Journal of Applied Horticulture, 27(1): 137-145, 2025
https://doi.org/10.37855/jah.2025.v27i01.26
Journal of Applied Horticulture
ISSN: 0972-1045

Analyzing the relationship between harvest timing and storage on the physico-mechanical properties of mangoes

Narsaiah Kairam[1,2], Pranita Jaiswal[3], Poonam Choudhary[1*], Mehak Arora[1] and Shyam Narayan Jha[2]

*[1]ICAR -Central Institute of Post -Harvest Engineering and Technology, Ludhiana -141004, India, [2]Division of Agricultural Engineering, Indian Council of Agricultural Research, New Delhi, India, [3]ICAR -Indian Agricultural Research Institute, New Delhi, India. *E-mail: poonam@icar.gov.in*

Abstract

This study shows the effect of harvesting stage and storage on the changes in weight, volume, dimensions, peel firmness, beta carotene, and color values for Dashehari and 'Banganapalli' cultivars. The percentage weight loss and volume loss increased with the storage period and harvesting stage and the maximum decrease was reported in the late harvested fruits of both cultivars. The color parameters (L, a, b) also increased with an increase in the storage period and harvesting stage. The size and sphericity of mangoes decreased due to shrinkage and water loss during the storage period. The maximum reduction in size and sphericity was observed in fruits harvested at the early stage. The fruit diameter, sphericity and overall acceptability were recorded maximum in the mid-stage harvested 'Dashehari' mangoes. The peel firmness of the fruits decreased during the storage and was observed maximum in early harvested fruits. The amount of β-carotene content was reported highest during storage in the late harvested 'Dashehari' mangoes. These specific parameters could predict the ideal harvesting and storage time for mangoes.

Key words: Mango, harvesting stage, storage, peel firmness, beta carotene, weight loss

Introduction

The mango (*Mangifera indica* L.) is a climacteric fruit that is widely grown in tropical regions. It belongs to the Ancardiaceae family. It is a juicy stone fruit widely accepted for its exceptional taste in terms of flavor and delicious sweetness. The determination of maturity at the time of harvesting is a critical factor for mangoes due to their perishable nature. Generally, mangoes are harvested at a hard green stage at which the mangoes have become physiologically mature. Accumulation of sufficient carbohydrates, organic acids, and other compounds takes place at physiological maturity which contributes to its flavor and quality. Handling and transportation of mangoes become easier if they are harvested at the hard green stage because of the peel firmness and being less susceptible to damage caused by transportation.

As the ripening process of mangoes progresses, there are substantial physicochemical and biochemical changes occurring in the fruit. The important physico-mechanical properties including weight, size, volume, skin color, and fruit firmness are the major determinants of fruit maturity, ripeness, and overall quality. The decrease in firmness of flesh is the most evident change in the fruit during the ripening process. The flesh becomes softer because a component of the cell wall, pectin is broken down by enzymatic activity which gives a softer texture to the fruit (Jain *et al.,* 2019). Additionally, the skin color changes from green to yellow, red, or a combination of these colors depending on the cultivar of mango during ripening (Sudheeran *et al.,* 2019). This shift in mango skin color with ripening is caused by the accumulation of carotenoid pigments caused by the transformation of chloroplast to chromoplast (Ranganath *et al.,* 2018). Various studies on the physicochemical changes occurring during ripening have been reported for different cultivars of mangoes by Gill *et al.* (2017), Mahayothee *et al.* (2020) and Goyal *et al.* (2023).

This study focused on analyzing the influence of the harvesting stage (early, mid, and late) and storage period on the physical properties to determine the best harvesting or maturity stage and storage duration in terms of optimal ripeness with quality good quality characteristics for both cultivars. This analysis can be helpful for mango growers, harvesters, and handlers for making scientifically reliable decisions in terms of optimal harvesting and storage duration to maintain fruit quality.

Materials and methods

In the present study, two mango cultivars, *i.e.*, 'Dashehari' originating from Punjab and 'Banganapalli' from Andhra Pradesh were selected (Table 1). The fruits were harvested at mature green stage at three different harvesting time from the same trees and orchards and stored under ambient conditions (temperature 30±2°C, and 65±5% relative humidity) for natural ripening. Due to short time availability, the 'Dashehari' mango cultivar was collected on three different dates in June whereas the 'Banganapalli' mango cultivar was collected in March, April, and May months.

