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Assessing the effect of starch-lipid composite films on nutritional profile and shelf life of Indian jujube (*Ziziphus mauritiana* Lamk.)

S. Kaur[1], S. Sharma[1]*, A. Kumar[2]*, A. Kumar[3], R. Gehlot[2] and V. Arya[4]

*[1]School of Agricultural Sciences & Technology, Regional Institute of Management and Technology, Mandi Gobindgarh, Punjab, 147301 India. [2]Centre of Food Science and Technology, Chaudhary Charan Singh Haryana Agricultural University, Hisar, 125004, India. [3]Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, 133207, India, [4]Department of Vocational Studies and Skill Development, School of Agricultural Sciences, Nagaland University, Medziphema 797106, Nagaland. *E-mail: ankitnagpal1995@gmail.com*

Abstract

The present investigation explores the application of starch-lipid composites to enhance the shelf life and maintain the nutritional quality of jujube fruits. The research investigates the efficacy of different concentrations of starch solutions (0.1 %, 0.2 %, and 0.3 %) combined with various edible oils (olive oil, mustard oil, and soybean oil) in preserving the physicochemical and biochemical characteristics of jujube during a 12-day storage period. Various parameters, *i.e.*, physiological loss in weight, decay percentage, moisture content, titratable acidity, pH, total soluble solids, TSS/acid ratio, total sugars, reducing sugars, non-reducing sugars, ascorbic acid, and total chlorophyll content, were evaluated. The results demonstrate that starch-lipid composite coatings significantly reduce physiological weight loss, decay, and moisture loss. Furthermore, these coatings preserve acidity, total soluble solids, and sugars in the fruit, along with retaining ascorbic acid and chlorophyll content. The study suggests that such edible coatings could be a valuable strategy to mitigate post-harvest losses, enhance shelf life, and maintain the nutritional quality of Indian jujube fruits.

Key words Edible coatings, nutritional profile, post-harvest losses, shelf life, starch-lipid composite films

Introduction

The Indian jujube (*Ziziphus mauritiana* Lamk.), is a vigorous, hardy medium-sized fruit tree belongs to Rhamnaceae family. This is valued for its capacity to withstand hard environmental circumstances (*i.e.*, high temperature, low relative humidity, and waterlogging), earning it the title “King of the arid-zone fruits”. Its range extends from India to Southwestern China and Malaysia. The genus *Ziziphus* contains about fifty species, 20 of which are native to India. Gola, Umran, Banarasi Karka, Mundia, Kaithli, Mehrun, Parbani, Elaichi and Sanam are important jujube varieties grown in India. Among all, Umran is a late-season variety of jujube and is mostly cultivated in Punjab and Haryana (Singh *et al.*, 2020).

Jujube fruits are rich in flavonoids, polyphenols, polysaccharides, proteins, amino acids, fatty acids, nucleotides, triterpenes, saponins, alkaloids, fibre, minerals (calcium, iron, and potassium), vitamins (A, B complex, and ascorbic acid), and important bioactive substances (Tepe *et al.*, 2022). Besides its multispectral benefits, the fruits are highly perishable and lose 30-40 % of their value after harvesting due to lack of cold chain facilities. To overcome such issues, edible coatings are catching widespread interest among researchers and growers. Edible coatings are characterised as a thin layer for primary food packaging that is composed of edible components that we can eat too (Morone *et al.,* 2019)social and environmental costs and calls for urgent and adequate measures. Such measures should target: (1. Edible coatings act as a protective barrier that extends shelf life in post-harvesting, processing, transportation, storage and consumption against dehydration, deterioration, spoilage and preserving appearances *i.e.*, colour, freshness, flavour and nutrients (Kubheka *et al.*, 2020).

Several polysaccharides have been studied or used as edible coatings. It contains starch and its derivatives, cellulose derivatives, carrageenan (including carrageenan glucosides), chitosan and pectin (Kocira *et al.*, 2021). Starch, composed of amylose and amylopectin, is primarily derived from plant jujubes and seed endosperm like corn, potato, cassava and cereals *etc.* can also be used. Generally, the varieties which contain high amylose starches can be utilized for edible film formation. Starch based coatings can also boost the microbiological stability of minimally processed fruits, vegetables and other processed items by delaying ripening and senescence (Sharma *et al.*, 2019). Therefore, the present study was conducted to evaluate the influence of starch based composite edible coating on shelf life as well as on quality parameters of Jujube during storage. The study will open up the possibility for enhancing shelf life as well as maintaining the nutritional qualities of Indian jujube fruit.

