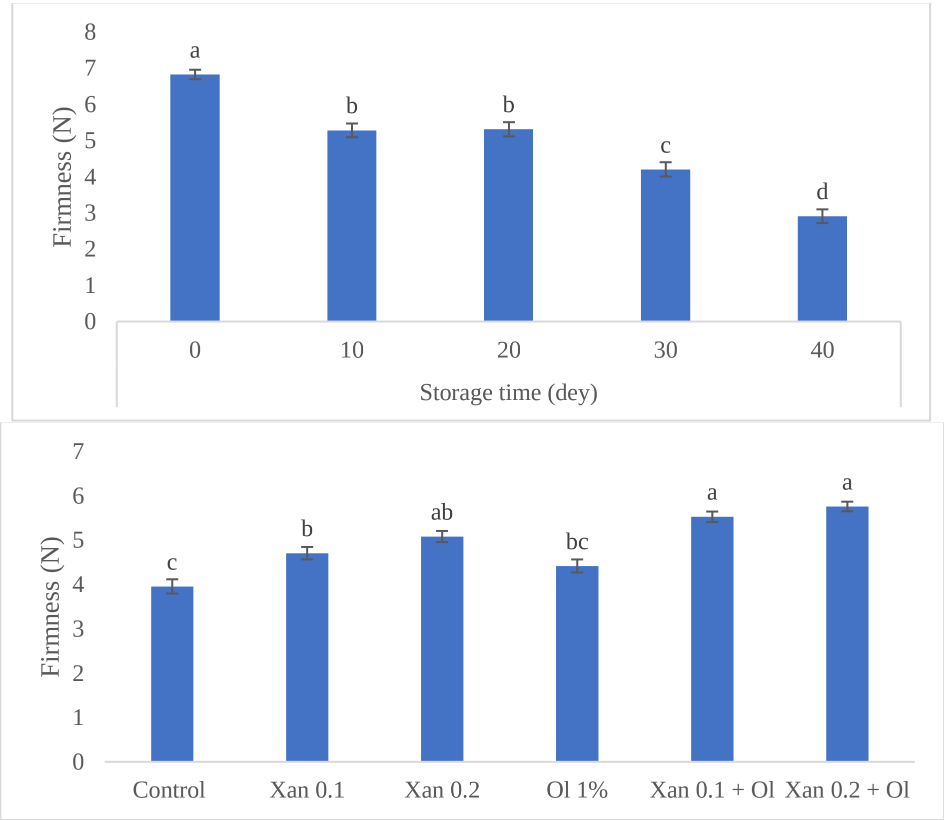


Fig. 2. The effect of storage periods and different coatings (Control, Xanthan 0.1%, Xanthan 0.2 %, Oleic acid 1%, Xanthan 0.1 % + Oleic acid, and Xanthan 0.2 % + Oleic acid) on the firmness of sapodilla fruit during four periods (10 days) of storage at 8 ± 1℃ and 85% relative humidity (RH)
The values represent mean ± SD from three replicates (n=3). Statistical analysis was performed using LSD test.

Respiration

As shown in Fig. 3, the fruits treated with Xan 0.2 % + Ol and Xan 0.1 % + Ol showed the lowest respiration rate compared to other samples. Edible coatings could modify gas transfer (carbon dioxide, oxygen, and ethylene) and consequently delay respiration rate and physiological processes, thus extending the shelf life of fruits and vegetables. Furthermore, previous studies have shown that the delay in respiration rate in fruits can be attributed to the inhibition of ethylene production (Hassan *et al*., 2018). The results of this study were consistent with the findings reported by Naveed *et al.* (2024), who documented a significant reduction in the respiration rate of jujube fruits covered with xanthan gum coating.