Table 1. Mango cultivars with their respective harvesting dates

Cultivar(s)	Harvesting date
Banganapalli (Andhra Pradesh)	March 17, 2022 (Early harvesting stage)
	April 18, 2022 (Mid -harvesting stage)
	May 10, 2022 (Late harvesting stage)
Dashehari (Punjab)	June 03, 2022 (Early harvesting stage)
	June 09, 2022 (Mid -harvesting stage)
	June 21, 2022 (Late harvesting stage)

Weight loss: The weight of the five freshly harvested mangoes of both cultivars was recorded. The same mangoes were stored and weighed at two-day intervals to record the final weight. The weight loss was calculated by comparison between the initial weight and the final weight using the following:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight-Final weight}}{\text{Initial Weight}} \times 100$$

Fruit volume: The change in volume of five mangoes of each cultivar at different harvesting stages and storage periods was determined by the water displacement method. The mangoes of both cultivars were immersed in a container with a known volume of water and measured the volume of water displaced.

Extraction and quantification of β -carotene from mango pulp: The β-carotene from mango pulp was extracted using the method of Petry and Mercadante (2016) with some modifications. One g of fresh pulp of 'Banganapalli' pulp was kept in a 100 mL mixture of methanol and ethyl acetate (1:1, v/v). This mixture was magnetically stirred for about 2 h. Then, the mixture was filtered and the filtrate was then saponified using 10% methanolic potassium hydroxide in the dark. Following saponification, a liquid-liquid partition was carried out in a separatory funnel using petroleum ether: diethyl ether (1:1, v/v) and sodium chloride (10%). The lower layer was discarded, and the upper layer was washed several times with 5% anhydrous sodium sulphate. The obtained solution was centrifuged at 8000 rpm for 20 min at 20℃. Then, the filtrate was concentrated in a rotary evaporator at a temperature ≤ 35 °C. The obtained extract was quantified using high-performance liquid chromatography (HPLC) (Agilent 1260 Infinity (CA, USA)) on a ThermoScientific Acclaim C-30 column (4.6x250 mm). A linear gradient elution of methanol (mobile phase A) and methyl-tert -butyl ether (mobile phase B) was used. The gradient program was fixed as: i) 75:25, 7 min; ii). 65:35, 15 min; iii). 25:75, 50 min; and iv). 85:15 up to 70 min. The flow rate was kept 1 mL/min for 7 min followed by 0.8 mL/min. The temperature of the column was kept at 29 °C at 450 nm of the detector.

Peel firmness: The peel firmness of five mangoes of each cultivar at different harvesting stages and storage periods was measured by texture analyzer using a 5 mm diameter (P/5) stainless steel cylindrical probe. The reach distance was fixed at 15 mm distance inside the mango.

Color: Color parameters in terms of lightness/darkness (L), yellowness (b), and greenness (a) were acquired on a handheld colorimeter for five mangoes of each cultivar at different harvesting stages and storage periods.

Fruit size and sphericity: The dimensions in terms of length, breadth, and thickness of five mangoes of each cultivar were measured using Vernier calipers. The size of mangoes was calculated in terms of geometric mean diameter (mm) using following equation suggested by Mohsenin (1980):

$$\text{Size} = (abc)^{1/3}$$

where a = height; b = breadth, and c = thickness of mangoes

The sphericity of mangoes was determined as:

$$\text{Sphericity} = \frac{\text{Geometric mean diameter}}{\text{Height}}$$

Sensory evaluation: The sensory evaluation of mangoes harvested at different maturity stages during storage was performed using a 9-point hedonic scale (Larmond, 1977). A panel of 10 judges with an equal number of male and female members were selected. The judges randomly tested mangoes for their appearance, texture, taste, flavor, and overall acceptability and provided them with a sensory evaluation form to record their observations. The information contained in the evaluation form was 9=Liked extremely; 8= Liked very much; 7= Liked moderately; 6=Liked slightly; 5= Neither liked nor disliked; 4= Disliked slightly; 3= Disliked moderately; 2= Disliked very much; and 1= Disliked extremely.

