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On-Tree Fruit Bagging and Cold Storage Maintain the Postharvest Quality of Mango Fruit

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Abstract: The present study investigates the influence of on-tree fruit bagging on the quality and shelf life of mango (*Mangifera indica* L. cv. 'Samar Bahisht Chaunsa') during cold storage (12 °C ± 1; 85–90% RH) for 0, 10 and 20 days (d) and subsequent shelf storage under ambient conditions (25 °C ± 1; 60–65% RH). Fruits were covered with brown paper bags at the marble stage and then harvested at commercial maturity. Results showed that 0 d and 10 d cold-stored fruits, irrespective of bagging treatments, retained eatable quality and shelf-life up to 7 d and 5 d during ambient storage, respectively. However, bagged fruits had better postharvest performance compared with non-bagged fruits by exhibiting slower weight loss, higher fruit firmness, more total soluble solids, vitamin C and total phenolic content and higher activities of catalase and superoxide dismutase during cold storage and ambient shelf storage. On the other hand, 20 d cold-stored fruits, both bagged and non-bagged, were decayed when kept under ambient conditions. It is proposed that mango fruit bagging could be a potential cultural practice to preserve postharvest quality up to 10 d of cold storage, followed by 5 d under ambient conditions.

Keywords: *Mangifera indica*; brown paper bag; cold storage; postharvest performance; antioxidants; phenolics

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1. Introduction

Mango (*Mangifera indica* L.), also known as the 'King of Fruits', is one of the most famous tropical fruits which has high nutritional value with excellent fragrance and delicious taste [1]. Pakistan is the world's 5th largest mango producer, accounting for about 5% of global demand [2]. In Pakistan, it is grown on an area of 158,000 hectares with an annual production of around 1.723 million tons [3]. Notably, the 'Samar Bahisht Chaunsa' mango, having a unique flavour and fragrance, is popular in domestic and foreign markets such as Saudi Arabia, the United Arab Emirates, Iran, the United Kingdom, and Kuwait [4–6].

Good agricultural practices and environmental factors during the fruit growing season largely determine the postharvest performance of the produce [7]. Among them, on-tree fruit bagging is an emerging agricultural practice that involves the covering of fruit with a cloth or paper bag, which is widely used for pear [8], apple [9], grape [10], and

mango [11,12]. Technically, it alters the microenvironment of the fruit, which facilitates the reduction of pest infestations, wounds, bruises, sunburn, blemishes, and scars [13]. For example, in the Konkan region (Maharashtra-India), prolonged winter and fog are unfavourable for mango production, and it damages the external appearance of the fruit. Therefore, the bagging practice is used to minimize the negative effect of unfavourable environmental conditions [14]. Bagging can also improve the internal quality of fruits by promoting pigmentation at harvest [15]. Apart from improving fruit physical appearance, bagging encourages fruit production without the application of pesticides [16]. Currently, this practice is commercially used in Japan, China, Australia, and the United States of America [17–19]. It is interesting to mention that countries such as Mexico, Chile and Argentina do not import fruits unless they were previously bagged [20].

Due to climacteric ripening behaviour and poor postharvest management practices, mango fruits have a short postharvest life span, these factors can restrict their export potential. Generally, fruit storage at low-temperature delays the ripening process, however, the optimal temperature ranges vary among fruit species. In mango, ambient storage temperature for 21 days (d) causes significantly higher physiological weight loss (7.31%) as compared to low-temperature storage at 10 °C (2.15%) [21]. With reduced fruit weight loss and respiration rate, low-temperature storage can prolong the postharvest shelf-life [22–24]. Hence, the inclusion of pre-harvest and post-harvest management practices in the production system can improve fruit quality and shelf life.

Pakistan has a number of mango varieties that have better adaptability under the prevailing agro-climatic conditions and can produce high-quality fruits. In recent times, the demand for Pakistani mango fruits is receiving more importance and commercial interest. To fulfil local and international demand, the production of high-quality fruit is a prerequisite. So far, mango is largely produced without bagging for domestic as well as the export market. Considering the above-mentioned benefits of fruit bagging and cold storage, it can be hypothesized that on-tree fruit bagging along with cold storage can further improve the postharvest performance of mango fruits. In this study, postharvest quality and shelf life under ambient and cold storage conditions were compared between the bagged and non-bagged fruits of the 'Samar Bahisht Chaunsa' mango.

2. Materials and Methods

2.1. Fruit and Bagging Material

For this study, the experimental fruits of the 'Samar Bahist Chaunsa' mango were grown in a commercial mango orchard in Multan, Pakistan (30°13′05″ N 71°34′15″ E). At the marble stage (45 d after the fruit set), the fruits were bagged using brown paper bags (25 × 20 cm) and at the same time, some fruits were tagged and labelled as control treatment—fruit not bagged.

2.2. Treatments

A total of 135 physiologically mature and healthy fruits (twenty-seven fruits from each tree) were harvested for each bagged and non-bagged treatment, and fruits were treated with Amistar fungicide (8 mL L^{-1} water) for 3 min to overcome sap burn injury. Afterwards, fruits were divided into three groups. One group was evaluated at harvest (0 d at cold storage) and the second and the third group were, respectively, evaluated after 10 d and 20 d of cold storage (12 °C ± 1, 85–90% RH). After each storage interval, fruit samples were sent to the Postharvest Science and Technology Lab, MNS University of Agriculture, Multan, Pakistan for shelf life and quality analysis at ambient conditions (25 °C ± 1, 60–65% RH). In each treatment, there were three replications and each replication had 15 fruits.

2.3. Measurements

The physiological parameters (ethylene production rate, and CO_2 production rate) and physical parameters (fruit peel colour and weight loss) were recorded daily until fruits

started to decay whereas destructive analyses were performed on the first day and last day of shelf storage.