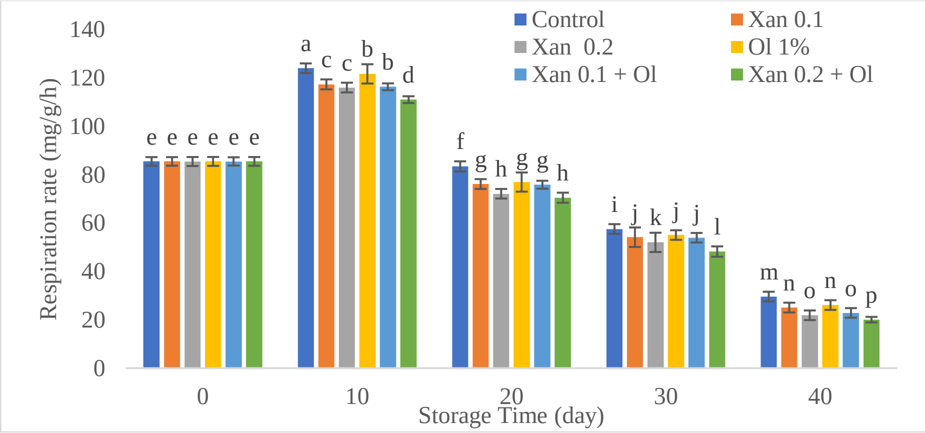


Fig. 3. The interaction effect between treatments (Control, Xanthan 0.1 %, Xanthan 0.2 %, Oleic acid 1%, Xanthan 0.1 % + Oleic acid, and Xanthan 0.2 % + Oleic acid) and storage periods on the respiration rate of sapodilla fruit during four periods (10 days) of storage at 8 ± 1℃ and 85% relative humidity (RH)
The values represent mean ± SD from three replicates (n=3). Statistical analysis was performed using LSD test.

Total Antioxidant Activity

The fruits treated with Xan 0.1% + Ol exhibited the highest antioxidant activity, which was 5.23 times greater than the activity observed in the control (Fig. 4). Usually, the production of reactive oxygen species (ROS) increases during fruit ripening and storage, leading to oxidative stress and fruit decay. Reports have shown that an increase in total phenolic content correlates with an increase in antioxidant capacity (Etemadipoor *et al*., 2020). In this study, since the combined xanthan coating with oleic acid disrupts the ripening process, it results in higher antioxidant activity in the fruit. Additionally, several changes in vitamin content throughout the ripening process can influence antioxidant activity.

Ascorbic Acid Content

The highest content of ascorbic acid was observed in the fruit treated with Xan 0.1 % + Ol (137.86 mg/100 g FW) compared to the control (100.41 mg/100 g FW) (Fig. 5). Ascorbic acid acts as an antioxidant in fruits and reduces fruit damage. This action is achieved through the elimination of free radicals produced during the ripening and oxidation process. The presence of oxygen can have a negative impact on the ascorbic acid content in fruits (Ayranci & Tunc, 2004). The presence of an edible coating on the fruit reduces the detrimental effects of oxygen, and this is accomplished through the performance of antioxidant compounds present in the coating and their role as a barrier against oxygen transfer (Oliveira *et al*., 2017).

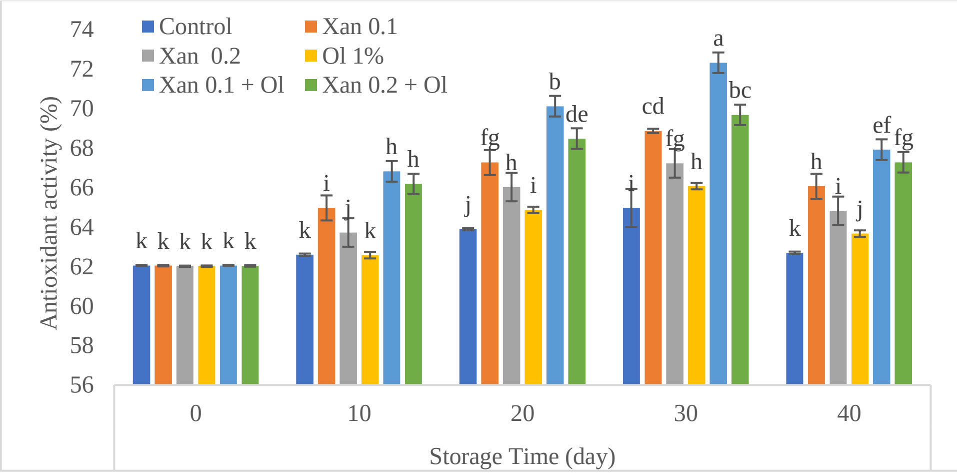


Fig. 4. The interaction effect between treatments (Control, Xanthan 0.1 %, Xanthan 0.2 %, Oleic acid 1%, Xanthan 0.1 % + Oleic acid, and Xanthan 0.2 % + Oleic acid) and storage periods on the total antioxidant activity of sapodilla fruit during four periods (10 days) of storage at 8 ± 1℃ and 85% relative humidity (RH)
The values represent mean ± SD from three replicates (n=3). Statistical analysis was performed using LSD test.

