

Enhancement of the fruit quality and postharvest life expectancy of mango fruit (*Mangifera indica* L.) applying ecofriendly bio-coatings

Farzana FATIMA¹, Abdul BASIT¹, Aqeel AHMAD¹, Syed T. SHAH¹,
Muhammad SAJID¹, Faiza AMAN¹, Heba I. MOHAMED^{2*},
Abeer ELHAKEM³

¹The University of Agriculture Peshawar, Faculty of Crop Production Sciences, Department of Horticulture, 25120, Pakistan;
fbibihort@gmail.com; mashballhort97@aup.edu.pk; abdulbasithort97@gmail.com; syedtanveer07@yahoo.com; masjid@aup.edu.pk;
faizaaman@aup.edu.pk

²Ain Shams University, Faculty of Education, Department of Biological and Geological Sciences, Cairo,
Egypt; hebaibrahim79@gmail.com (*corresponding author)

³Prince Sattam Bin Abdulaziz University, College of Sciences and Humanities, Department of Biology, 11942 Al-Kharj,
Saudi Arabia; a.elhakem@psau.edu.sa

Abstract

The higher losses of fruits and vegetables during post-harvest handling are a serious matter for any country whose economy is based on agriculture. The products of this plant are a significant source of horticultural produce storage used for the control of different post-harvest losses, which include diseases as well as microorganisms. Bio-coatings may be used as a better alternative to the synthetic chemicals. The impact of edible coating on the quality and storage life of mango (cv. 'Anwar Rataul') fruit was investigated by harvesting the fruits at a firm green stage of physiological maturity and coating them with corn oil, peanut oil, sunflower oil, soya bean oil, and animal fat. The uncoated and coated fruits were stored at 25 °C and the relative humidity (RH) was 75%. The fruits were analyzed for physicochemical quality attributes during storage at 0 (harvest time), 5, 10, 15, 20, and 25 days. The data showed that most of the parameters were affected significantly by the materials of coating and storage intervals ($P \leq 0.05$). The fruits coated with animal fat had significantly superior fruit color, taste, aroma, firmness, total sugar content, and acidity of fruit juice, total soluble solids, and ascorbic acid content, as well as delayed ripening. Animal fat-coated fruits retained titratable acidity, ascorbic acid content ($\text{mg} \cdot 100\text{g}^{-1}$) and fruit firmness ($\text{kg} \cdot \text{cm}^{-2}$) with minimal disease incidence, and weight loss (%), whereas uncoated fruits did not retain all quality attributes and deteriorated after 20 days of storage. In conclusion, mango fruits could be coated with animal fat and stored for up to 25 days without deterioration in quality.

Keywords: coatings; mango; storage life; quality; waste percent; weight loss

Received: 15 Sep 2022. Received in revised form: 12 Oct 2022. Accepted: 19 Oct 2022. Published online: 05 Dec 2022.

From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Introduction

Fruit weight loss is primarily the result of respiration, transpiration, and metabolic activities. The prolonging of shelf life and maintaining the fruits and vegetables' post-harvest quality is largely concerned with indices of maturity and coating of edible materials which are significantly safe and good for health (Mogazy *et al.*, 2022). The majority of horticultural products is perishable and rot after harvesting. It releases water vapors and CO₂ and takes in O₂ (Shah *et al.*, 2020). Among the most environmentally friendly technologies used to increase the quality of fruits and vegetables, extend storage life and reduce moisture loss, oxidation, and gas exchange is the use of edible coatings (Basit *et al.*, 2019). Mango (*Mangifera indica* L.) is known as the "King of fruits" (Nunes *et al.*, 2007; Mukhtar *et al.*, 2022). It is one of the most important fruits grown in subtropical and tropical regions of the world. Mangoes are used in their fresh form as well as processed as juices, jams, jellies, squashes, and pickles. In Pakistan, mango is considered as the second main fruit and is grown on an area of 94 thousand hectares. There has been an increasing demand for mango in international markets, which has increased the prospect of capturing good returns for mango producing countries (Anwar *et al.*, 2008; Galán Saúco, 2010). But, like all other fresh produce, its market potential is associated with the market access and quality of fruit (Anwar and Malik, 2007).

The mango ripening period is characterized by several biochemical reactions such as ethylene production enhanced, increased respiration rate and conversion of starches to sugar, and changes in organic acid, volatile compounds, and phenolic compounds that decrease the postharvest life (Herianus *et al.*, 2003). The rate of postharvest changes generally increases with increasing temperature (Díaz-Montes and Castro-Muñoz, 2021). Therefore, the mango fruit, when held at a high temperature, rapidly loses its quality attributes (Khuwijitjaru *et al.*, 2022). It is estimated that 20–30% of mangoes produced in Pakistan are lost due to poor post-harvest management. The magnitude of losses from postharvest losses in mango fruit is about 320.7 thousand tones, which is worth Rs. 3.0 billion (Tahir *et al.*, 2002). Rapid deterioration after harvest and postharvest diseases limits the storage potential of mango fruit (Gupta and Jain, 2014).

Biodegradable coatings have been well-thought-out to prolong the shelf life and increase the acceptability of stored fruits (Cosme *et al.* 2017; Naeem *et al.*, 2020). The biodegradable coatings are prepared from natural polymers and, after consumption of fruits, can be decomposed by microorganisms (Amin *et al.*, 2015). Thus, these coatings are sustainable, harmless, and environmentally friendly approaches to help preserve fruits and vegetables (Ebrahimi and Rastegar, 2020). Different post-harvest procedures, i.e., edible coating, chemical application, use of fungicide, wax emulsion, growth regulators, calcium treatment, storage at low temperature (Chahal and Bal, 2003; Elkhatry *et al.*, 2022), and several types of materials for packaging are made to maintain the quality and prolong the shelf life of the fruits after harvest (Bisen *et al.*, 2008). Efforts have been made to prolong the shelf life of mango and decrease pathogenic wastage of mango fruit by physical and chemical treatments (Baloch and Bibi, 2012; Zeng *et al.*, 2006).