2.3.1. Respiration Rate and Ethylene Production

The respiration rate and ethylene production rate were determined by the release of CO_2 and ethylene, respectively. Four fruit derived from each replicate per treatment were placed in a 2.25 L plastic container and sealed at room temperature. After 60 min of incubation, a portable gas analyzer (F-940 Gas Analyzer, Felix, Camas, WA, USA) was used to detect the release of CO_2 and ethylene in a static system. The respiration rate and ethylene production were expressed as μmol CO_2 Kg^{-1} h^{-1} and μmol C_2H_4 Kg^{-1} h^{-1}, respectively.

2.3.2. Peel Colour

Three sites close to the equatorial part of each mango were chosen to determine the peel colour with a colourimeter (CR-400, Konica Minolta, Tokyo, Japan), which was expressed as L^* value (L^* = 100 is white and L^* = 0 is black), a^* value [green (−) to red (+) axis], and b^* value [blue (−) to yellow (+) axis].

2.3.3. Fruit Firmness

Fruit firmness was determined using a handheld penetrometer (FR-5120, Lutron Electronics Enterprises, Taiwan) equipped with an 8 mm diameter flat probe. Two readings were obtained from 2 equidistant points on the equatorial axis of each fruit, after the removal of the skin. Firmness was expressed as a force in Newton (N).

2.3.4. Weight Loss

Fruit weight loss was calculated by taking initial weight on the 0 d and final weight on the sampling day until fruits started to decay.

$$\text{Weight Loss (\%)} = (\text{WO} - \text{WS})/\text{WS} \times 100$$

where WO and WS represent the initial and the final weights of mangoes, respectively.

2.3.5. Soluble Solids Content

Soluble solids content (SSC) was measured using a digital refractometer (PAL-1, Atago Co., Tokyo, Japan) and expressed in percentage (%).

2.3.6. Titratable Acidity and Juice pH

Titratable acidity (TA) was determined by taking 10 mL juice in a 100 mL volumetric flask, followed by the addition of 2–3 drops of phenolphthalein to the juice sample. After that, the sample was titrated against 0.1 N NaOH solution until the endpoint light pink was obtained. TA was expressed as %. Whereas, juice pH was calculated by using a digital pH meter (Starter 3100 OHAUS Corporation, Parsippany, NJ, USA).

2.3.7. Ascorbic Acid Content

The content of ascorbic acid was determined as suggested by Ruck [25] and modified by Xylia, Chrysargyris, Ahmed and Tzortzakis [24]. Briefly, a 10 mL homogenized juice sample was placed in a 100 mL volumetric flask and the final volume was achieved by adding 0.4% oxalic acid. After that, the mixture was filtered through Whatman No. 41 filter paper. About 5 mL of the filtrate aliquot was taken in a flask and titrated against the dye (2,6-Dichlorophenolindophenol) until the light pink colour was achieved. The content was expressed as mg 100 mL^{-1} juice.

2.3.8. Total Phenolic Content and Total Antioxidant Activity

Briefly, 1 g pulp tissue was homogenized with a 5 mL cold extraction mixture [HCL: acetone:methanol (2:8:90)]. After that, samples were centrifuged at 9000 rpm for 5 min at 4 °C and supernatant was collected and used for total antioxidant activity (TAC) and total phenolic content (TPC) determination.

The TAC was assessed by following a method described by Saleem et al. [26]. 50 µL extract was homogenized with 5 µL of 2,2-diphenylpicrylhydrazyl solution (0.004%) in a test tube, followed by 30 min of dark incubation at room temperature. After incubation, 200 µL of each sample was collected in a microplate, and samples were run through a spectrophotometer (Epoch Eliza reader, Winooski, VT, USA) at a wavelength of 517 nm and expressed as % inhibition.

The amount of TPC was measured by following the Folin-Ciocalteu assay. In test tubes, 100 µL of the supernatant was mixed with 200 µL of Folin-Ciocalteu reagent (10%) and vortexed for 10 s. After that, 800 µL of sodium carbonate solution (700 mM) was added and vortexed for another 10 s. Then, the mixture was subjected to dark incubation at room temperature for 2 h. After incubation, 200 µL of the mixture was placed on a microplate, and samples were read at a wavelength of 765 nm. The amount of TPC was expressed as mg Gallic Acid Equivalents (GAE) in a 100 g FW sample (GAE mg 100 g^{-1}).

2.3.9. Determination of Catalase, Peroxidase and Superoxide Dismutase Enzyme Activity

Briefly, 1 g pulp tissue was homogenized with 2 mL of phosphate buffer (pH 7.0–7.8) by using a mortar and pestle. After that, samples were centrifuged at 9000 rpm for 5 min at 4 °C and the supernatant was collected and used for the determination of catalase (CAT), peroxidase (POD) and superoxide dismutase (SOD) enzyme activity. The enzyme activities were expressed as Unit mg^{-1} protein [27]

Catalase Activity

The extracted sample (100 µL) was mixed with a 100 µL solution of hydrogen peroxide (5.9 mM). To evaluate CAT activity, sample absorbance was noted at a wavelength of 240 nm by using a spectrophotometer (Epoch Eliza reader, Winooski, VT, USA).

Peroxidase Activity

100 µL of hydrogen peroxide (40 mM), 100 µL guaiacol, and 800 µL phosphate buffer (50 mM, pH 5) were used in an 8:1:1 to make the POD reaction mixture. Afterwards, 100 µL of enzyme extract was homogenized with 100 µL of the reaction mixture and then subjected to spectrophotometric (Epoch Eliza reader, Winooski, VT, USA) examination at 470 nm.