Materials and methods

Experimental material and chemicals: Freshly harvested, evenly sized, and disease-free jujube fruits (*Zizyphus marutiana* Lamk.) *cv.* Umran were obtained from Regional Fruit Research Station (Patiala), Punjab Agricultural University, Ludhiana. The fruits were then dipped in 2 % sodium hypochloride for 2 minutes, followed by rinsing with tap water and surface drying. The potato starch (Starch soluble (Expotato) extra pure) manufactured by Loba chemie pvt. Ltd., India was used for the experiment. The oils, including olive oil (Oligro oil), mustard oil (Fortune kachi ghani), and soybean oil (Nature fresh soybean oil), were purchased from the local market. All chemicals used in physico-chemical and biochemical analysis were of analytical grade and procured from Sigma-Aldrich, USA.

Preparation of edible coatings; For the preparation of starch dispersions (0.1 %, 0.2 %, and 0.3 %), respective amounts of potato starch (in paste form) were placed in 100 mL of distilled water in a 250 mL beaker and brought to a boiling on a hot plate and stirred until all of the starch is dispersed completely. Fruits were manually coated with different concentrations of starch solution (0.1 %, 0.2 % and 0.3 %) and sprayed with three types of edible oils (mustard oil, soybean oil and olive oil). The fruits were packed in paper bags and kept at ambient temperature (28 ^{0}C). The coated fruits were studied for their physical, physicochemical, and biochemical composition upto 12 days of storage period at 4-day intervals (0, 4th, 8th and 12th day).

Evaluation of physical parameters: To assess physiological loss in weight (PLW), the weight of jujube fruits were taken just after coating and stipulated intervals and the physiological weight loss of fruit was expressed in percentage (AOAC, 2016). Decay percentage was calculated based on the number of fruits spoiled (unfit for human consumption) at every four days interval and results were expressed in percentage (Ismail *et al.*, 2010). To calculate the moisture content (%), 5 grams of sample was taken in pre-weighed aluminum dishes with a lid. The sample was kept in a hot air oven at 105 ^{o}C for 5 hrs. The weight of the sample after drying was recorded and results were expressed in percentage (Ranganna, 2011).

Evaluation of physico-chemical parameters: To assess titratable acidity (%), 10 g of fruit sample was macerated in distilled water. The suspension was filtered through Whatman No. 1 filter paper and the final volume was made up to 100 mL. The aliquot was titrated against standard sodium hydroxide (NaOH (0.1N)) using phenolphthalein as an indicator. The value of titratable acidity was expressed as percent anhydrous citric acid (Ranganna, 2011). The pH of fruits was recorded at 0, 4th, 8th and 12th day intervals using pH meter. Total soluble solids (TSS) in fruit juice were determined with the help of a digital refractometer (Milwaukee) and expressed in degree Brix (°B) (Ranganna, 2011). Brix acid ratio (TSS: acid ratio) was calculated by dividing the TSS value by the titratable acidity.

For the determination of total sugar (%), 50 mL of aliqout was mixed with 5 mL of citric acid and left for a period of 24 h for complete inversion. Then, it was neutralized by 0.1 N NaOH using phenolphthalein as an indicator. Subsequently, the solution was taken into the burette and titrated against 10 mL of Fehling's solutions for the estimation of total sugars. Dextrose was taken as a standard (Rangana S, 2011). To estimate reducing sugars (%), 10 g of fruit sample was extracted with 100 mL distilled water and added 2 mL of lead acetate (45 %). Then, 2 mL of potassium oxalate (22 %) was added to remove excess lead, made up a volume up to 250 mL and filtered. This filtrate was taken and titrated against a mixed Fehling solution using methylene blue as an indicator (Rangana, 2011). The value of non-reducing sugar (%) was recorded by subtracting the value of reducing sugar from total sugar.