Coating of fruit is one of the common techniques used to increase the storage life of different fruits (Baldwin, 1994). Edible coating may decrease decay percentage, prolong storage life and maintain the qualitative attributes (Abd-ALLA and Haggag, 2010; Nwufu *et al.*, 1994; Heidari *et al.*, 2011; Bibi and Bloch, 2014; Fouda and Sofy, 2022). An edible coating creates a modified atmosphere inside the fruit and reduces weight loss during transport and storage. While different coating materials are commercially available, the efficiency of coating materials depends on the diffusivity of specific molecules such as O₂ and CO₂. Increased CO₂ and decreased O₂ within the fruit decrease the respiration rate and production of ethylene and retard the growth as well as the attack of microorganisms (Cuq *et al.*, 1995). While coating materials such as shellac and carnauba wax have been used for pome and citrus fruits, mineral oil and waxes are used for vegetables such as sweet peppers, tomatoes, and cucumbers. In recent years, cellulose-sucrose fatty acid ester coatings have become famous for plum, apricot and guava (McGuire and Hallman, 1995; Sumnu and Bayindirli, 1995). Oils have disease-preventative, antioxidant properties and promote longevity, while animal fat possesses antifungal,

antimicrobial, and hydrophobic properties. Despite the benefits of fruit coating, consumer acceptance and health safety are of prime significance in selecting coating material for fruits (Chien *et al.*, 2007).

The current study aims to use different edible oils (corn, peanut, sunflower, and soya bean) and animal fat as coating materials to increase the shelf life, maintain quality, and reduce postharvest losses in mango fruit.

Materials and Methods

Sampling and site selection

The mango fruit 'Anwar Rataul' cultivar was used in the experiment. The Government Fruit Nursery Farm, Agriculture Extension Department, Dera Ismail Khan, Pakistan, provided the mango fruits, which were harvested at a firm green physiologically mature stage. Using hardboard containers kept at 25 °C, mango fruits were immediately transported to the postharvest laboratory, Department of Horticulture, The University of Agriculture, Peshawar, Pakistan. The mango fruits were cleaned with distilled water to get rid of any surface impurities before being gently blown dry with air.

Treatments

The mango fruits were coated with corn oil, peanut oil (Aceites Borges Pont S.A Spain), sunflower oil, soya bean oil (SAS trading, Bangkok, Thailand) and animal fat (sheep fat melted at 70 °C for 20 minutes and then cooled at an ambient temperature of 30±1 °C). For coating purposes, the harvested fruits were dipped in the coating material for one minute to achieve a uniform coating on the surface of the fruit. The control fruits were left without coating. The uncoated and coated fruits were stored at 25 °C temperature while the relative humidity (RH) was kept at 75% using a Hot Pack incubator (Philadelphia, PA).

Analysis of fruit

Two hundred and fifty 'Anwar Rataul' cultivar fruits were chosen for each test. Each experiment was conducted three times, and the results of the repeated analyses were averaged out. The mango fruits were analyzed for various parameters at various storage durations of 0, 5, 10, 15, 20, and 25 days. Three replications of the two-factor experiment (coating materials and time intervals) were used in the Completely Randomized Design (CRD) layout.

Organoleptic evaluation

The color and taste of the samples were assessed by the Hedonic scale (Shah *et al.*, 2020), with a 10-point scale as the best. A panel of eighteen experts between 20 and 40 years of age was constituted. From each sample, a total of eighteen mango fruits were randomly selected and each cut into five slices. Among the experts, the material on fruit was similarly divided. The panelists assigned numbers between 0 and 10 to each sample, with 0–2.0 denoting green, 2.1–4.0 light green, 4.1–6.0 light yellow, 6.1–8.0 yellow, and 8.1–10 full yellow, denoting the mango fruit's skin color.

The taste and aroma of mango samples were graded as 0-2.0, meaning extremely disliked, 2.1-4.0 fair, 4.1-6.0 good, 6.1-8.0 considered very good, and 8.0 to 10 indicates excellent taste and aroma).

Mango's external firmness was measured using a Bosch penetrometer, model FT 327. The force (in g.mm⁻²) required for a 2 mm probe to puncture the fruit peel at various four points was used to measure firmness, and the average values were taken. The results were rescaled using the Hedonic scale for comparison purposes; the ranges were 2.0-4.0 very soft, 4.1-6.0 soft, 6.1-8.0 slightly soft, and 8.1-10 firm.

Physico-chemical analysis

A hundred milliliters of juice were titrated against sodium hydroxide with a concentration of 0.1 N to determine the total titratable acidity (AOAC, 2000). In this instance, the turning pink of the phenolphthalein (an indicator), sodium hydroxide, and juice mixture in question served as the endpoint for the experiment.

Fruit firmness (kg.cm⁻²)

Fruit firmness was measured using an 8mm probe and a handheld penetrometer (Effigi, FT-011). The mango fruit was in one's hand. A small amount of skin was peeled in order to expose the flesh. A penetrometer that had been reset to zero was pushed into the peeled area while being held between the thumb and forefinger. Slowly and with increasing pressure, it was pressed until the notch touched the fruit's surface, at which point the dial's reading was recorded. Every replication had three readings by treatment, which were noted and calculated on average (Pocharski *et al.*, 2000).

Total soluble solids (TSS %)

The ascorbic acid and soluble solids were determined using the pulp that was obtained after thoroughly mixing five mango fruits. Ten grams of mango pulp were mixed with 250 mL of deionized water using a blender. The total soluble solids were determined using a digital refractometer (Atago-Palette PR 101, Atago Co. Ltd., Itabashi-Ku, Tokyo, Japan) as described by AOAC (2000).