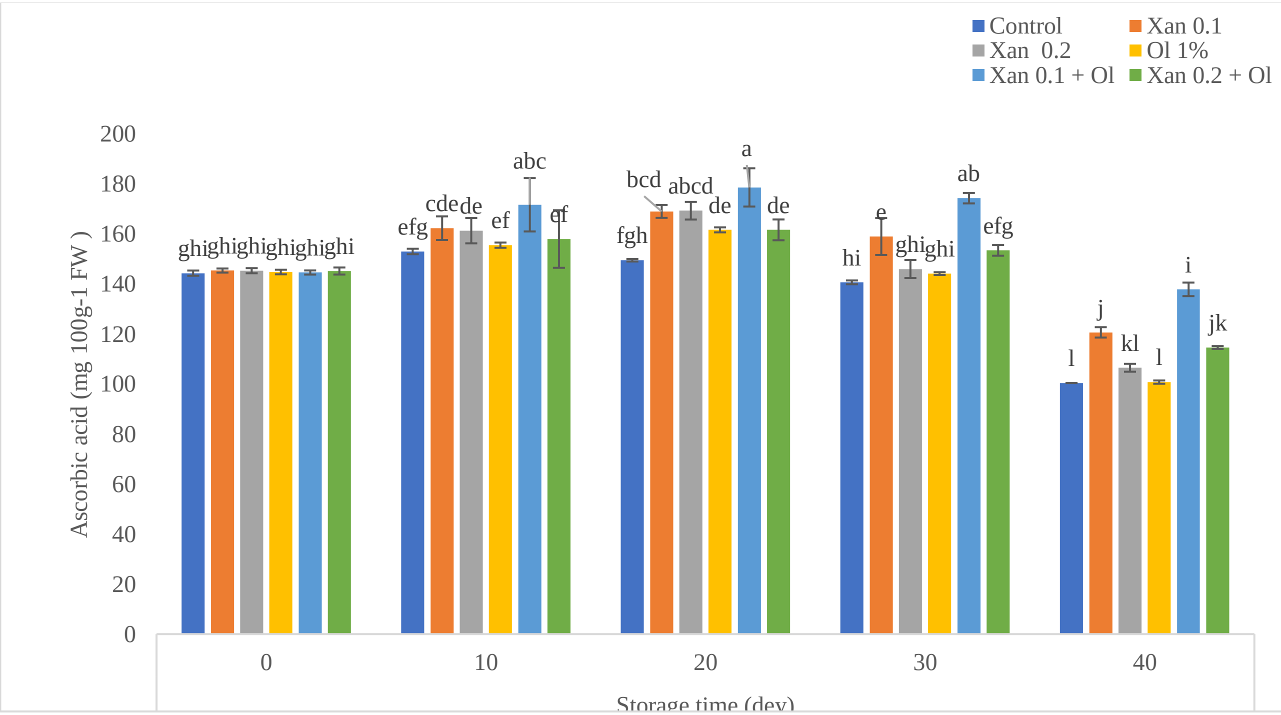
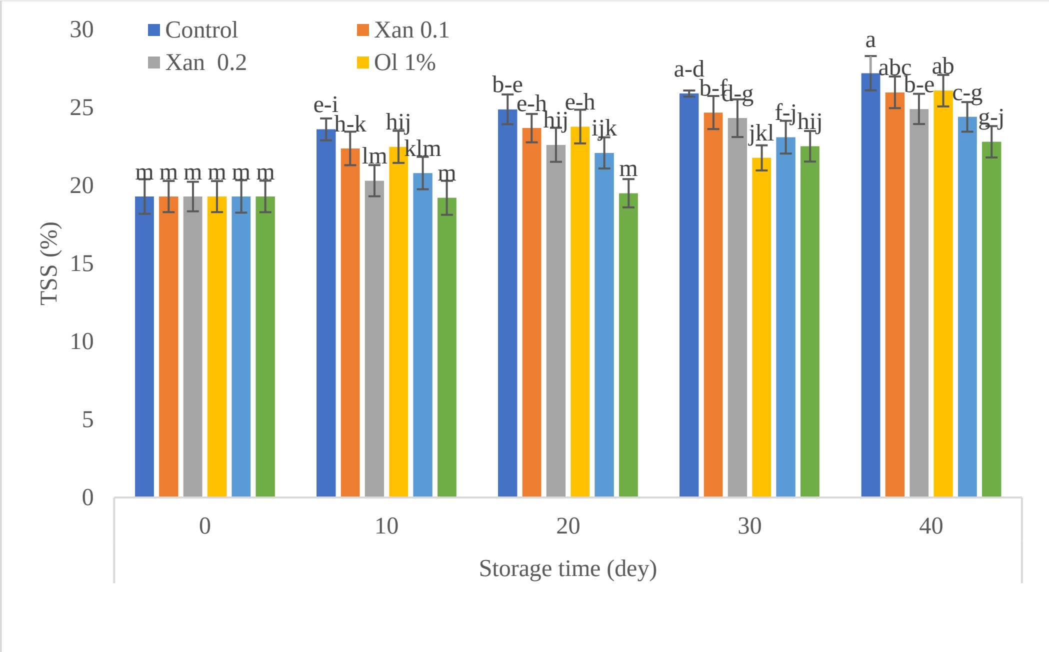
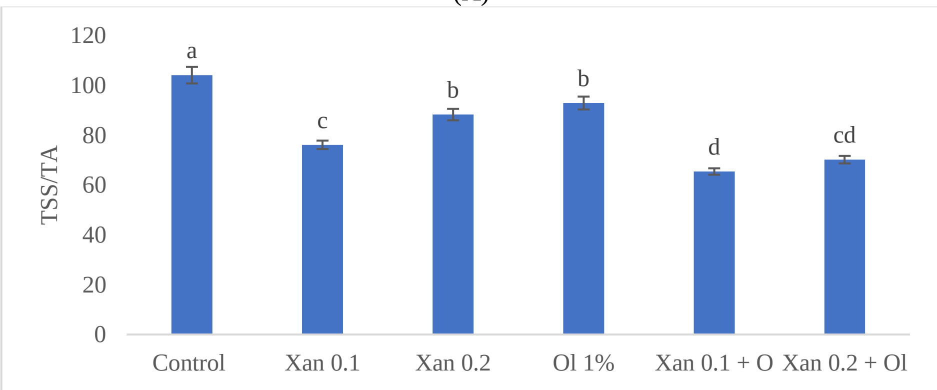