Evaluation of biochemical parameters: To assess ascorbic acid content, 10 grams of sample was blended with 100 mL of HPO_3 (3 %) and filtered. Then, the aliquot was titrated with standard dye 2, 6-dichlorophenol-indophenol dye to a light pink endpoint and the ascorbic acid content was calculated and expressed as mg 100 g. Ascorbic acid (1 mg/mL) was taken as standard (Rangana S, 2011). For the determination of total chlorophyll content, 5 g of the sample was macerated with acetone (85 %) till the residue became colourless. The absorbance of the solution was taken at 660 nm and 642.5 nm against the solvent (acetone (85 %) as blank (Ranganna, 2011). Total chlorophyll content was estimated using the following formula and results were expressed as mg g^{-1}:

Total chlorophyll (mg g^{-1}) = (7.12 x OD at 660 nm) + (16.8 x OD at 642.5 nm)

Statistical analysis: The data of physicochemical and biochemical analysis jujube were statistically analyzed using a completely randomized design with SPSS software (IBM, SPSS Inc., USA). Data was expressed as mean ± standard deviation and two-way ANOVA was used to analyze the data. The p-values were calculated and the results were expressed as CD at 5 % level of significance. Data was also analyzed using a post hoc test (Tukay's Multiple Range Test) (Freeman *et al.*, 1985).

Results and discussion

Physical observations of jujube fruit: The physiological weight loss in jujube fruits increased with the advancement of the storage period as shown in Fig. 1. The loss of moisture may be through transpiration and utilization of some reserve food materials in the process of respiration (Assumi *et al.*, 2009). The maximum loss in weight was observed in uncoated fruits. Data reflects the maximum physiological loss in weight was (35.97 %) in control (T_0) whereas, the maximum retention in weight was (22.05 %) in T_2. Coating materials act as a partial barrier to oxygen, carbon dioxide and solute migration that helps to prevent weight loss in fruits by forming a barrier between the surface of the fruit and the outer environment of the fruit (Singh, 2010; Bhardwaj et al., 2024). Guava fruit has high perishability, susceptibility to chilling injury (CI).

The data on the decay of fruits during storage reveals that there was a significant increase in decay percent during storage (Fig. 2). The fruit decay percent increased at the end of storage. The least decay in fruit was recorded in T_2 (olive oil+ 0.2 % starch) (15.14 %) and the highest was noted in uncoated fruits (48.75 %). The decay in fruits treated with olive oil may strongly limit the growth of microbes, fungal organisms and moulds that cause decomposition in fruits during storage (Mani *et al.*, 2017). Olive oil slows down respiration and the ripening process, resulting in a lower proportion of deterioration in composite coating treatments (Rao *et al.*, 2016).

Concerning moisture content, the coated fruits retain maximum moisture content as compared to uncoated fruits (Etemadipoor *et al.*, 2019). By the end of storage period, the lowest moisture content was recorded in untreated fruits (T_0) (37.21 %) while, the