Superoxide Dismutase Activity

100 µL of enzyme extract was homogenized with 200 µL of methionine, 500 µL of phosphate buffer (50 mM, pH 5), 200 µL of Triton X, 100 µL of Nitro blue tetrazolium, and 800 µL of distilled water. The mixture was then exposed to UV light for 15 min, followed by the addition of 100 µL of riboflavin. Then the samples were exposed to spectrophotometric (Epoch Eliza reader, Winooski, VT, USA) observation at 560 nm to determine the absorbance values.

2.4. Statistical Analysis

The experiment was designed using a randomised complete block design with a two-factor factorial layout (bagging treatment and storage interval). Using Statistix 9® software, the acquired data was statistically analysed (ANOVA and LSD test at $p \leq 0.05$ level). The figures were generated using Sigma Plot 10.0 (SPSS, Chicago, IL, USA).

3. Results

3.1. Ethylene Production, Respiration Rate and Weight Loss

The change in ethylene production between the bagged and non-bagged treatments was not significant at each cold storage interval. However, irrespective of bagging treatment, there was a rise in ethylene production at 10 d of storage, followed by no significant change on 20 d of cold storage (Figure 1A). During shelf-life storage, ethylene production in 0 d cold-stored fruits followed an increasing trend, irrespective of bagging treatments (Figure 1B). However, ethylene production fluctuated in 10 d cold-stored fruits throughout the ambient storage (Figure 1C).

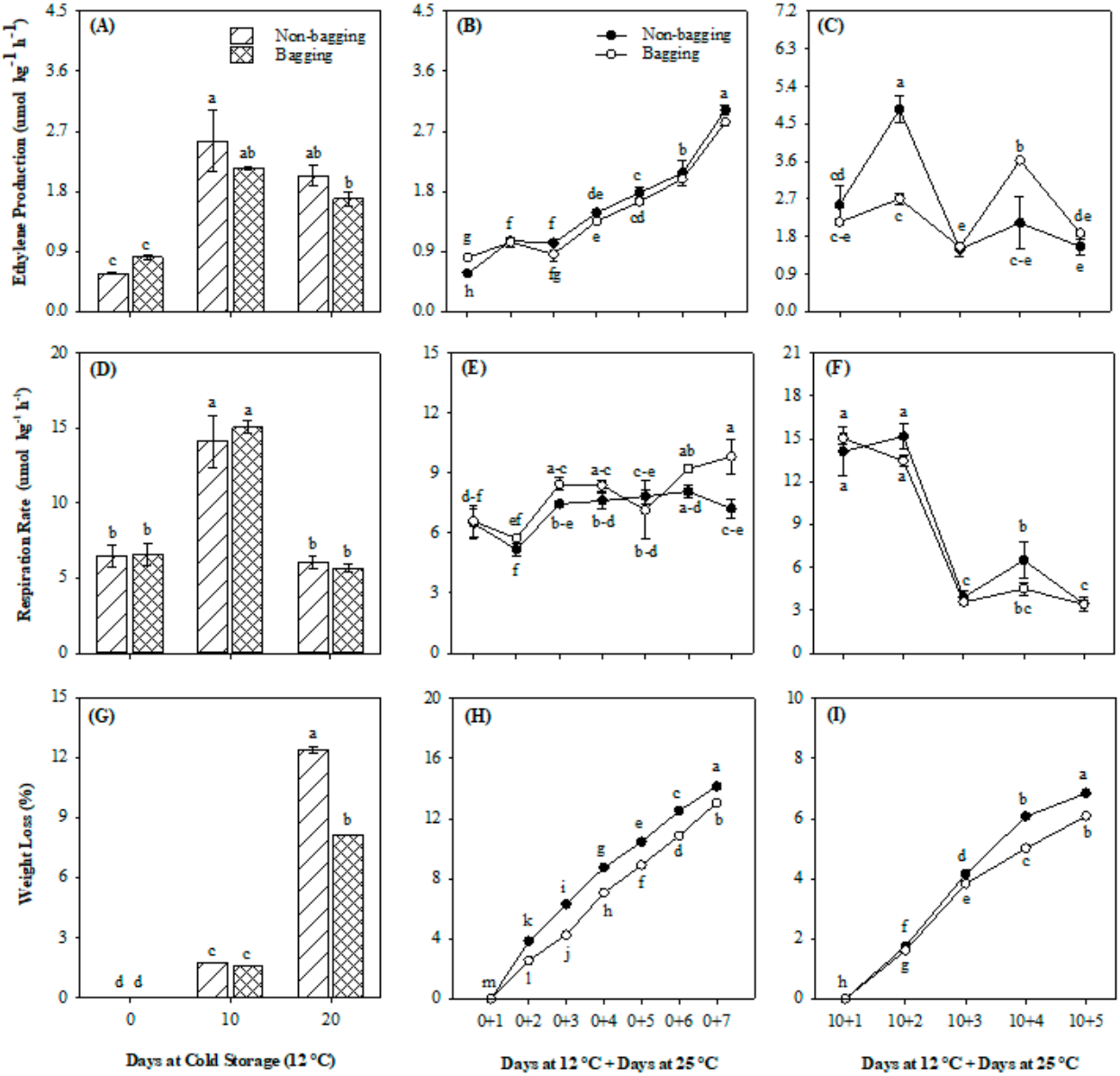

Figure 1. Effect of on-tree fruit bagging treatments on post-harvest ethylene production (**A**–**C**), respiration rate (**D**–**F**) and weight loss (**G**–**I**) in mango fruit during cold storage intervals and under subsequent ambient conditions. Error bars show standard errors of the means (n = 3). Different letters indicate significant differences according to the LSD test at $p \leq 0.05$. When 20-day cold-stored fruits were kept under ambient conditions, fruits were decayed within 24 h hence no tests were performed.