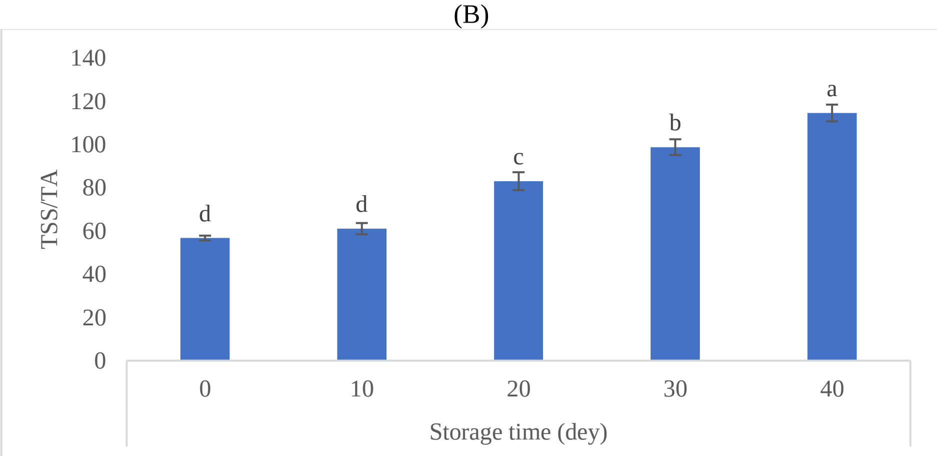
Fig. 5. The interaction effect between treatments (Control, Xanthan 0.1 %, Xanthan 0.2 %, Oleic acid 1%, Xanthan 0.1 % + Oleic acid, and Xanthan 0.2 % + Oleic acid) and storage periods on the ascorbic acid content of sapodilla fruit during four periods (10 days) of storage at 8 ± 1℃ and 85% relative humidity (RH)
The values represent mean ± SD from three replicates (n=3). Statistical analysis was performed using LSD test.