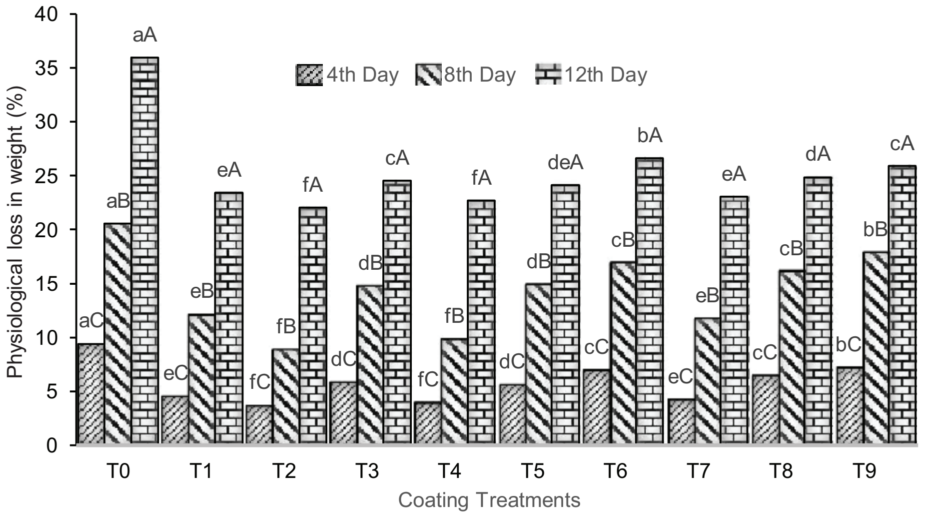

Fig. 1. Effect of edible coating on physiological loss in weight of jujube fruit

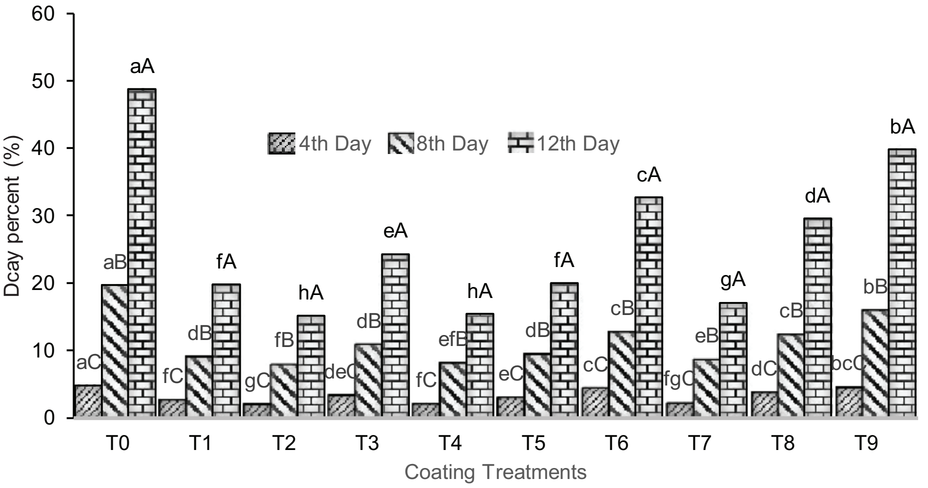

Fig. 2. Effect of edible coating on decay percent of jujube fruit

highest retention of moisture content was observed in T_2 (olive oil + 0.2 % starch) (72.44 %) as depicted in Table 1. There was a significant decrease in moisture content with progression in the storage period due to transpiration and utilization of some reserve food materials in the process of respiration (Assumi *et al.*, 2009; Singh, 2010).

Physico-chemical observations of jujube fruit: The data revealed that there was a decreasing trend of acidity in all the treatments during storage as the storage period progressed. By the end of storage maximum loss in acidity was observed in control (T_0) (0.12 %), whereas, treatment T_2 (olive oil + 0.2 % starch) recorded maximum acidity content (0.35 %). It is also considered that coatings reduce the rate of respiration and may therefore delay the utilization of organic acids. It was also found that edible coatings are beneficial for prolonging the shelf life of jujube which could be due to decreases availability of organic acids for enzymatic reaction of respiration (Dutta *et al.*, 2016). However, the results of the present study revealed that the acidity values in the control fruits were significantly lower as compared to coated fruits (Table 1).

Data concerned with pH indicates the increment in pH of jujube fruit with progression in the storage period. The pH is inversely proportional to the titratable acidity. As aforementioned, fruit acidity decreased due to the consumption of organic acids in the process of respiration leading to an increase in pH of fruits. Coated fruits showed less pH as compared to control (uncoated) fruits. The maximum pH of 5.12 was observed in control while the minimum pH was recorded in T_2 (olive oil+0.2 % starch) (4.21) followed by the pH of 4.23 in T_4 (soybean oil+0.1 % starch) by the end of storage period (Table 1). Fruit can utilize the acids contained in it during storage, resulting in a reduction in acid and an increase in the pH of the fruits. It has been also observed that coatings reduce respiratory and metabolic rates which results in a decrease in the level of organic acid utilization and decrease in pH (Baraiya *et al.*, 2012).