Similar to ethylene production, the effect of bagging treatments on respiration rate was found non-significant at each storage interval. However, the respiration rate was

higher in 10 d of cold storage fruits as compared to 0 d and 20 d of cold storage (Figure 1D). Under ambient storage, 0 d stored fruits had no changes in respiration rate on each shelf day, except significantly more respiration rate in bagged fruits on the seventh day (7 d) of ambient storage (Figure 1E). Moreover, 10 d cold-stored fruits showed a sudden decline in respiration rate on the third day (3 d) of ambient storage, however, the difference was non-significant between the bagging treatments (Figure 1F).

There was an increase in weight loss with the passage of storage intervals, however, the difference between the bagged and non-bagged fruits was non-significant on each interval, except on 20 d of cold storage with significantly less weight loss in bagged fruits as compared to non-bagged fruit (Figure 1G). During ambient storage, 0 d stored fruits (both bagged and non-bagged) exhibited an increased weight loss with the advancement in shelf storage. However, more weight loss was observed in non-bagged fruits starting from the second day (2 d) to the seventh day (7 d) of ambient storage (Figure 1H). Similarly, weight loss changes were observed in 10 d cold-stored fruits under ambient storage (Figure 1I).

3.2. Fruit Firmness

A significant effect of bagging treatments was found on fruit firmness at different cold storage intervals. Except on 20 d of cold storage, bagged fruits maintained higher values of fruit firmness as compared to non-bagged fruits on 0 d and 10 d of cold storage intervals. Overall, there was a significant decline in fruit firmness with the passage of cold storage interval (Table 1). During ambient storage, 0 day and 10 d cold-stored fruits exhibited more fruit firmness in bagged fruits as compared to non-bagged fruits. Moreover, fruit firmness was significantly decreased to the last day of their shelf life which was 7 d and 5 d in 0 d and 10 d cold-stored fruits, respectively (Table 1).

Table 1. Effect of on-tree fruit bagging treatments on mango fruit firmness during cold storage intervals and under ambient conditions. Values are means of triplicates ± SD. Different letters in superscripts indicate significant differences according to LSD test at $p \leq 0.05$. D, decayed fruit hence no tests were performed.

Treatment	Fruit Firmness (N)	
	Non-Bagging	Bagging
	a. Days at 12 °C	
0	142.67 ± 0.33 ^{b}	150.00 ± 0.58 ^{a}
10	79.33 ± 0.88 ^{d}	94.23 ± 0.50 ^{c}
20	39.00 ± 0.58 ^{e}	37.17 ± 0.73 ^{f}
	b. Days at 12 °C + Days at 25 °C	
0 + 0	142.67 ± 0.33 ^{b}	150.00 ± 0.58 ^{a}
0 + 7	27.30 ± 1.37 ^{d}	94.80 ± 0.79 ^{c}
10 + 0	79.33 ± 0.88 ^{b}	94.23 ± 0.50 ^{a}
10 + 5	38.47 ± 0.36 ^{d}	46.93 ± 1.90 ^{c}
20 + 0	39.00 ± 0.58 ^{b}	37.17 ± 0.73 ^{a}
20 + 1	D	D

3.3. Fruit Peel Colour (L, a* and b*)*

Except in 10 d cold-stored fruits, bagging treatments did not affect the L^* value (Figure 2A). During ambient storage, 0 d cold-stored fruits exhibited no significant change throughout the storage, except a significantly high value of L^* in bagged fruits on the seventh day (7 d) (Figure 2B). Moreover, when 10 d stored fruits were kept under ambient storage conditions, bagged fruits exhibited a higher value of L^* as compared to control (Figure 2C). Similar to the effect of bagging treatments on L^* value, a* value was also significantly changed in 10 d cold-stored fruits (Figure 2D). During ambient storage, 0 d cold-stored non-bagged fruits exhibited an increasing profile from the second day (2 d) to the seventh day (7 d) while bagged fruits had decreasing profile from the second day (2 d) to the sixth day (6 d) with non-significant changes followed by a significant increase

(Figure 2E). During ambient storage, 10 d cold-stored bagged fruits had significantly higher values of *a** on the second day (2 d) and fourth day (4 d) (Figure 2F). As for the *b** value is concerned, only 10 d cold-stored fruits exhibited significant changes due to bagging treatments (Figure 2G). During ambient storage, 0 d cold-stored non-bagged fruits had a significantly higher value of *b** on the fifth day (5 d) and seventh day (7 d) as compared to bagged fruits (Figure 2H). While 10 d cold-stored bagged fruits showed higher values of *b** on the first day (1 d), second day (2 d) and fifth day (5 d) as compared to non-bagged fruits (Figure 2I).