Statistical analysis: The statistical analysis was carried out by three-way Analysis of Variance (ANOVA) at $P \leq 0.05$ using OPSTAT software, and the least significant difference was determined by Duncan's Multiple Range tests. All the experiments were performed on five mangoes with three replications and the results were expressed in mean ± standard error.

Results and discussion

Weight loss: Weight loss is an important parameter that provides valuable information about water loss, the rate of metabolic process, and changes in the quality of fresh produce and perishables during storage and transportation. In the present study, both cultivars exhibited an increase in weight loss in mangoes during the storage period and harvesting stage (Fig. 1a). However, weight loss (%) was significantly lesser in the 'Dashehari' cultivar during storage as compared to the 'Banganapalli' cultivar. The maximum weight loss (%) was reported in the late-harvested fruits of both cultivars. On the 6^{th} day of storage, weight loss of 53% and 76% higher was observed in mangoes harvested in the late season as compared to the early harvested fruits of 'Dashehari' and 'Banganapalli' cultivars, respectively. Weight loss in mangoes occurs primarily due to the loss of moisture or water content from the fruit either by respiration, transpiration, or some metabolic changes during the ripening and storage (Thinh *et al.,* 2013). Water loss in mangoes can significantly impact the fruit's texture, appearance, flavor, and shelf life (Silva *et al.,* 2017). Similar results on weight loss in mangoes during storage were reported by various researchers (Gill *et al.,* 2017; Jincy *et al.,* 2017; Maina *et al.,* 2019). However, the literature on weight loss during different harvesting stages is still meager. The statistical analysis results showed that weight loss (%) in the 'Dashehari' cultivar on the 2^{nd} day of storage from early, mid, and late harvesting and 4^{th} day of storage from early and mid-harvesting were at par while the 'Banganapalli' cultivar showed significant differences in weight loss (%) during different storage period and harvesting stages. The interaction between the cultivar, harvesting stage, and storage period was found statistically highly significant (P<0.0001).

Fruit volume: The change in volume of mangoes provides insight into their physical changes during the storage period. Loss in volume (ΔV) of mango fruits of different harvesting stages of 'Dashehari' and 'Banganapalli' cultivars during storage is presented in Fig. 1b. The maximum volume loss (ΔV) was reported on the 6th day of storage in the late harvested 'Dashehari' cultivar (35.21%) followed by mid -harvested 'Dashehari' cultivar (27.71%). However, volume loss was significantly lower in