The data also revealed that the TSS content was gradually increased up to 8th day of storage and decreased thereafter. By the end of the storage period, a minimum TSS content of 7.12 ^{0}B was recorded in control (T_0), whereas T_2 (olive oil+0.2 % starch) retained the maximum TSS content of 10.06 ^{0}B (Table 1). A gradual increase in starch content was observed up to full maturation and then it decreased during ripening, which may contribute to the changes in TSS. Also, TSS showed a gradual decrease with the advancement of time intervals which might be due to high respiration rate and senescence (Sooch & Mann, 2021). There was a significant change in the TSS/acid ratio of coated as well as uncoated fruits with the progressive storage period (Table 2). TSS/acid ratio significantly increased in all the treatments with the advancement of the storage period. On 12th day of storage, the lowest TSS/acid ratio was observed in T_2 (olive oil + 0.2 % starch) (28.74) while the highest TSS/acid ratio of 59.33 was recorded in the control (T_0) (Table 1). The rapid increase in TSS/acid ratio was due to a sharp increase in TSS and the corresponding decrease in acidity (Purohit *et al.*, 2003).

Concerning total sugars, it is evident that there was a significant change in total sugars during the storage period (Table 2). The sugar content was increased up to 8th day of storage, afterward; it was gradually decreased in all treatments. On 12th day, the maximum total sugar content of 9.78 % was retained by T_2 (olive oil + 0.2 % starch) whereas, the minimum total sugar content of 7.36 % was observed by control (T_0). The level of rise in total sugar content was significantly lower in coated fruits as compared to uncoated fruits due to the rapid breakdown of starch into sugars as a result of moisture loss. The phenomenon being explained is that the increase in sugars with the extension of the storage period is due to the hydrolysis of starch into sugars. Conversely, the utilization of sugar as a respiratory substrate causes a decrease in sugar content (Nandane & Jain, 2011). Similar trends were observed for reducing sugars during the storage period (Table 2). The reducing sugar content increased up to 8th day of storage afterward, it declined by the end of the storage period. On 12th day of storage, the lowest reducing sugar content of 4.22 % was

Table 1. Changes in physico-chemical composition in coated jujube during storage

Treatment	Moisture Content (%)				Acidity (%)				TSS (°B)				pH			
	0 day	4th day	8th day	12th day	0 day	4th day	8th day	12th day	0 day	4th day	8th day	12th day	0 day	4th day	8th day	12th day
T_1	91.24^{aA}	86.73^{abB}	72.04^{bcC}	67.83^{bD}	1.04^{aA}	0.63^{cdB}	0.41^{dC}	0.27^{dD}	10.12^{aC}	11.74^{deB}	12.62^{abcA}	9.45^{bcD}	4.07^{aD}	4.21^{cdC}	4.37^{efgB}	4.52^{cdA}
T_2	91.24^{aA}	89.05^{aAB}	85.69^{aB}	72.44^{aC}	1.04^{aA}	0.77^{aB}	0.51^{aC}	0.35^{aD}	10.12^{aC}	11.28^{fB}	12.94^{aA}	10.06^{aC}	4.07^{aA}	4.12^{dA}	4.14^{hA}	4.21^{eA}
T_3	91.24^{aA}	82.87^{cdB}	69.32^{cC}	50.19^{dD}	1.04^{aA}	0.58^{eB}	0.36^{fC}	0.22^{fD}	10.12^{aB}	12.14^{bcA}	12.28^{cdA}	8.88^{dC}	4.07^{aD}	4.32^{cdC}	4.47^{cdeB}	4.97^{bA}
T_4	91.24^{aA}	88.24^{abAB}	85.52^{aB}	65.96^{bC}	1.04^{aA}	0.72^{bB}	0.49^{bC}	0.32^{bD}	10.12^{aC}	11.44^{efB}	12.86^{aA}	9.78^{abC}	4.07^{aA}	4.13^{dA}	4.19^{ghA}	4.23^{eA}
T_5	91.24^{aA}	85.63^{bcB}	69.77^{cC}	54.45^{cD}	1.04^{aA}	0.61^{dB}	0.38^{eC}	0.25^{eD}	10.12^{aB}	11.93^{cdA}	12.37^{bcA}	9.06^{cdC}	4.07^{aD}	4.27^{cdC}	4.43^{defAB}	4.57^{cA}
T_6	91.24^{aA}	79.63^{eB}	62.03^{dC}	48.17^{dD}	1.04^{aA}	0.52^{fB}	0.28^{hC}	0.17^{hD}	10.12^{aC}	12.46^{bA}	11.71^{eB}	7.63^{eD}	4.07^{aC}	4.56^{bB}	4.62^{bcB}	5.04^{abA}
T_7	91.24^{aA}	87.69^{abB}	72.92^{bC}	65.26^{bD}	1.04^{aA}	0.65^{cB}	0.45^{cC}	0.30^{cD}	10.12^{aC}	11.63^{defB}	12.78^{abA}	9.62^{bC}	4.07^{aC}	4.18^{cdBC}	4.26^{fghAB}	4.39^{dA}
T_8	91.24^{aA}	82.13^{deB}	62.84^{dC}	48.76^{dD}	1.04^{aA}	0.56^{eB}	0.32^{gC}	0.19^{gD}	10.12^{aC}	12.39^{bA}	11.84^{deB}	8.67^{dD}	4.07^{aD}	4.34^{cC}	4.59^{bcdB}	5.01^{abA}
T_9	91.24^{aA}	75.82^{fB}	54.08^{eC}	41.13^{eD}	1.04^{aA}	0.49^{hB}	0.26^{iC}	0.15^{iD}	10.12^{aC}	12.88^{aA}	11.55^{efB}	7.45^{efD}	4.07^{aD}	4.64^{bC}	4.76^{bB}	5.09^{abA}
Control	91.24^{aA}	71.28^{gB}	50.89^{eC}	37.21^{eD}	1.04^{aA}	0.29^{hB}	0.23^{jC}	0.12^{jD}	10.12^{aC}	13.06^{aA}	11.14^{fB}	7.12^{fD}	4.07^{aC}	4.85^{aB}	4.96^{aB}	5.12^{aA}