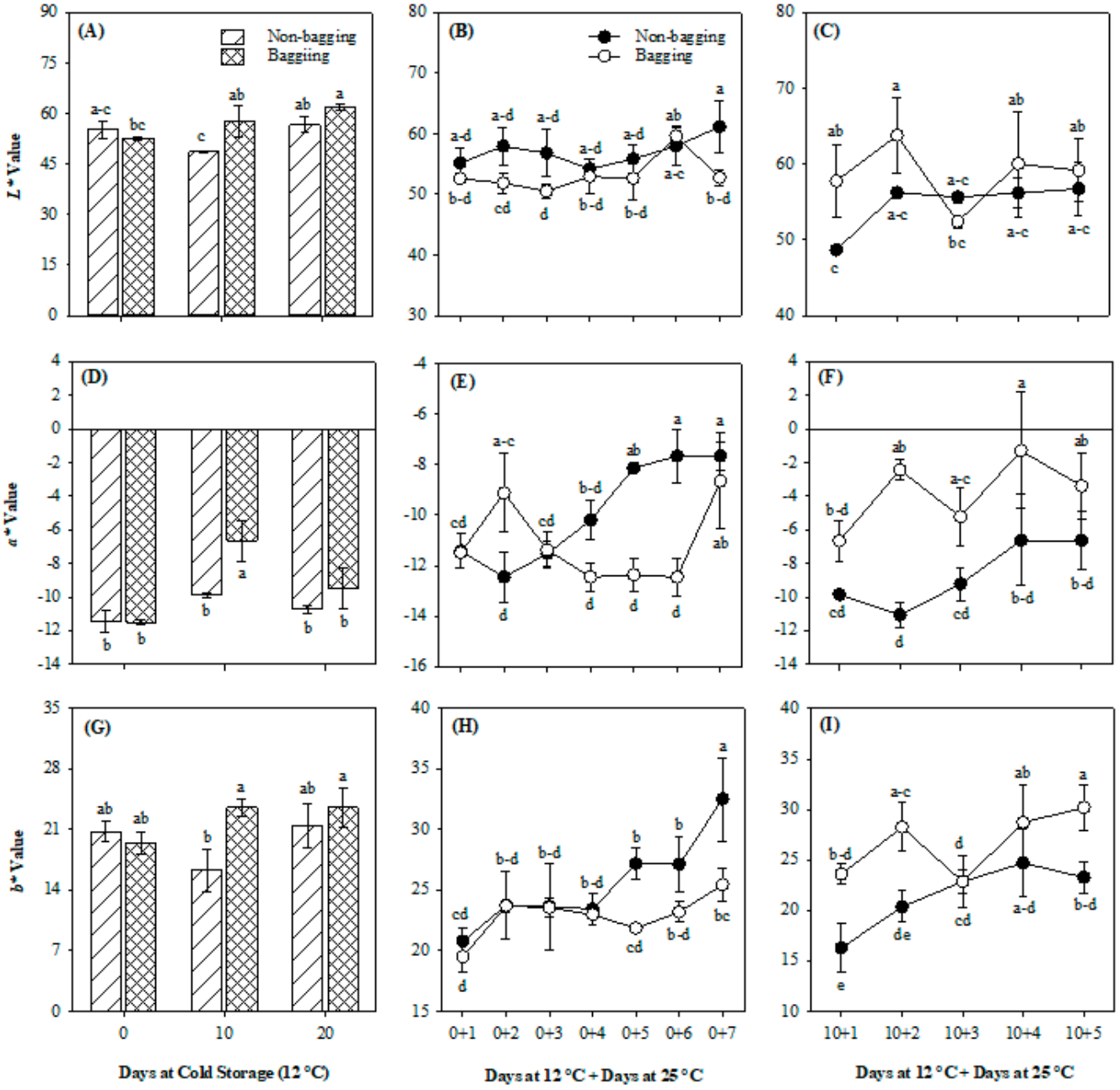

Figure 2. Effect of on-tree fruit bagging treatments on *L** value (**A**–**C**), *a** value (**D**–**F**) and *b** value (**G**–**I**) in mango fruit during cold storage intervals and under subsequent ambient conditions. Error bars show standard errors of the means (n = 3). Different letters indicate significant differences according to the LSD at $p \leq 0.05$. When 20-day cold-stored fruits were kept under ambient conditions, fruits were decayed within 24 h hence no tests were performed.

3.4. Soluble Solids Content, Titratable Acidity and Juice pH

Except on 0 d of cold storage, bagging treatments had a significant effect on SSC. There was increased SSC content in bagged fruits than in non-bagged fruits on 10 d and 20 d of cold storage. Overall, there was an increasing profile of SSC from 0 d to 20 d of cold storage (Table 2). Moreover, 0 d and 10 d cold-stored bagged fruits yielded more SSC than non-bagged fruits. Also, a significant increase in SSC was found during ambient storage (Table 2). There was a significant difference in TA content due to bagging treatments on each storage interval, except for 20 d storage (Table 2). Overall, the TA content followed the decreasing trend with the passage of cold storage intervals. During ambient storage of 0 d and 10 d cold-stored fruit, TA contents were significantly reduced with the passage of days, irrespective of bagging treatments (Table 2). Bagging treatments significantly changed the juice pH on each storage interval (Table 2). Bagged fruits had lower juice pH than non-bagged fruits. During the ambient storage of 0 d cold-stored fruit, the change in juice pH was non-significant between the first day (1 d) and seventh day (7 d); however, a significant increase in juice pH was observed in both bagged and non-bagged fruits on the fifth day (5 d) as compared with the first day (1 d) (Table 2).

Table 2. Effect of on-tree fruit bagging treatments on soluble solids contents (SSC), titratable acidity (TA) and juice pH in mango fruit during cold storage intervals and under ambient conditions. Values are means of triplicates ± SD. Different letters in superscripts indicate significant differences according to LSD test at $p \leq 0.05$. D, decayed fruit hence no tests were performed.