Total sugar

The content of total sugar was determined by the titration method. The filtrate of pulp dispersion was titrated against Fehling solutions according to the known procedure (AOAC, 2000).

Ascorbic acid

The titrimetric methodology, as described in Aly *et al.* (2017), was used to determine the ascorbic acid content of mango fruit. For this, 10ml of juice was placed in the conical flask, and 100ml of juice was obtained by adding 0.4% of an oxalic acid solution. A beaker containing 10 ml of mango juice was used to titrate the juice against a standardized 2,6-dichlorophenol indophenol dye solution until a light pink color appeared for fifteen seconds.

Titratable acidity (%)

The percent acidity of mango fruit was determined by the standard method of AOAC (2000).

pH of fruit juice

The pH of various mango juice samples taken from various samples chosen at random was measured using a pH meter with model number IOLAB pH 720. The pH meter was standardized with common buffer before pH was determined. Mango juice samples were made using a juicer, and the electrode of a pH meter was dipped in the juice before the temperature dial was adjusted based on the juice sample. The reading was noted as soon as the pH meter's scale stopped shifting.

Weight loss (%)

Mango fruit weight loss in percent was calculated for each replication of each treatment. The three chosen fruits were properly marked with a black permanent marker to prevent mixing with other fruits. The marked mango fruits were all chosen at random. The data recorded through balance (Electrical) were used to calculate the means of the chosen samples.

Calculation formula for percentage of weight loss:

$$\text{Weight loss} = \frac{\text{Weight of fresh fruit} - \text{weight after duration}}{\text{Weight of fresh fruit}} \times 100$$

Disease incidence (%)

Fruits that displayed softness and fungus attack were classified as diseased fruits, with data expressed as a percentage. The disease incidence in mango fruits was calculated daily using the formula below for each replication and treatment.

$$\text{Disease incidence} = \frac{\text{Disease incidence}}{\text{Total no.of fruit}} \times 100$$

The fruit ripened stage

The days were counted to ripened stage of every coated fruits.

Statistical analysis

The average of three replicates was used to express each value. Using the SPSS statistical package (SAS Institute Inc., Cary, NC), the analysis of variance (ANOVA), and Duncan's multiple range tests were performed on the data.

Results and Discussion

Evaluation of organoleptic attributes

Color, taste, and aroma

Peel color, taste, and aroma are regarded as very important aspects which determine the quality and marketability of horticultural commodities. Further, the acceptance of a consumer is usually determined by the peel color of fruits. The least color, taste, and aroma and the highest firmness of fruit were observed at harvest time (0 day). The minimum values were observed for peanut oil (color = 2.23, taste = 2.64, and aroma = 2.42) followed by soya bean oil (color = 2.34, taste = 2.76, and aroma = 2.55). After 15 days, the maximum color (8.01), taste (8.22) and aroma (8.12) values were recorded for un-coated fruit, and the minimum color (5.26), taste (5.69) and aroma (5.47) values were noted for peanut oil coating in Figures 1-3. However, the color, taste and aroma score declined with increasing storage duration and was the minimum color (4.65), taste (4.96) and aroma (4.89) after 20 days of storage. The uncoated fruit got completely rotten after 20 days, and data could not be recorded for a 25-day storage duration (Figures 1-3). The storage for 25 days of fruit coated with animal fat had the maximum color (8.02), taste (8.24) and aroma (8.14), followed by sunflower-coated fruits with color (7.02), taste (7.29) and aroma (7.10). It is clear that the color, taste, and aroma of mango fruit increase during ripening. However, coatings slowed down the development of fruit color, taste, and aroma and maintained these attributes for a longer period than un-coated fruits. It could be due to decreased respiration rate and other biochemical reactions responsible for ripening of fruit during storage (Amarante *et al.*, 2001; Herianus *et al.*, 2003). The highest color score was noted in fully coated fruits, and it was due to the low respiration rate in these fruits (Shah *et al.*, 2020). When storage duration is increased, the fruit color is decreased or lost due to the vanishment of colorful pigment from the fruit surface (Ribeiro *et al.*, 2007). The improvement of fruit color during storage is due to degradation of chlorophyll, carotenoids, and anthocyanin synthesis (Zhu *et al.*, 2008). The fruit ripening rate is slowed down by the use of coatings, which maintain the aroma, taste, and color, and prolong the shelf life of the fruit (Dang *et al.*, 2008). Coating act as a semipermeable obstacle against oxygen, CO₂, moisture and solute movement; therefore, the water loss, alternative oxidation reaction and respiration rate is reduced thus fruit taste becomes satisfactory to consumer (Singleton *et al.*, 1999). The minimum score of tastes in uncoated fruits is due to anaerobic respiration, which leads to more ethanol production and odd flavors (Guire, 1997). In contrast to other vegetable oils, castor oil requires little or no deodorization; a process that removes the relatively volatile contents that cause undesirable colors, aromas, and flavors in produce, allowing it to retain all of these quality characteristics (Vinay *et al.*, 2016).