Table 2. Changes in TSS:Acid and sugar composition of coated jujube during storage

Treatment	TSS:Acid				Total sugar (%)				Reducing sugars (%)				Non-Reducing sugars (%)			
	0 day	4th day	8th day	12th day	0 day	4th day	8th day	12th day	0 day	4th day	8th day	12th day	0 day	4th day	8th day	12th day
T_1	9.73^{aD}	18.63^{fgC}	30.78^{fB}	35.00^{eA}	8.23^{aD}	9.52^{cdB}	11.07^{bA}	8.77^{bC}	4.15^{aC}	5.13^{bAB}	5.28^{aC}	4.96^{bAB}	4.15^{aC}	5.13^{bAB}	5.50^{bC}	3.61^{bAB}
T_2	9.73^{aD}	14.64^{iC}	25.37^{hB}	28.74^{gA}	8.23^{aD}	9.08^{dC}	11.56^{aA}	9.78^{aB}	4.15^{aB}	5.48^{aA}	5.52^{aB}	5.41^{aA}	4.15^{aB}	5.48^{aA}	5.73^{aB}	4.15^{aA}
T_3	9.73^{aD}	20.93^{eC}	47.23^{aA}	40.36^{dB}	8.23^{aB}	10.08^{abA}	10.26^{cA}	8.28^{cB}	4.15^{aB}	4.82^{cA}	4.68^{bB}	4.77^{cA}	4.15^{aB}	4.82^{cA}	5.13^{cB}	3.33^{cA}
T_4	9.73^{aD}	15.88^{hC}	26.24^{hB}	30.56^{fA}	8.23^{aD}	9.15^{dC}	11.52^{aA}	9.66^{aB}	4.15^{aB}	5.37^{aA}	5.42^{aB}	5.24^{aA}	4.15^{aB}	5.37^{aA}	5.79^{aB}	4.19^{aA}
T_5	9.73^{aD}	19.55^{fC}	32.55^{eB}	36.24^{eA}	8.23^{aB}	9.82^{bcA}	10.28^{cA}	8.51^{bcB}	4.15^{aB}	4.87^{cA}	4.90^{abB}	4.83^{cA}	4.15^{aB}	4.87^{cA}	5.11^{cB}	3.49^{cA}
T_6	9.73^{aD}	23.96^{cC}	41.82^{cB}	44.88^{cA}	8.23^{aB}	10.29^{abA}	10.18^{cA}	7.68^{dC}	4.15^{aB}	4.52^{dA}	4.49^{bB}	4.41^{dA}	4.15^{aB}	4.52^{dA}	5.40^{bB}	3.10^{dA}
T_7	9.73^{aD}	17.89^{gC}	28.40^{gB}	32.06^{fA}	8.23^{aC}	9.32^{cdB}	11.46^{aA}	9.64^{aB}	4.15^{aC}	5.26^{abAB}	5.33^{aC}	5.06^{abAB}	4.15^{aC}	5.26^{abAB}	5.82^{aC}	4.35^{abAB}
T_8	9.73^{aD}	22.12^{dC}	37.00^{dB}	45.63^{cA}	8.23^{aB}	10.27^{abA}	10.22^{cA}	8.23^{cB}	4.15^{aB}	4.76^{cA}	4.71^{abB}	4.64^{cA}	4.15^{aB}	4.76^{cA}	5.23^{cB}	3.41^{cA}
T_9	9.73^{aD}	26.28^{bC}	44.42^{bB}	49.66^{bA}	8.23^{aB}	10.32^{abA}	10.15^{cA}	7.47^{dC}	4.15^{aC}	4.42^{dA}	4.38^{bC}	4.33^{dA}	4.15^{aC}	4.42^{dA}	4.48^{dC}	2.98^{dA}
Control	9.73^{aD}	45.03^{aC}	48.43^{aB}	59.33^{aA}	8.23^{aB}	10.46^{aA}	10.11^{cA}	7.36^{dC}	4.15^{aA}	4.34^{dA}	4.26^{cA}	4.22^{dA}	4.15^{aA}	4.34^{dA}	5.55^{bA}	2.98^{dA}