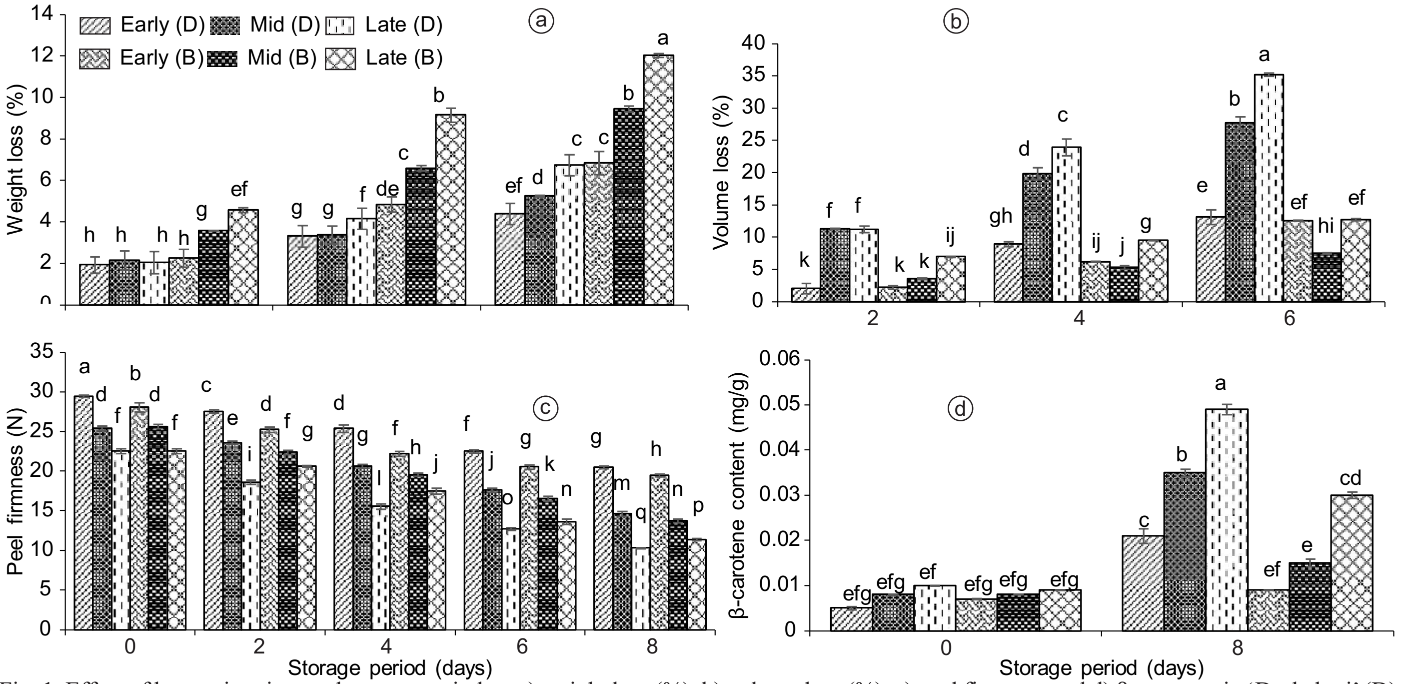


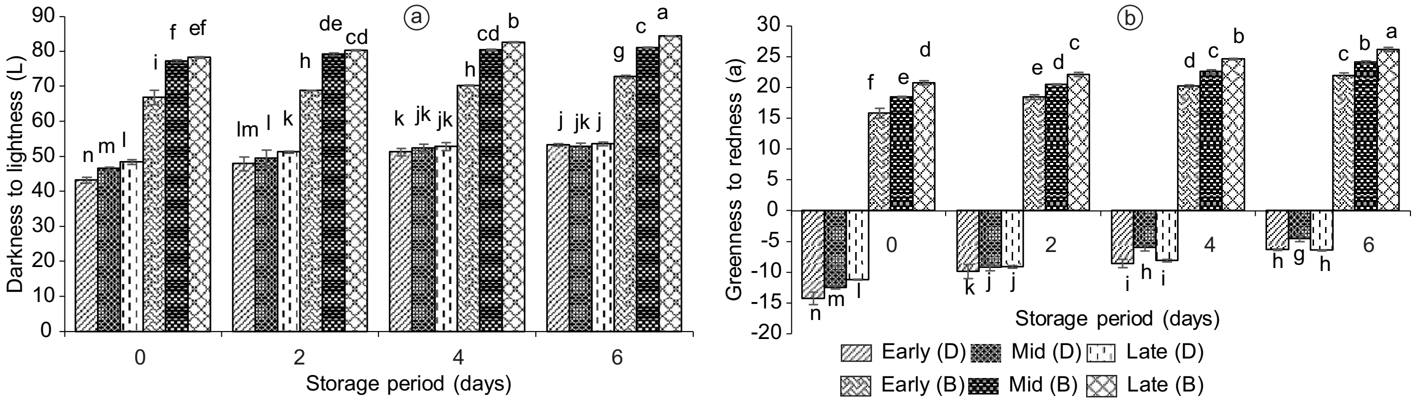
Fig. 1. Effect of harvesting time and storage period on a) weight loss (%), b) volume loss (%), c) peel firmness and d) β-carotene in 'Dashehari' (D) and 'Banganapalli' (B) cultivars. n=5. Standard error is shown with bar. Different letters show significant differences ($P \leq 0.05$)

the 'Banganapalli' cultivar irrespective of harvesting stages as compared to that of the 'Dashehari' cultivar during storage. The fruit weight and volume showed a strong correlation, therefore when there is a considerable weight loss in fruits, it can result in a noticeable change in fruit volume during storage (Lurie, 1998). When water is lost from fruits, their overall weight decreases, and this decrease in weight can lead to a reduction in volume. Similar results have been reported in cucumber (Bahnasawy and Khater, 2014) and sweet orange (Ullah *et al.,* 2018) during storage.