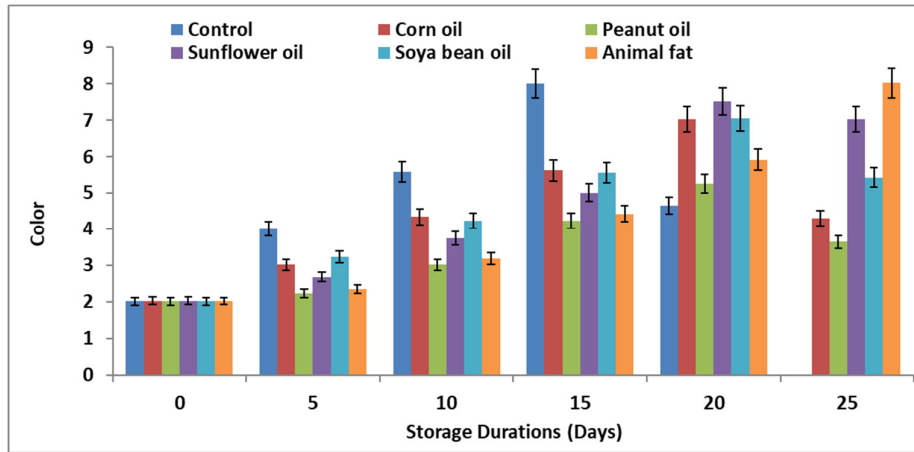


Figure 1. Effect of coatings and storage durations on mango color
The values are the means of three replicates with standard deviation (\pm SD)

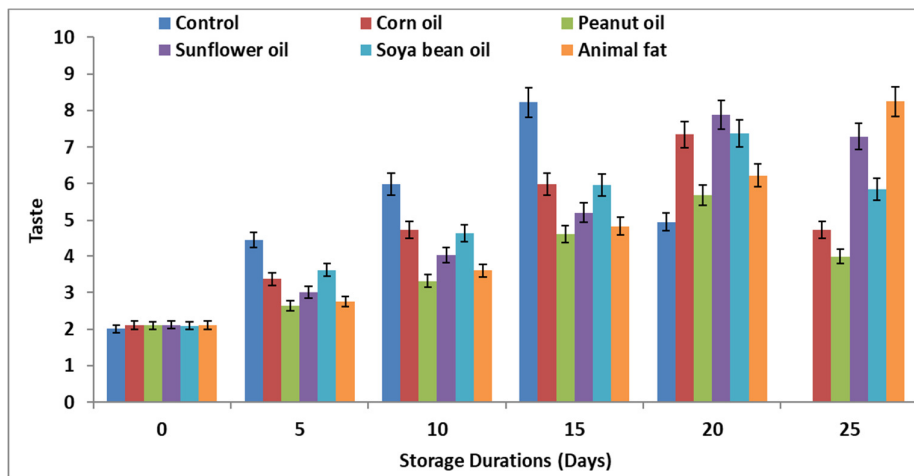


Figure 2. Effect of coating materials and storage durations on mango fruit taste
The values are the means of three replicates with standard deviation (\pm SD)

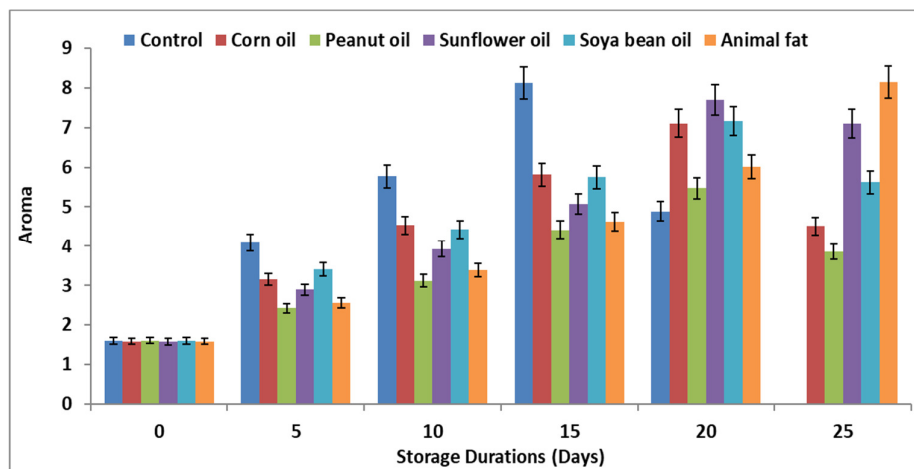


Figure 3. Effect of coating materials and storage durations on aroma of mango fruit
The values are the means of three replicates with standard deviation (\pm SD).

*Physicochemical attributes*Fruit firmness

The highest fruit firmness was noted at 0 and 5 days of storage, but it decreased with increasing storage duration (Figure 4). The fruit firmness was the maximum (8.88) and was recorded in fresh fruits stored for 0 days. The fruit firmness remained almost non-significant with 10 days of storage but thereafter varied significantly with storage duration and coating materials. After 15 days of storage, the least amount of fruit firmness (7.54) was noted for fruits coated with peanut oil and stored for 15 days. However, the minimum firmness of fruit (4.01) after 20 days of storage was of uncoated fruits, whereas the maximum fruit firmness (8.55) was noted in fruits coated with animal fat. Whereas the fruit firmness declined further with increasing storage duration to 25 days, the maximum fruit firmness (8.12) was recorded in animal fat-coated fruits, and the minimum firmness of fruit (4.11) was noted in peanut oil at 25 day of storage duration (Figure 4). Since the animal fat coating slows down the respiration of the fruits, that decreases the catabolic reactions and so retains the highest fruit firmness (Sumnu and Bayindirli, 1995; Valero *et al.*, 1998). The data showed that the results of corn oil and soya bean oil were non-significant from each other for color, taste, and aroma at 10, 15, and 20 day of storage durations.