T1-Olive oil + 0.1 % Starch; T2-Olive oil + 0.2 % Starch; T3-Olive oil + 0.3 % Starch; T4-Soybean oil + 0.1 % Starch; T5-Soybean oil + 0.2 % Starch; T6-Soybean oil + 0.3 % Starch; T7-Mustard oil + 0.1 % Starch; T8-Mustard oil + 0.2 % Starch; T9-Mustard oil + 0.3 % starch

*Different alphabets in superscripts represents significant difference CD ($P \leq 0.05$) *Values A, B, C…. in superscripts represents significant difference within storage intervals *Values a, b, c…. in superscripts represents significant difference between different treatments.

registered in control (T_0) whereas, T_2 (olive oil+0.2 % starch) treated fruits retained the highest reducing sugar (5.41 %). The rate of rise in sugar accumulation in fruits indicated a faster rate of ripening, which was reduced by the use of coatings in the present investigation. It is noteworthy that the slower respiration also slows down the production and utilization of metabolites resulting in lower sugars in coated fruits (Widyastuti *et al.*, 2023). The data reveals that, coatings are highly effective in retaining the maximum sugar content in fruits as compared to uncoated fruits by developing an oxygen barrier on the fruit surface and thus reducing metabolic rate (Quirós-Sauceda *et al.*, 2014). Similar patterns of total and reducing sugars were observed in the case of non-reducing sugars.

Biochemical observations of jujube fruit: The data presented in Table 3 reveals that there was a significant decrease in ascorbic acid and total chlorophyll content during storage. Also, the uncoated fruits showed maximum decrease as compared to treated fruits. By the end of storage, the lowest ascorbic acid content was observed in uncoated fruits (52.78 mg g^{-1}) and the highest ascorbic acid content was observed in T_2 (olive oil + 0.2 % starch) (91.49 mg g^{-1}). The percent decrease in ascorbic acid content in T_2 was 22.61 %, which was found to be minimal as compared with the control (55.35 %). The slow decline in ascorbic acid levels in treated fruits compared to control fruits could be attributed to the restriction of deep penetration of oxygen into the fruit tissues that restricts oxidative destruction of ascorbic acid (Kamboj, 2018).