(A)



(B)



(C)

Fig. 6. The interaction effect between treatments (Control, Xanthan 0.1 %, Xanthan 0.2 %, Oleic acid 1%, Xanthan 0.1 % + Oleic acid, and Xanthan 0.2 % + Oleic acid) and storage periods on the total soluble solids (TSS) (A), and TSS/TA ratio (B-C) of sapodilla fruit during four periods (10 days) of storage at 8 ± 1℃ and 85% relative humidity (RH)

The values represent mean ± SD from three replicates (n=3). Statistical analysis was performed using LSD test.

Therefore, the combined xanthan coating with oleic acid enabled the fruits to retain higher levels of ascorbic acid compared to other treatments. This was accompanied by reduced oxygen permeability and limited moisture transfer from the fruit surface. In a similar report, Kumar *et al*. (2023) reported that an edible coating based on xanthan gum and pomegranate peel extract on mango fruit enhanced the physical and antioxidant properties of the fruit due to providing increased flexibility.

Total Soluble Solids and TSS/TA Ratio

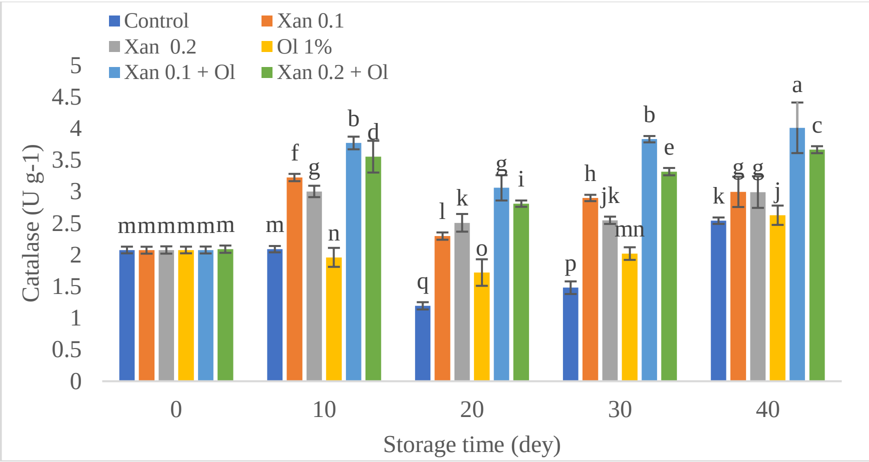
The highest increase in TSS (27.2 %) was observed in the control fruit at the end of storage, while the lowest increase (22.80 %) was observed in fruits coated with Xan 0.2 % + Ol (Fig. 6-A). Generally, the TSS of fruits gradually accumulates during ripening. This phenomenon may be due to the hydrolysis reaction and conversion of starch into simple sugars. At the end of storage, the control fruit showed an increase in the TSS/TA ratio by 104.099 compared to its initial state, while the Xan 0.1 % + Ol coating resulted in a decrease in the TSS/TA ratio (Fig. 6-B). The TSS/TA ratio gradually increased during storage (Fig. 6-C). Etemadipoor *et al*. (2020) reported similar results on coated guava fruits with a combination of Arabic gum, oleic acid, and cinnamon essential oil.