Treatment	SSC (%)		TA (%)		Juice pH	
	Non-Bagging	Bagging	Non-Bagging	Bagging	Non-Bagging	Bagging
			a. Days at 12 °C			
0	7.55 ± 0.38^{e}	8.33 ± 0.06^{e}	0.62 ± 0.01^{a}	0.45 ± 0.02^{b}	4.63 ± 0.09^{c}	4.27 ± 0.06^{d}
10	14.53 ± 0.24^{d}	15.63 ± 0.35^{c}	0.59 ± 0.00^{a}	0.41 ± 0.02^{bc}	5.44 ± 0.09^{a}	4.65 ± 0.06^{c}
20	23.03 ± 0.33^{b}	25.50 ± 0.55^{a}	0.38 ± 0.00^{cd}	0.35 ± 0.03^{d}	5.19 ± 0.02^{b}	4.27 ± 0.0^{d}
			b. Days at 12 °C + Days at 25 °C			
0 + 0	7.55 ± 0.38^{d}	8.33 ± 0.06^{c}	0.62 ± 0.01^{a}	0.45 ± 0.02^{b}	4.63 ± 0.09^{b}	4.27 ± 0.06^{b}
0 + 7	25.42 ± 0.42^{b}	27.03 ± 0.27^{a}	0.29 ± 0.04^{c}	0.19 ± 0.01^{d}	5.42 ± 0.08^{a}	5.74 ± 0.16^{a}
10 + 0	14.53 ± 0.24^{c}	15.63 ± 0.35^{c}	0.59 ± 0.00^{a}	0.41 ± 0.02^{b}	5.44 ± 0.09^{a}	4.65 ± 0.06^{c}
10 + 5	22.29 ± 0.35^{b}	25.10 ± 0.36^{a}	0.40 ± 0.01^{b}	0.26 ± 0.02^{c}	4.64 ± 0.01^{c}	4.86 ± 0.03^{b}
20 + 0	23.03 ± 0.33^{b}	25.50 ± 0.55^{a}	0.38 ± 0.00^{a}	0.35 ± 0.03^{a}	5.19 ± 0.02^{a}	4.27 ± 0.0^{b}
20 + 1	D	D	D	D	D	D

3.5. Vitamin C, Total Antioxidant Activity and Total Phenolic Contents

A significantly more vitamin C content was found in bagged fruits as compared to non-bagged fruits during each cold-storage interval. However, there was a significant decrease in non-bagged fruit with the passage of cold storage time (Table 3). During the ambient storage of 0 d cold-stored fruit, the change in vitamin C content was non-significant between the first day (1 d) and the seventh day (7 d). However, a significant decline in vitamin C content was observed in both bagged and non-bagged fruits on the fifth day (5 d) as compared with the first day (1 d) (Table 3). The effect of bagging treatment was found non-significant on TAC during cold-storage intervals and also during ambient storage (Table 3). However, there was a significant difference in TPC due to bagging treatments on each storage interval. Bagged fruits exhibited more TPC as compared to non-bagged fruits (Table 3). During ambient storage, 0 d cold-stored fruits had no significant change in TPC, irrespective of bagging treatments. While, 10 d cold-stored fruits presented an increased profile of TPC from the first day (1 d) to the fifth day (5 d), irrespective of bagging treatments (Table 3).

Table 3. Effect of on-tree fruit bagging treatments on vitamin C, total antioxidant activity (TAC) and total phenolic content (TPC) in mango fruits during cold storage intervals and under ambient conditions. Values are means of triplicates ± SD. Different letters in superscripts indicate significant differences according to LSD test at $p \leq 0.05$. D, decayed fruits hence no tests were performed.

Treatment	Vitamin C (mg 100 mL^{-1} Juice)		TAC (% Inhibition)		TPC (mg GAE 100 g^{-1})	
	Non-Bagging	Bagging	Non-Bagging	Bagging	Non-Bagging	Bagging
			a. Days at 12 °C			
0	32.98 ± 0.42 ^{b}	38.40 ± 0.67 ^{a}	83.97 ± 0.17 ^{a}	87.68 ± 0.50 ^{a}	72.26 ± 0.67 ^{bc}	83.03 ± 3.53 ^{a}
10	21.23 ± 0.18 ^{d}	27.80 ± 0.26 ^{c}	85.71 ± 1.05 ^{a}	83.83 ± 3.44 ^{a}	67.71 ± 0.66 ^{c}	76.16 ± 2.48 ^{b}
20	12.30 ± 0.46 ^{f}	15.70 ± 0.26 ^{e}	81.83 ± 2.76 ^{a}	82.31 ± 1.23 ^{a}	74.96 ± 1.15 ^{b}	85.55 ± 1.40 ^{a}
			b. Days at 12 °C + Days at 25 °C			
0 + 0	32.98 ± 0.42 ^{c}	38.40 ± 0.67 ^{a}	83.97 ± 0.17 ^{b}	87.68 ± 0.50 ^{a}	72.26 ± 0.67 ^{bc}	83.03 ± 3.53 ^{a}
0 + 7	34.70 ± 1.21 ^{bc}	36.88 ± 0.48 ^{ab}	84.49 ± 0.78 ^{b}	86.98 ± 0.54 ^{a}	67.44 ± 0.74 ^{c}	80.32 ± 3.98 ^{ab}
10 + 0	21.23 ± 0.18 ^{c}	27.80 ± 0.26 ^{a}	85.71 ± 1.05 ^{a}	83.83 ± 3.44 ^{a}	67.71 ± 0.66 ^{c}	76.16 ± 2.48 ^{b}
10 + 5	15.77 ± 0.26 ^{d}	26.67 ± 0.42 ^{b}	86.98 ± 0.17 ^{a}	88.95 ± 0.77 ^{a}	78.77 ± 2.29 ^{ab}	85.13 ± 1.66 ^{a}
20 + 0	12.30 ± 0.46 ^{b}	15.70 ± 0.26 ^{a}	81.83 ± 2.76 ^{a}	82.31 ± 1.23 ^{a}	74.96 ± 1.15 ^{b}	85.55 ± 1.40 ^{a}
20 + 1	D	D	D	D	D	D