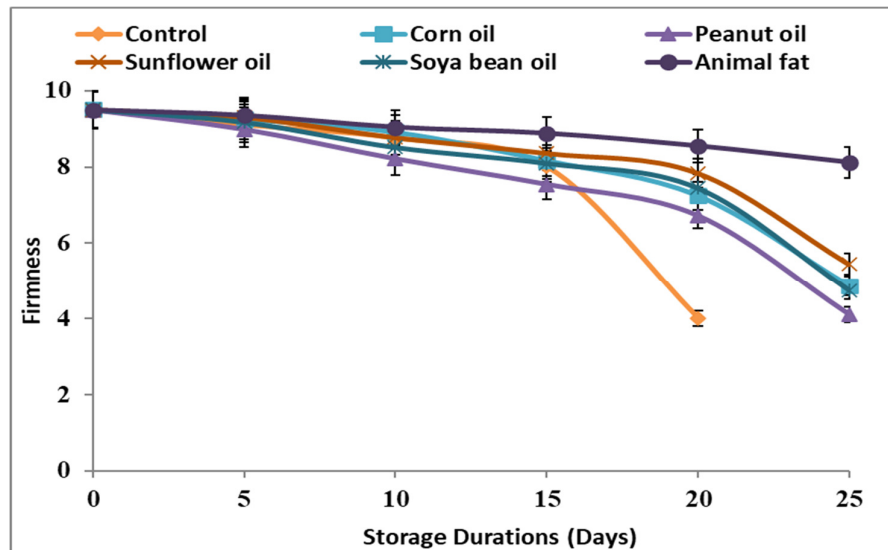


Figure 4. Effect of coating materials and storage durations on firmness of mango fruit. The values are the means of three replicates with standard deviation (\pm SD).

Total soluble solids and total soluble sugars

The total soluble solids (TSS) of the fruits slowly accumulate during the ripening process. This phenomenon could be due to the conversion of starch into simple sugars and the reaction of hydrolysis. The TSS and total sugars were lowest in mango fruit at harvest time (day 0 of storage), followed by fruits stored for 5 days. The total soluble solids (TSS) and total sugars increased with increasing periods of storage (Figures 5 and 6). With 15 days of storage, the maximum total soluble solids and total sugar (27.42 and 26.38 %) were recorded in uncoated fruit and the minimum (15.12 and 14.03 %) was in peanut oil coated fruit. At increasing storage duration to 20 days, at the same storage interval, the minimum total soluble solids and total sugar (16.82 and 16.18 %) were in uncoated fruit, while maximums (25.65 and 24.62 %) were noted in sunflower coatings. The total soluble solid (27.38) and total sugars (23.51 %) were the maximum in fruits coated with animal fat and sunflower oil, but the minimum was 16.74 and 18.67 %, with peanut and corn oil coated fruits, respectively, stored for 25 days. Storage of mango fruits for 25 days resulted in the maximum total sugar (26.34) in fruits coated with animal fat followed by sunflower oil (22.44%), whereas the minimum total sugar was recorded

with peanut (15.72%) followed by 17.55 % with corn oil coated fruits, stored for 25 days (Figures 5 and 6). The increase of total soluble solids and total sugar in mango fruits during the ripening process is attributed to the biochemical conversions of starch into sugar. Insoluble protopectin into pectin and loss of organic acid through oxidation are responsible for the increase of total soluble solids, carotenoids and sugar content (Kittur *et al.*, 2001; Malundo *et al.*, 2001; El-Beltagi *et al.*, 2019; El-Beltagi *et al.*, 2022). It was observed that total sugars and TSS of control (uncoated) fruit were the highest on day 15 of storage, and they declined by day 20. On the other hand, the peak of TSS and total sugars was delayed by 5 days in coated fruit and the decline was observed after 25 days of storage. Among the different coating materials, the total soluble solids and total sugar were the highest in animal fat-coated fruit at 25-day storage duration. The reason behind that was that coating of animal fat reduced the respiration process, which resulted in a slowing down of the respiration process and production of ethylene, so the storage durations of animal fat-coated fruits increased (Kittur *et al.*, 2001; Mehaisen, 2005). The ripening of the fruits is prolonged by slowing down the rate of respiration because it reduces the conversion of starch to sugars and hence retains the higher TSS of the fruits (Kittur *et al.*, 2001; Lum, 2011). Moalemiyan *et al.* (2012) stated that an increase in total soluble solids may be related to weight loss, causing an increase in sugar content. Furthermore, the complex carbohydrates present in the mangoes' conversion into soluble sugars also increased the total soluble solids concentration. Coatings provide effective protection from environmental oxygen while impeding the activities of metabolic processes involved in the rapid conversion of acids to sugar (Baswal *et al.*, 2020).

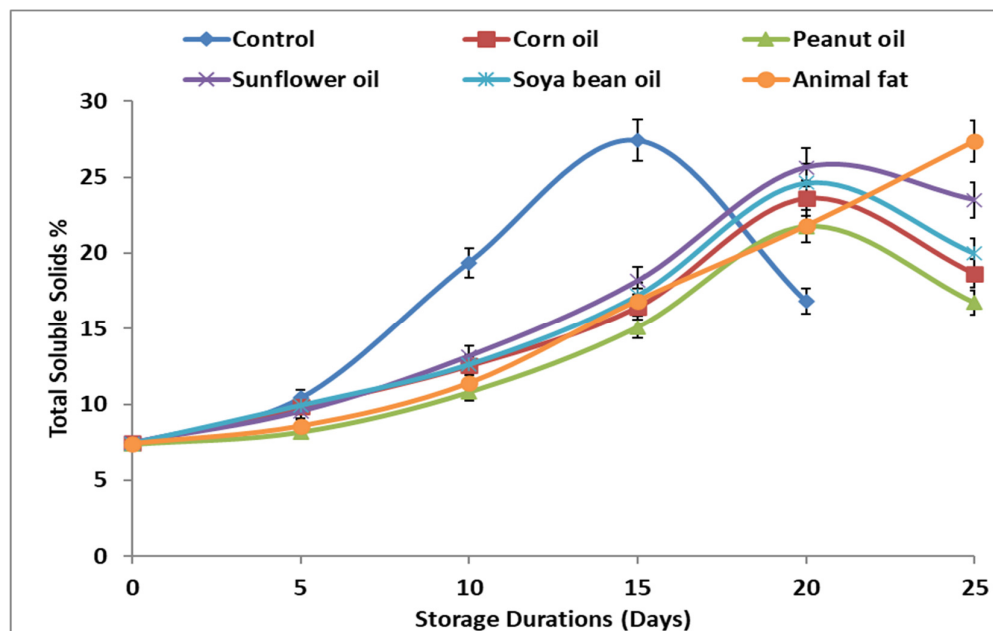


Figure 5. Effect of coating materials and storage durations on total soluble solids of mango fruit. The values are the means of three replicates with standard deviation (\pm SD).