Enzymatic Activity

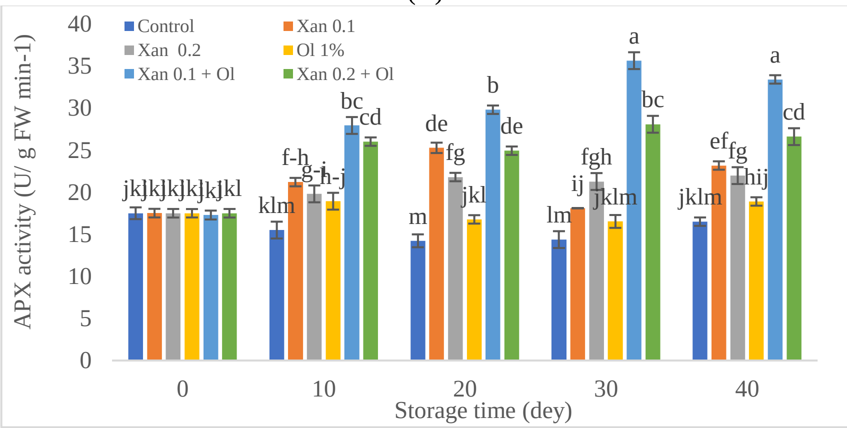
The activity of CAT enzyme showed a significant increase within the first 20 days of storage. The highest enzyme activity was observed in fruits treated with a combination of 0.1% Xan + Ol during the second storage period (Fig. 7-A). Similar findings were reported for other fruits such as chickoo (Camargo *et al*., 2016) and lychee (Zhang *et al*., 2018). The peak increase in APX activity was observed on the tenth day in Xan 0.1 % + Ol treatment, followed by a decrease (Fig. 7-B). Our findings are consistent with a previous study conducted by Ali *et al.* (2021), who found that using a CMC coating prior to storage preserved higher enzymatic activities and deactivated free radicals, reducing senescence in 'Kinnow' mandarin fruit under low-temperature conditions. The maximum activity of SOD enzyme in the coated fruits was observed 40 days after storage, and the peak in Xan 0.1 % + Ol-coated fruits was significantly higher than the control ($P < 0.05$) (Fig. 7-C). These results are similar to study conducted by Yuan *et al*. (2023), which examined the effect of a combined treatment of 1-methylcyclopropene and melatonin on the quality characteristics and active oxygen metabolism of stored mango fruit. An oxidative stress occurred throughout the entire storage period, characterized by an increase in active oxygen species such as superoxide, hydrogen peroxide, and hydroxyl radicals. The antioxidant system, which includes enzymes such as POD, SOD, CAT, and APX, plays an important role in preventing or reducing damage caused by ROS (Wang & Gao, 2013).

Conclusion

In conclusion, this study demonstrated that the application of edible coatings made from xanthan gum (XG) at concentrations of 0.1% and 0.2%, combined with oleic acid (Ol) at a concentration of 1%, effectively prolonged the shelf life of sapodilla fruit. The treated fruits exhibited reduced weight loss, with Xan 0.2% + Ol treatment showing the minimum weight loss. Additionally, the treated fruits maintained higher firmness levels compared to the control, except for the Ol treatment. The coatings also significantly reduced fruit respiration and enhanced antioxidant capacity, as well as increased levels of ascorbic acid. Xan 0.2% + Ol treatment resulted in the lowest total soluble solids (TSS) level. Furthermore, Xan 0.1% + Ol coating demonstrated higher activity levels in the superoxide dismutase (SOD), catalase (CAT), and ascorbate peroxidase (APX) enzymes compared to Xan 0.2% + Ol coating and the control.



(A)



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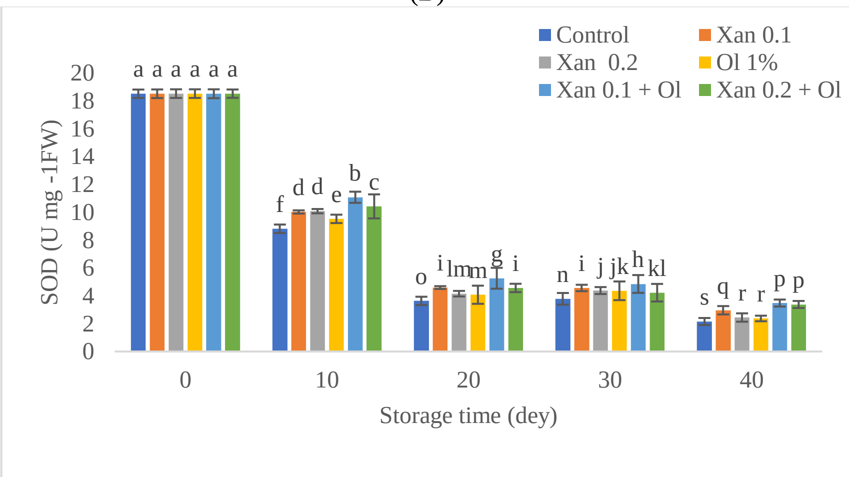