3.6. Antioxidative Enzyme Activities (CAT, POD and SOD)

Bagged fruits had significantly higher CAT activity than non-bagged fruits, except for 20 d of cold storage (Table 4). Moreover, a non-significant change in CAT activity was found during shelf storage of 0 d and 10 d cold-stored fruits (Table 4). Except for 0 d of cold storage, POD activity had a non-significant difference during cold storage (Table 4). Moreover, a non-significant change in POD activity was found during ambient storage of 0 d and 10 d cold-stored fruits (Table 4). There was a significant difference in SOD activity between bagged and non-bagged fruits on each storage interval, except for 20 d of cold storage. Non-bagged fruits improved the SOD activity on 10 d of cold storage as compared to 0 d of cold storage. However, bagged fruits did not show any significant change during cold storage (Table 4). During ambient storage, 0 d cold-stored non-bagged fruits improved their SOD activity. However, on the seventh day (7 d), no change was observed in bagged fruit's SOD activity (Table 4). A significant decline in SOD activity was observed in both 10 d cold-stored bagged and non-bagged fruits under shelf storage (Table 4).

Table 4. Effect of on-tree fruit bagging treatments on catalase (CAT), peroxidase (POD) and superoxide dismutase (SOD) activities in mango fruit during cold storage intervals and under ambient conditions. Values are means of triplicates ± SD. Different letters in superscripts indicate significant differences according to the LSD test at $p \leq 0.05$. D, decayed fruit hence no tests were performed.

Treatment	CAT (U mg^{-1} Protein)		POD (U mg^{-1} Protein)		SOD (U mg^{-1} Protein)	
	Non-Bagging	Bagging	Non-Bagging	Bagging	Non-Bagging	Bagging
			a. Days at 12 °C			
0	3.97 ± 0.19 ^{c}	8.39 ± 1.24 ^{a}	0.16 ± 0.01 ^{b}	2.79 ± 0.48 ^{a}	53.41 ± 1.63 ^{c}	86.78 ± 3.23 ^{a}
10	4.18 ± 0.70 ^{c}	7.29 ± 0.28 ^{ab}	0.59 ± 0.19 ^{b}	0.59 ± 0.36 ^{b}	75.25 ± 2.25 ^{b}	86.61 ± 2.60 ^{a}
20	3.62 ± 0.40 ^{c}	5.27 ± 1.12 ^{bc}	0.73 ± 0.43 ^{b}	0.93 ± 0.36 ^{b}	81.32 ± 0.76 ^{ab}	87.06 ± 3.06 ^{a}
			b. Days at 12 °C + Days at 25 °C			
0 + 0	3.97 ± 0.19 ^{c}	8.39 ± 1.24 ^{a}	0.16 ± 0.0 ^{c}	2.79 ± 0.48 ^{a}	53.41 ± 1.63 ^{c}	86.78 ± 3.23 ^{a}
0 + 7	6.66 ± 1.19 ^{ab}	9.86 ± 1.23 ^{a}	1.23 ± 0.48 ^{bc}	2.05 ± 0.45 ^{ab}	69.54 ± 2.92 ^{b}	83.88 ± 1.64 ^{a}
10 + 0	4.18 ± 0.70 ^{b}	7.29 ± 0.28 ^{a}	0.59 ± 0.19 ^{a}	0.59 ± 0.36 ^{a}	75.25 ± 2.25 ^{b}	86.61 ± 2.60 ^{a}
10 + 5	3.05 ± 0.15 ^{b}	8.12 ± 1.10 ^{a}	0.66 ± 0.08 ^{a}	1.04 ± 0.10 ^{a}	70.13 ± 1.74 ^{c}	74.84 ± 2.79 ^{bc}
20 + 0	3.62 ± 0.40 ^{a}	5.27 ± 1.12 ^{a}	0.73 ± 0.43 ^{a}	0.93 ± 0.36 ^{a}	81.32 ± 0.76 ^{a}	87.06 ± 3.06 ^{a}
20 + 1	D	D	D	D	D	D

4. Discussion

Accelerated ripening and softening are major factors shortening the shelf life and restricting the supply chains of mango fruit. Ripening of the mango fruit is a genetically complex process triggered by an increase in ethylene production and respiration rate [28]. In the current study, both bagged and non-bagged mango fruits exhibited a significant increase in ethylene production and respiration rate up to 10 d of cold storage, suggesting the initiation of the ripening process. After 20 d of cold storage, mango fruits reduced the respiration rate than those in 10 d cold-stored fruits. Montalvo et al. [29] found the highest rate of respiration in 'Ataulfo' mango during ripening which then decreased at the advanced stages of the fruit ripening process. Therefore, the reduction in the respiration rate observed in our study might be related to the fruit ripening process. Moreover, the differences in ethylene production and respiration rate between bagged and non-bagged mango fruits were not significant. These data are in accordance with other climacteric fruits, such as pears that exhibited similar results [30].

The marketing of fleshy fruits is seriously affected by weight loss and firmness loss during postharvest handling. Increased values of fruit firmness are linked with the increased potential of the fruit to travel long distances without quality deterioration. According to our results, when fruits were kept under ambient conditions after 0 d and 10 d of cold storage, weight loss increased progressively; however, bagged fruits exhibited slow weight loss which suggests that bagging treatment could slow down the metabolic process. Sharma et al. [31] also reported that when 'Delicious' apple fruits were bagged 30 d before harvest, a reduction in postharvest weight loss was observed as compared to non-bagged fruits. Furthermore, fruits exhibit more weight loss under ambient conditions with rapid ethylene production during ripening [32]; thereby, fruits become shrivelled and mushy and ultimately reduce their market value and quality [33]. Fruit firmness is reduced via the disintegration of cell walls which involves numerous enzymes such as polygalacturonate, galactosidases, and pectin methylesterase, as well as fruit respiration [34,35]. During ripening, mango fruits lose their firmness over time [36]. In the present study, a significant reduction in fruit firmness was observed over time, either during cold storage or ambient conditions; however, increased values of fruit firmness were recorded in bagged fruits. Our findings are in line with the results of Sharma, Pal, Asrey, Sagar, Dhiman and Rana [31] who noticed that the fruit firmness in bagged 'Delicious' apple fruits was retained in higher values as compared to control.