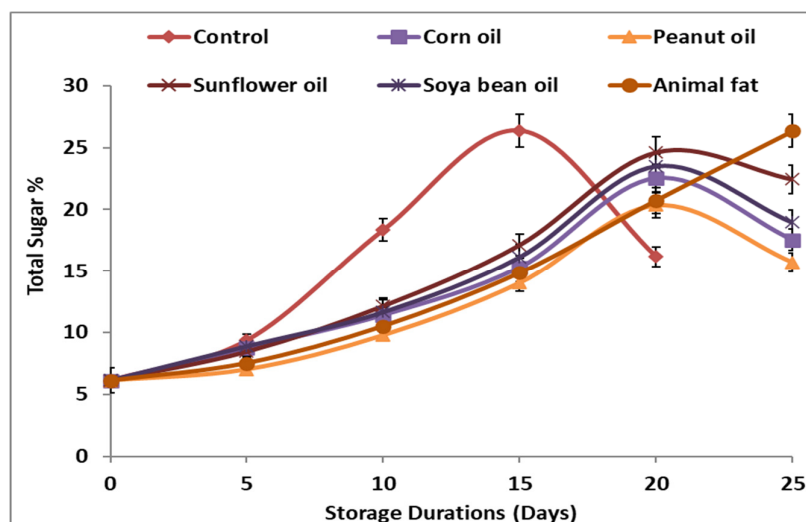


Figure 6. Effect of coating materials and storage durations on total sugar of mango fruit. The values are the means of three replicates with standard deviation (\pm SD).

Titrateable acidity (%) and ascorbic acid

The influence of storage durations was significant on acidity and ascorbic acid, while the impact of coating materials was significant on acidity and ascorbic acid in most of the cases ($P \leq 0.05$) in Figures 7 and 8. The acidity and ascorbic acid were highest at harvest time (0 day) and were followed by fruits stored for 5 days and decreased with increasing storage durations (Figures 7 and 8). The maximum acidity (1.72 %) and ascorbic acid ($133.32 \text{ mg} \cdot 100\text{g}^{-1}$) were noted in fruits coated with animal fat, whereas the minimum acidity (0.84 %) and ascorbic acid ($109.31 \text{ mg} \cdot 100\text{g}^{-1}$) were recorded in uncoated fruits (T_0) after 10 days of storage. However, after 15 days of storage, uncoated fruit had the lowest acidity (0.49%) and ascorbic acid ($64.17 \text{ mg} \cdot 100\text{g}^{-1}$), while animal fat-coated fruit had the highest acidity (1.42%) and ascorbic acid ($117.36 \text{ mg} \cdot 100\text{g}^{-1}$). Fruits coated with peanut oil had the highest acidity (0.92%) and ascorbic acid ($88.64 \text{ mg} \cdot 100\text{g}^{-1}$) after 25 days, while animal fat-coated fruits had the lowest acidity (0.51%) and ascorbic acid ($62.49 \text{ mg} \cdot 100\text{g}^{-1}$). This might be due to the fact that coated fruits reduced the respiration and water loss from the fruits, which resulted in a slowing down of the decrease in acidity and ascorbic acid of fruits during storage (Sumnu and Bayindirli, 1995; 2003; Baldwin *et al.*, 1999; Amarante *et al.*, 2001; Herianus *et al.*, 2003; Hamed *et al.*, 2019).

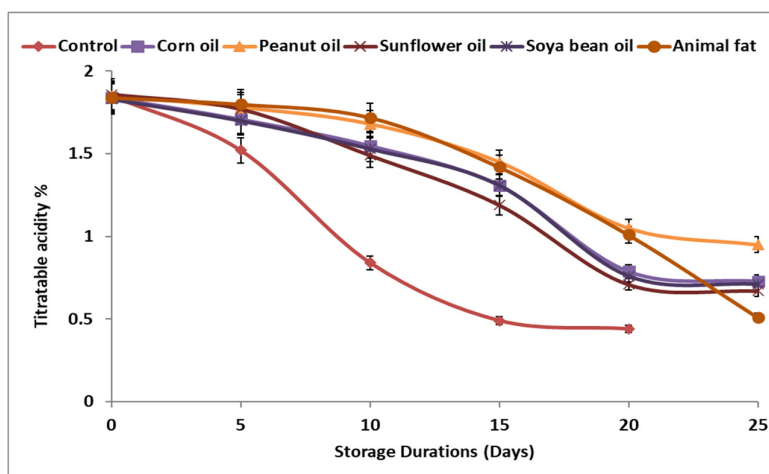


Figure 7. Effect of coating materials and storage durations on titrateable acidity of mango fruit. The values are the means of three replicates with standard deviation (\pm SD).