(C)

Fig. 7. The interaction effect between treatments (Control, Xanthan 0.1 %, Xanthan 0.2 %, Oleic acid 1%, Xanthan 0.1 % + Oleic acid, and Xanthan 0.2 % + Oleic acid) and storage periods on catalase (A), ascorbate peroxidase (B), and superoxide dismutase (C) activities of sapodilla fruit during four periods (10 days) of storage at 8 ± 1℃ and 85% relative humidity (RH)

The values represent mean ± SD from three replicates (n=3). Statistical analysis was performed using LSD test.

As a conclusion, Xan 0.2% + Ol and Xan 0.1% + Ol treatments exhibited the highest overall quality among the examined treatments. Given the challenges associated with postharvest preservation of this fruit, the application of these coatings presents a suitable method for extending the storage period and maintaining the quality.

Author Contributions

D. Rezakhani Nejad: Data curation, investigation, methodology, software, writing–original draft. **A. Mirzaalian Dastjerdi, S. Rastegar:** Conceptualization, data curation, project administration, supervision, writing–review and editing.

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تأثیر پوشش خوراکی بر پایه صمغ زانتان غنی‌شده با اسید اولئیک بر کیفیت انبارمانی و خواص آنتی‌اکسیدانی میوه چیکو (*Manilkara zapota*)

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چکیده

میوه‌ی چیکو یا (sapodilla) به‌دلیل فسادپذیری بالا و از دست دادن سریع رطوبت، عمر مفید محدودی دارد. استفاده از پوشش‌های خوراکی به‌دلیل تأثیرگذاری در افزایش طول عمر مفید میوه‌ها، مورد توجه زیادی قرار گرفته است. هدف از این مطالعه ارزیابی اثربخشی پوشش خوراکی ساخته شده از صمغ زانتان (۰/۱ و ۰/۲ درصد) همراه با اسید اولئیک (۱ درصد) در افزایش طول عمر مفید میوه‌ی چیکو در دمای ۱ ± ۸ درجه سانتی‌گراد و رطوبت نسبی ۸۵–۹۰ درصد است. کاهش وزن در میوه‌های تحت تیمار به‌طور قابل توجهی کمتر بود، به‌طوری‌که کمترین کاهش وزن در تیمار (صمغ زانتان ۰/۲ درصد + اسید اولئیک) مشاهده شد. بجز تیمار اسید اولئیک، سایر تیمارها در مقایسه با شاهد، سفتی بالاتری را نشان دادند. در پایان آزمایش، تیمارها به‌طور قابل توجهی تنفس میوه را کاهش دادند. در میوه‌های تحت تیمار همچنین در مقایسه با شاهد، ظرفیت آنتی‌اکسیدانی به‌طور قابل توجهی افزایش یافته و سطوح بالاتری از اسید آسکوربیک را نشان دادند. پایین‌ترین سطح TSS (۲۲/۸ ٪) در تیمار (صمغ زانتان ۰/۲ درصد+ اسید اولئیک) مشاهده شد. علاوه بر این، نتایج نشان داد که میوه‌های تحت پوشش (صمغ زانتان ۰/۱ درصد + اسید اولئیک) فعالیت بالاتری را در آنزیم‌های سوپراکسید دسموتاز (SOD)، کاتالاز (CAT) و آسکوربات پراکسیداز (APX) نسبت به میوه‌های تیمار شده با (صمغ زانتان ۰/۲ درصد + اسید اولئیک) و نمونه‌های شاهد نشان دادند. به طور کلی، میوه‌های تحت تیمار با (صمغ زانتان ۰/۲ درصد + اسید اولئیک) و (صمغ زانتان ۰/۱ درصد + اسید اولئیک) در مقایسه با شاهد و سایر تیمارها، بالاترین کیفیت کلی را نشان دادند. بنابراین، استفاده از این تیمارها برای حفظ کیفیت میوه‌ی چیکو توصیه می‌شود.

واژه‌های کلیدی: انبار، اولئیک اسید، پوشش خوراکی، زانتان، ساپودیلا (چیکو)

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