By the end of storage, a maximum decline in total chlorophyll content of 0.19 mg/g was registered in control (T_0) fruits, whereas T_2 (olive oil + 0.2 % starch) showed maximum retention in total chlorophyll content (0.62 mg g^{-1}) as compared to all other treatments. On average, 57.95 % of total chlorophyll content was found to be decreased during 12 days of storage. The colour changes from green to yellow during ripening are frequently associated with variations in pigment content, such as an increase in carotenoid concentration and a reduction in chlorophyll level (Hernández *et al.*, 2016). The slower rate of respiration and ethylene production might be the cause of the coating's ability to delay chlorophyll breakdown (Ali *et al.*, 2011). The coating materials change the surrounding environment and prevent the synthesis of ethylene during storage, which delays ripening as well as the degradation of chlorophyll and the synthesis of carotenoids (Arroqui *et al.*, 2003).

Table 3. Changes in biochemical composition in coated jujube during storage

Treat-ments	Ascorbic acid (mg g^{-1})				Total chlorophyll (mg g^{-1})			
	0 day	4^{th} day	8^{th} day	12^{th} day	0 day	4^{th} day	8^{th} day	12^{th} day
T_1	118.22^{aA}	93.45^{bB}	81.08^{cC}	77.65^{cC}	0.88^{aA}	0.66^{dB}	0.52^{dC}	0.43^{dD}
T_2	118.22^{aA}	105.21^{aB}	98.16^{aC}	91.49^{aD}	0.88^{aA}	0.78^{aB}	0.71^{aC}	0.62^{aD}
T_3	118.22^{aA}	81.77^{dB}	72.93^{dC}	64.19^{eD}	0.88^{aA}	0.58^{fB}	0.43^{fC}	0.38^{fD}
T_4	118.22^{aA}	103.17^{aB}	95.09^{aC}	88.21^{bD}	0.88^{aA}	0.73^{bB}	0.64^{bC}	0.51^{bD}
T_5	118.22^{aA}	86.12^{cB}	78.22^{cC}	68.84^{dD}	0.88^{aA}	0.61^{eB}	0.48^{eC}	0.40^{eD}
T_6	118.22^{aA}	76.16^{eB}	66.24^{efC}	59.81^{fD}	0.88^{aA}	0.48^{hB}	0.33^{hC}	0.27^{hD}
T_7	118.22^{aA}	96.03^{bB}	86.47^{bC}	79.06^{cD}	0.88^{aA}	0.69^{cB}	0.56^{cC}	0.46^{cD}
T_8	118.22^{aA}	79.05^{deB}	68.97^{deC}	61.42^{efD}	0.88^{aA}	0.52^{gB}	0.37^{gC}	0.31^{gD}
T_9	118.22^{aA}	74.32^{fgB}	65.13^{efC}	56.27^{gD}	0.88^{aA}	0.46^{hB}	0.29^{iC}	0.22^{iD}
Control	118.22^{aA}	72.08^{gB}	63.96^{fC}	52.78^{hD}	0.88^{aA}	0.38^{iB}	0.26^{jC}	0.19^{jD}

T1-Olive oil + 0.1 % Starch; T2-Olive oil + 0.2 % Starch; T3-Olive oil + 0.3 % Starch; T4-Soybean oil + 0.1 % Starch; T5-Soybean oil + 0.2 % Starch; T6-Soybean oil + 0.3 % Starch; T7-Mustard oil + 0.1 % Starch; T8-Mustard oil + 0.2 % Starch; T9-Mustard oil + 0.3 % starch. *Different alphabets in superscripts represents significant difference CD ($P \leq 0.05$) *Values A, B, C…. in superscripts represents significant difference within storage intervals *Values a, b, c…. in superscripts represents significant difference between different treatments.

The study highlights the efficacy of starch-lipid composite films as impactful edible coatings for Indian jujube storage. Notably, these coatings preserve key physicochemical attributes, including titratable acidity, total soluble solids, and TSS/acid ratio, crucial for maintaining jujube quality. Moreover, the starch-lipid coatings contribute to the retention of essential components *i.e.*, total sugars, reducing sugars, non-reducing sugars, ascorbic acid, and total chlorophyll content. Beyond their role in nutritional preservation, these coatings align with the demand for sustainable and eco-friendly food preservation practices. The findings offer practical applications for the agricultural and food industries, presenting starch-lipid composites as a promising solution to curb post-harvest losses and enhance the market viability of Indian jujube.

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