Peel firmness: Firmness is an important parameter that indicates the maturity and ripeness of fruits. It provides information about the post-harvest fruit quality and suitability for consumption or processing. In the present study, the peel firmness was linearly decreased in both cultivars with an increase in harvesting stage and storage period (Fig. 1c). The fruit of both cultivars harvested at an early stage of maturity showed the maximum hardness as compared to the other stages. These findings suggest that the longer the fruits remain on the tree before being harvested, the softer they become. Similar results have been reported in three varieties of mangoes (Alphonso, 'Banganapalli' and Neelum) during 10 days of ripening, and maximum reduction in peel firmness was found in the 'Neelum' cultivar (Nambi *et al.,* 2016b). Likewise, the stored persimmon fruits harvested at different maturity stages showed significant differences in firmness and the fruits harvested at yellow-orange colored stage showed maximum firmness (Khan *et al.,* 2017). As mangoes ripen, they become softer due to cell wall breakdown, changes in carbohydrate structure, and conversion of insoluble pectin into soluble forms, and a decrease in firmness is observed (Ali *et al.,* 2011). Ornelas-Paz *et al.* (2018) also observed a decrease in firmness in late-harvested fruits.

β-carotene: The β-carotene was increased in mangoes during the storage period for both cultivars (Fig. 1d). However, the increase in β-carotene was substantially higher in the case of **'**Dashehari' mangoes during storage which might be due to more conversion of chlorophyll to carotenoids in Dasherhri cultivar. These findings were confirmed by the changes in color value from greenness to redness in the present study. The maximum beta carotene content was found in 'Dashehari' (0.05 mg/g FW) mangoes on the 8th day of storage as compared to 'Banganapalli' mangoes (0.03 mg/g FW). These findings concurred with the observation recorded by Baloch and Bibi (2012) suggesting that beta carotene content increased with the maturity stage and reported higher content in ripe fruit pulp than in raw mango pulp. Similar results were obtained by Kour *et al.* (2018), in which the maximum beta carotene content for the 'Dashehari' cultivar was reported to be 1.55 mg/100 g after 120 hours of ripening. However, no significant difference was observed in the beta carotene content of fresh fruits harvested at three different maturity stages in both cultivars. Due to a rise in the synthesis of mevalonic acid and geraniol, which raised the amount of carotene, an increase in β-carotene became more pronounced as the storage stage progressed. The metabolic conversion of starch into sugar, the conversion of chlorophyll into carotenoids, and the oxidation-induced loss of organic acid resulting in the rise of sugar and carotenoid content throughout the storage process (Kour *et al.,* 2018).

Color: Green is the typical color of unripe mangoes, and as they ripen, the skin color changes to yellow, orange, red, or a combination of these colors, depending on the cultivar. In the present study, the 'L' value progressively increased significantly in all stages of the harvesting and during storage in both cultivars. However, the 'L' value of the 'Banganapalli' cultivar was reported higher as compared to the 'Dashehari'. The maximum 'L' value (84.327) was reported in the late harvested 'Banganapalli' cultivar mangoes during the 6th day of storage while the minimum 'L' value (43.21) was found in early harvested 'Dashehari' mangoes. These findings suggest that the fruits harvested in the later stages of maturity develop more colored pigments as compared to the early harvested fruits. Similar results were also reported



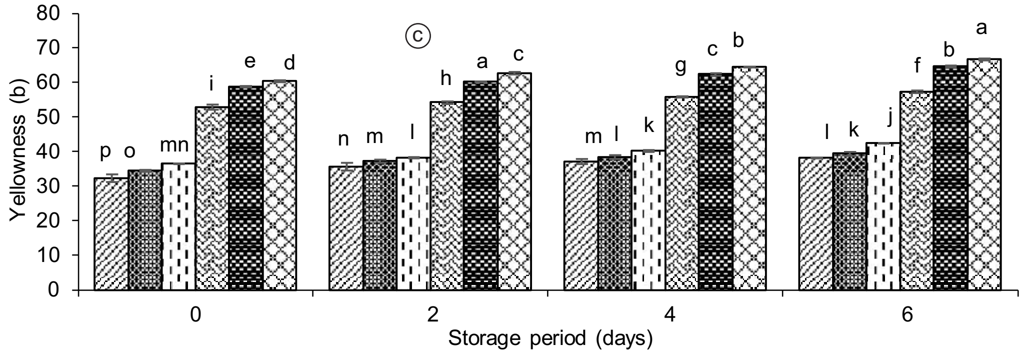


Fig. 2. Effect of harvesting time and storage period on a) lightness (L) value, b) greenness to redness (-a to +a) value, and c) yellowness (b) value in 'Dashehari' (D) and 'Banganapalli' (B) cultivars. n=5. The standard error is shown with a bar. Different letters show significant differences ($P \leq 0.05$).