An increase in respiration by the action of ethylene triggers the degradation of chlorophyll and biosynthesis of carotenoids. In addition, Ding and Syakirah [37] stated that the low chlorophyll content in bagged fruits is due to low light radiation. In our study, bagged fruits exhibited brighter skin colour compared to non-bagged fruits. In a previous study [38], brown paper bags improved the yellow skin in the 'Keitt' mango when compared to the non-bagged fruits. Similar findings were also found in bagged litchi and peach fruits [39,40].

SSC is considered as a sweetness index, mainly determined by the total concentration of sugar compounds. Sugar metabolism is a complex mechanism that is regulated by enzymatic reactions, and genetic and environmental factors [41]. Ni et al. [42] reported that due to lower activities of sucrose degradation enzyme (acid invertase) and higher activities of sucrose synthesis enzymes (sucrose synthase and sucrose-phosphate synthase), bagged fruits had more sugar accumulation than non-bagged fruits. In the present study, significantly higher SSC contents were observed in bagged fruits as compared to non-bagged fruits which might be due to the changes in enzymatic activities. Moreover, it was observed that SSC contents were increased under ambient conditions followed by cold storage. Likewise, an increase in SSC at the shelf followed by cold storage was observed in mango fruit [17,43,44].

During fruit ripening, a decrease in TA is linked to the conversion of organic acids into sugars [45]. In our study, low TA and high juice pH values were observed in bagged fruits as compared to non-bagged fruits. Previously, Sarker et al. [46] and Islam, Akter, Rahman,

Uddin, Bari, Islam and Rahman [17] reported a decrease in TA in bagged mango fruits. In addition, similar changes have been also reported in other fruit crops due to bagging treatment [42,47].

Vitamin C (*L*-ascorbic acid) is a water-soluble vitamin that is abundant in mango fruits and is considered a major non-enzymatic antioxidant [48]. In plants, L-ascorbic acid metabolism is correlated with oxidative stress defence, while ascorbic acid accumulation in plant tissues and organs is altered by physiological phenomena such as senescence, cell expansion development and, various biotic and abiotic stimulants [49,50]. In our study, vitamin C content was decreased over time during cold storage and ambient storage, however, less reduction was observed in bagged fruits as compared to non-bagged fruits. The reduction in vitamin C content during prolonged cold storage could be due to an imbalance of ascorbic acid-redox homeostasis in fruits [50]. Moreover, it is suggested that fruits in brown paper bags were not directly exposed to sunlight, resulting in increased xanthophyll content, and hence bagged fruits preserved more vitamin C than non-bagged fruits. Previous reports [44,51] have also reported enhanced vitamin C content in bagged mango fruits than in non-bagged.

Total phenols and flavonoids create an active oxygen scavenging defence mechanism that ensures plant cell homeostasis [52]. Phenolic substances in fruits are considered vital molecules since they contribute to the antioxidant protection of the plant cell [53]. According to our study, the amount of TPC was high in bagged fruits as compared to non-bagged fruits during cold storage and ambient storage. Hudina and Stampar [54] observed the higher content of phenolic compounds (epicatechin and caffeic acid) in bagged pear fruits which ultimately resulted in improved TPC. The higher content of phenolic content in bagged fruits could be attributed to the decreased degradation rate of the phenolic molecules, due to the reduced rate of oxidation and polymerization reactions provoked by light exposure [55].

Fruit bagging changes the microclimate around the developing fruits. According to Zhang et al. [56], bagged fruits are exposed to higher average temperatures and humidity which can stimulate the production of reactive oxygen species. Zhu et al. [57] quantified significantly more H_2O_2 and O^{2-} content in bagged peach fruits than in non-bagged fruits. Taken together, these results support our finding that possibly because of the increase in the reactive oxygen species, SOD and CAT activity were significantly more activated in bagged fruits. During ambient storage, the SOD activity also remained higher in bagged fruits as compared to non-bagged fruits. Similarly, Nagamani et al. [58] reported the increased SOD activity in the pulp tissue of the mango 'Alphonso' during fruit ripening. Moreover, SOD, POD, CAT, and ascorbate peroxidase activity were greater in bagged apple fruit than in non-bagged fruit [59]. According to Razzaq et al. [60], cold storage treatment reduced the rate of enzyme activity in mango 'Samar Bahisht Chaunsa'. However, in the present study, only POD activity was significantly reduced during cold storage. Overall, the irregular behaviour of enzyme activities is considered to be caused by variations in CAT activity [60,61].

5. Conclusions

In conclusion, 0 d and 10 d cold-stored mangoes, regardless of bagging treatments, had a 7 d and 5 d shelf life under ambient conditions, respectively. Although bagged and non-bagged mango fruits did not differ significantly in terms of their storage life, bagged fruits had more fruit firmness, soluble solids, vitamin C, total phenolic contents and higher antioxidative enzyme activities, as compared to non-bagged fruits. On the other hand, when 20 d cold-stored fruits were kept under ambient conditions, fruits immediately lost their quality and exhibited poor shelf life. Overall, on-tree fruit bagging plus cold storage (up to 10 d) is a potential practice to preserve the high-quality status of postharvest mangoes.

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