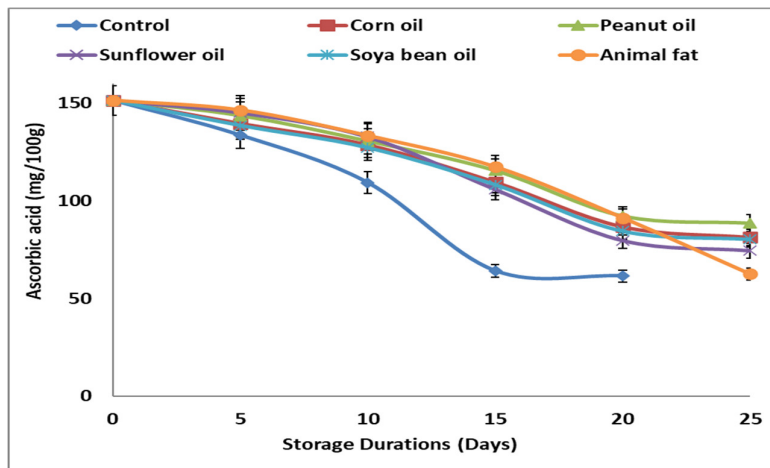


Figure 8. Effect of coating materials and storage durations on ascorbic acid of mango fruit
The values are the means of three replicates with standard deviation (\pm SD)

pH of fruit juice

Data in Figure 9 pertaining to the pH of fruit juice was significantly influenced by coating materials. The highest pH of fruit juice (4.56) was noted in fruits coated with sunflower oil, followed by the pH of fruit juice (4.47) found in animal fat-coated fruits, while the lowest pH of fruit juice (3.76) was recorded in uncoated fruits. Noted data on storage durations showed that storage durations had significantly affected the pH of fruit juice. The maximum pH of fruit juice (4.71) was noted at 20 days of storage duration, followed by storage at 15 days for which pH of fruit juice was recorded (4.64), whereas the minimum pH of fruit juice (3.86) was observed at 25 days of storage duration. Data related to interaction showed that on the initial day of the storage, the pH of fruit juice of all fruits was statistically the same. After 25 days of storage, all the coated fruits were decayed except the animal fat-coated fruits, which were still healthy after 25 days of storage. However, a significant difference among the coated fruits was observed in the increasing pH of the fruit juice. The fruits coated with animal fat observed the maximum pH of fruit juice (5.48) at 25 days of storage duration in fruits coated with animal fat, whereas the minimum pH of fruit juice pH (3.94) was recorded in fruits coated with peanut oil at 0 days of storage duration. Coatings that slow the ripening process of the fruits resulted in better sustainability of aroma, color, and taste as well as keeping the pH low for an extended period of time; thus, the fruits' storage duration increased. These results are in parallel with Raese and Drake (1993), who stated that ripening of fruit is delayed because of the application of animal fat coat. As animal fat coating reduces the respiration rate, so acid consumption is slowed down in the respiration process. Similarly, Imran *et al.* (2000) showed that the increased phenomenon of pH in storage is because of the development of free acid and pectin hydrolysis.

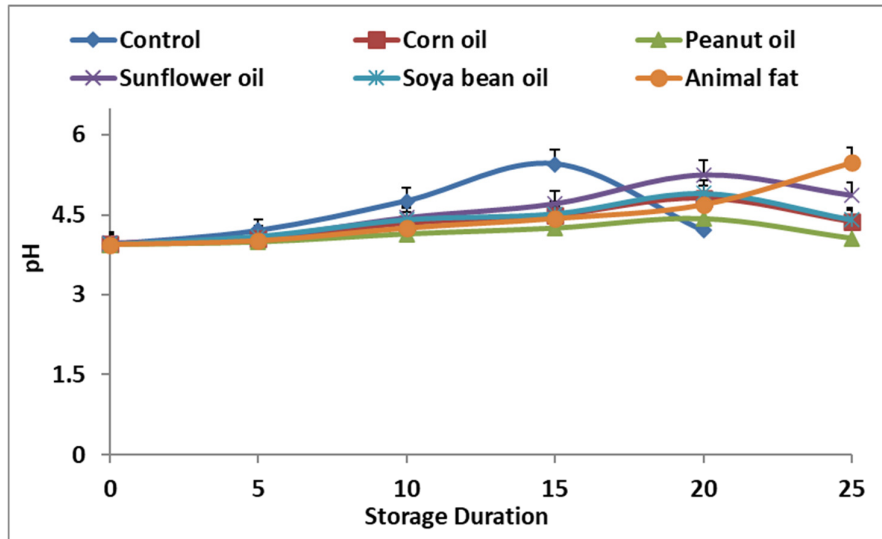


Figure 9. Effect of coating materials and storage durations on pH of mango fruit. The values are the means of three replicates with standard deviation (\pm SD).

Weight loss (%)

Storage resulted in a significant increase in weight loss. The weight loss of uncoated fruits was 5.22, 10.42, 18.25, and 27.44 % with 5, 10, 15, and 20 day of storage durations accordingly. The fruit coating resulted in a significant decrease in weight loss. Thus, the minimum fruit weight loss (2.35%) increased from 4.72, 7.52, and 11.24 % in fruits stored for 5, 10, 15, and 20 days (Figure 9). Among the different coating materials, the fruits coated with corn oil had the maximum weight (26.23%), followed by soya bean oil (26.72 %), whereas the minimum weight loss (16.31 %) was recorded in animal fat-coated fruits after 25 days of storage (Figure 10). Evaporation from the surface of the fruits is an important factor in reducing the weight of the fruits. While animal fat coating is a barrier to reduce the moisture loss from the surface of the fruit, it contributes to reduced weight loss during the storage of the fruits (Wills *et al.*, 1998; Veravrbeke *et al.*, 2003; Akalin *et al.*, 2006).