by Nambi *et al.* (2016a) in Alphonso mangoes and by Quirós-Sauceda *et al.* (2019) in Ataulfo mangoes. The 'L' value for the 'Dashehari' cultivar was changed from 43.21 to 53.24 whereas in the 'Banganapalli' cultivar it was changed from 66.9 to 72.75 after 6 days of ripening during the early harvesting stage. Similar to our results, in 'Dashehari' mangoes the 'L' value was increased from 38.2 to 45.0 from 48 hours of ripening period to 144 hours of ripening period (Gill *et al.,* 2015). Like the 'L' Value, 'a' and 'b' values also increased significantly in both the cultivars with an increase in maturity stage and the storage duration (Fig. 2b and 2c). The changes in greenness to redness were more in the case of 'Dashehari' mangoes as compared to the Banganapalli cultivar during storage which might be due to more conversion of chlorophyll molecules in mango peels to carotenoids. The 'a' value ranged from -14.66 to -6.34 and 15.95 to 22.3 during the early harvested 'Dashehari' and 'Banganapalli' cultivars, respectively. Similar results were reported by (Gill *et al.,* 2015). These findings suggest that the skin color of mangoes is highly dependent on the cultivars and varies accordingly. The 'a' and 'b' values were higher for the 'Banganapalli' cultivar mangoes irrespective of maturity stage and storage period as compared to the 'Dashehari' mangoes.

Fruit size and sphericity: The changes in dimensions during storage are generally minor and may vary depending on the specific variety, maturity stage, and storage conditions of the mangoes. The changes in height, breadth, and thickness of mangoes were substantial for both cultivars during storage. The maximum geometric mean diameters were observed in the mid-harvest stage for 'Dashehari' mangoes and the late harvest stage for 'Banganapalli' mangoes (Fig. 3a). Therefore, the harvesting could be best for mid-season in the case of 'Dashehari' mangoes and in late season for 'Banganapalli' mangoes to obtain the optimal size and quality of fruits. A similar trend was also observed for the sphericity of mangoes in both cultivars (Fig. 3b). The sphericity of 'Banganapalli' mangoes was higher than that of the 'Dashehari' mangoes. The decrease in size and sphericity of mangoes was due to the water loss and shrinkage in the breadth and width of mangoes during storage.

Sensory evaluation: The consumer acceptance of the fruit depends on the overall acceptability score of the fruit. The overall acceptability of fruits depends on the consumers' flavor, taste, and appearance score. In the case of the 'Banganapalli' cultivar, the overall acceptability was improved with the increase in storage

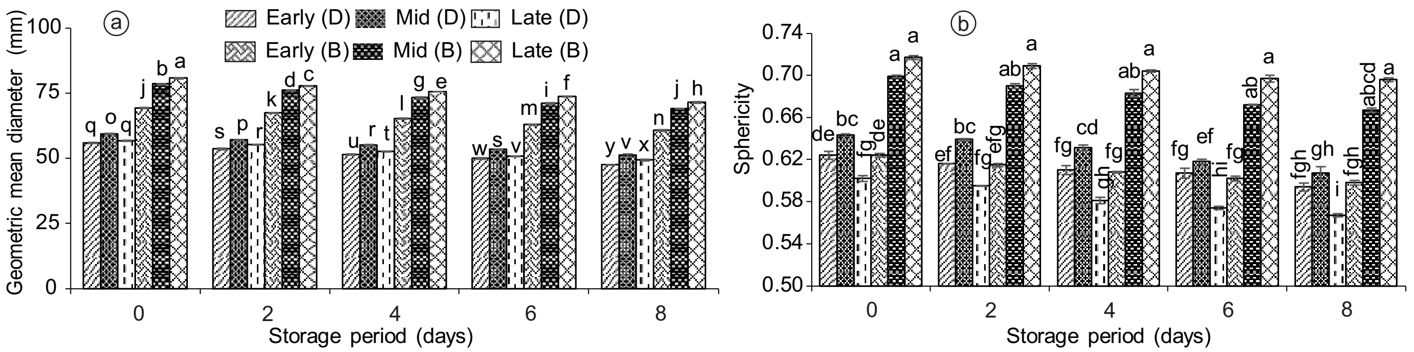


Fig. 3. Effect of harvesting time and storage period on a) geometric mean diameter (size) and b) sphericity in 'Dashehari' (D) and 'Banganapalli' (B) cultivars. n=5. The standard error is shown with a bar. Different letters show significant differences ($P \leq 0.05$).

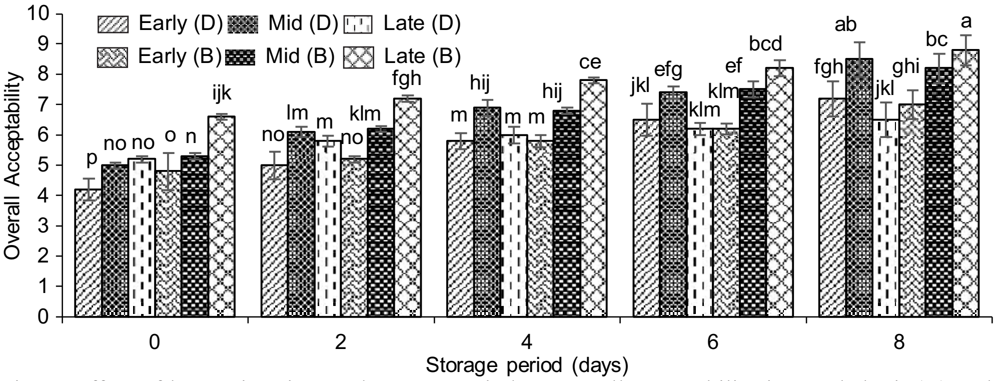


Fig. 4. Effect of harvesting time and storage period on overall acceptability in 'Dashehari' (D) and 'Banganapalli' (B) cultivars. n=10. The standard error is shown with a bar. Different letters show significant differences ($P\leq0.05$).

period and maturity stage (Fig. 4). The decrease in fruit hardness and acid content and the corresponding rise in total soluble solids and sugars are ascribed to the increase in the sensory quality score (Kour *et al.*, 2018). According to Saranwong *et al.* (2004), mangoes harvested at the later stages showed superior eating quality during storage than those picked earlier. Likewise, Kyaing *et al.* (2022) reported that among the various cultivars such as 'Sein Ta Lone' (STL), 'Ma Chit Su' (MCS), 'Hin Thar' (HT), and 'Yin Kwae' (YK), STL exhibited the highest overall acceptability scores of 8.02 and 8.38 at the later stages of ripening, respectively. In the present study, the 'Dashehari' cultivar harvested at the mid-stage exhibited maximum sensory scores during storage. The maximum color changes, increased size, and sphericity might contribute to the maximum sensory scores of mid-stage harvested 'Dashehari' mangoes. However, late-stage harvested 'Dashehari' mangoes showed a downfall in consumer acceptance of the fruit which might be due to the over-ripening of the fruit. These results corresponded to the findings by Kour *et al.* (2018).

The study showed that weight, volume and dimensions decreased more during the mid and late harvesting stages for both cultivars. Significantly higher color coordinates were observed in the 'Banganapalli' cultivar than 'Dashehari' cultivar. Fruits of both cultivars harvested late had reduced firmness and lighter color than early and mid harvest fruits. The 'Dashehari' fruits harvested in mid-harvest had better size, sphericity, colour and overall acceptability than the fruits harvested in late harvest in the 'Banganapalli' cultivar, but the maximum value for these attributes was achieved in the 'Banganapalli' cultivar harvested in late harvest. In addition, β-carotene content increased during storage, reaching a maximum in late harvested fruits. These maturity indicators underscore the usefulness of these indicators in determining the most appropriate harvest timing and storage period for mangoes to match market supply and demand considerations.

Acknowledgments

The authors are thankful to the National Agriculture Science Fund and ICAR Extramural Research for financial support. Facilities conferred by the Director, ICAR -CIPHET, Ludhiana, Punjab (India) are extremely acknowledged.

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Received: October, 2024; Revised: October, 2024; Accepted: November, 2024