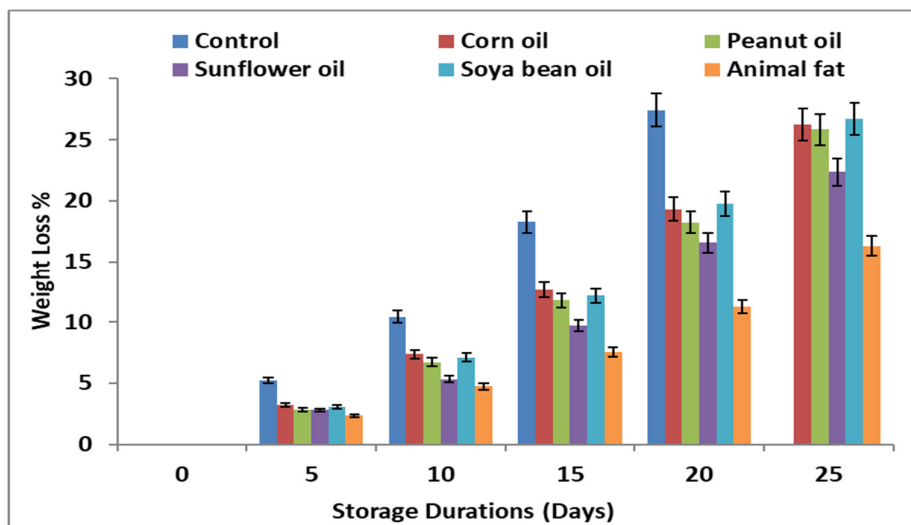


Figure 10. Effect of coating materials and storage durations on mango fruit weight loss. The values are the means of three replicates with standard deviation (\pm SD).

Disease incidence (%)

The percent of waste increased with increasing storage durations (Table 1). At any storage interval the waste percentage was the highest in uncoated fruits, so that it was 3.1, 8.72 and 50.45 % in uncoated fruit stored for 10, 15 and 20 days accordingly. By contrast, fruits coated with animal fat resulted in the minimum waste percentage at each storage interval so that it was 0, 1.12 and 2.10 % in animal fat-coated fruits stored for 10-, 15- and 20-days storage. The uncoated fruit deteriorated after 20 days storage durations (Table 1). The waste percent was also lowest (4.12 %) for animal fat-coated fruit at 25 days storage durations. The waste percent in animal fat-coated fruits was low; the possible reason might be the antifungal, antimicrobial and hydrophobic properties of the animal fat (Sprong *et al.*, 2001; Dawood *et al.*, 2022). Animal fat has also the property to make the fruit protective from disease by making the fruit surface condition unfavorable for disease attack (Sprong *et al.*, 2001; Schaafsma, 2005; Baloch *et al.*, 2013; Mohamed and Abd–El Hameed, 2014; Ashry *et al.*, 2018). Interruption in the oxygen transport from the environment to the fruit surface might also have contributed to reduced growth of microbial (Shah and Hashmi, 2020; El-Sheshtawy *et al.*, 2022; Maksoud *et al.*, 2022).

Table 1. Effect of coating materials and storage durations on the waste percent of mango fruits

Coating Materials	Storage Durations					
	0	5	10	15	20	25
Control	0	0	3.1 ^{a†}	8.72 ^a	50.45 ^a	-
Corn oil	0	0	1.15 ^c	2.36 ^c	6.62 ^c	10.36 ^b
Peanut oil	0	0	2.45 ^b	4.52 ^b	7.49 ^b	12.36 ^a
Sunflower oil	0	0	0 ^d	1.67 ^d	3.55 ^d	6.94 ^c
Soya bean oil	0	0	1.16 ^c	2.14 ^c	6.54 ^c	10.15 ^b
Animal fat	0	0	0 ^d	1.12 ^c	2.10 ^c	4.12 ^d

[†]Values having different superscript in the columns are significantly different under the limit of $P < 0.05$ according to Duncan's multiple range tests.

Days to ripened stage

Various coating materials had a significant impact on the days to ripening stage. The maximum days to ripening stage were taken by the animal fat-coated fruits, whereas the minimum days to ripening stage were noted in uncoated fruits to reach the ripened stage (Figure 11).

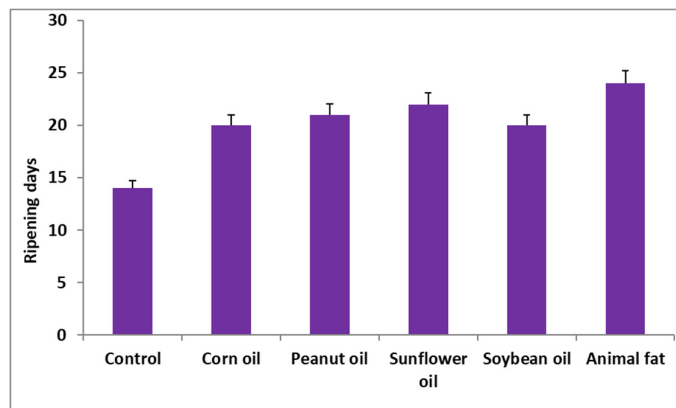


Figure 11. Effect of coating materials on days to ripened stage of mango fruits during storage. The values are the means of three replicates with standard deviation (\pm SD).

The storage life was longest in animal fat-coated fruit because it took a longer time to reach a ripened stage. The reason behind that is that animal fat coating blocks the lenticels of the fruit surface and reduces the respiration, which, on the other hand, slows down the process of ripening of the fruits (Dhalla and Hanson, 1988; Hagenmaier and Baker, 1993; Kittur *et al.*, 2001; Akalin *et al.*, 2006).

Conclusions

The findings demonstrated that coating types and storage times had a significant impact on the majority of the parameters. Based on the findings, it was determined that fruits with animal fat coatings had significant differences in their color, taste, aroma, firmness, total sugar content, total soluble solids, and delayed ripening by up to 25 days after being stored. Fruits covered with animal fat maintained their acidity and ascorbic acid content with little weight loss and waste percentage, whereas uncoated fruits did not maintain all of their quality characteristics during storage and started to lose quality after 20 days.

Authors' Contributions

Conceptualization, F.F. and M.S.; methodology, F.F.; software, S.T.S.; validation, A.B., F.F.; formal analysis, A.B, F.F.; investigation, A.A.; resources, F.F.; data curation, A.B, F.F.; writing–original draft preparation, A.B., H.I.M and E.EL.; writing–review and editing, A.B, S.T.S.; visualization, A.B., S.T.S.; supervision, F.F.; project administration, F.F., funding acquisition, F.F., H.I.M and E.EL. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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