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Research Article

Evaluation of mango fruit quality in relation to harvest time in the subtropical region of India

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Abstract

Reliable estimation of mango fruit maturity has great significance in ensuring enhanced fruit quality, shelf life and market value. There is hardly any univocal criterion that can be used to correctly detect the optimum stage of fruit harvest under varied climatic conditions. Hence an experiment was conducted to optimize a reliable criterion for one of the most important commercial mango varieties of India ('Dashehri') under sub-tropical region. Fruits were harvested progressively in five pickings viz. 90, 95, 100, 105 and 110 days after full bloom (DAFB). Heat unit, fruit firmness, dry matter, soluble solids content and SSC/acid ratio were considered as stable attributes in defining maturation due to their low standard deviation and coefficient of variation. Harvesting of 'Dashehri' mango between 95-100 DAFB exhibited enhanced color development (a^* and b^*), fruit quality and sensory attributes with no incidence of jelly seed. On the other hand, late harvesting of fruits not only caused high incidence of jelly seed but also affected the shelf life. The findings were also evident with principal component analysis. Early harvested fruits were characterized with sub-optimal color attributes, high post-harvest weight loss and low SSC, sugar and β-carotene content. The results indicated that DAFB can be used as a reliable non-destructive index to predict optimum time of fruit harvest. Accordingly, optimal range of SSC, dry matter, firmness, heat unit accumulation and SSC/acid ratio was quantified at maturation under subtropical climatic conditions of north India.

Keywords: color attributes; mango; maturity index; non-destructive; quality attributes

Introduction

Harvesting of fruits at optimal maturation is crucial for ensuring quality, longer shelf life and market value of fruit crops. Identification of optimum stage of fruit maturation becomes more vital especially in climacteric fruits as their maturity coincide with the rapid increase in respiration rate and ethylene production (Paul *et al*., 2012). Early harvesting of fruits results sub-optimal quality, whereas late harvesting induces internal breakdown due to rapid changes in biochemical components (Jha *et al*., 2011). Mango (*Mangifera indica* L.) is

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the most important fruit crops of India owing to its scale of production, consumer preference and market potential. In subtropical region of India, 'Dashehri' is the most important variety due to its scale of production, fruit quality and market demand. Moreover, this variety has also been granted geographical indication (GI) for its unique taste, distinct flavor and aroma, which are linked with specific production location (Rajan and Mishra, 2021). Jha *et al*. (2006) observed that harvesting of fruits at optimum maturity was the most important determinant of quality and storage life. Kour *et al*. (2018) reported that in northwest India, 'Dashehri' can be harvested at 111 days after fruit set for obtaining quality fruits, whereas Kishore *et al*. (2015) reported that 'Dashehri' attainted its maturity in May in eastern tropical region of India. Thus, maturation of fruits varies according to the climatic conditions. In order to fetch high market price, mango is usually harvested prematurely and ripening process is completed during transportation and storage, thus fruit quality is compromised (Baloch and Bibi, 2012). It is crucial to identify the most appropriate time of fruit harvesting based on the physiological maturity. There are hardly any univocal criteria that can be used to correctly detect the maturity as they exhibit variation with the climatic conditions (Herold *et al*., 2005). Among the widely used non-destructive criteria for determining the mango fruit ripeness, the most sensible refers to the number of days since full flowering (Yahia, 1998). This, however, must be optimized according to the locations and marketing objectives (Souza *et al.,* 2015). Information on ripening quality of fruits harvested at different maturity stages is essential to elucidate the feasibility of extension in shelf life of mango. However, the days required for fruit maturation varies with geographical region and growing conditions of the trees (Kienzle *et al*., 2011).

How to measure fruit quality has always been one of the most attractive research topics in the fruit science. At present, most of the available investigative methods are still destructive and time-consuming. Several methods require sample preparation as well as costly instruments and chemicals which cannot be used for large-scale sample evaluation. With the increasing demands for precise detection of fruit quality, non-destructive fruit evaluation methods are followed. However, problems like low detection accuracy and poor replicability still remain in the non-destructive detection system. Thus, it is necessary to develop a simple and reliable non-destructive index for determination of optimum harvest time of mango in subtropical region of north India which is known for large scale mango production (~7.5 million MT). Moreover, the optimization of harvest time will augment the production of export quality fruit. Keeping in view the scale of production and fruit quality of 'Dashehri', the present investigation was conducted to ascertain the influence of harvest time (non-destructive maturity index) on overall fruit quality to ensure extended shelf life with better market value. Moreover, the level of variation in heat unit accumulation, dry matter, firmness, SSC and SSC/acid ratio, and their correlation with the harvest time were also studied to ascertain the reliability of the maturity index.

Materials and Methods

Site and experimental details

Studies were conducted at ICAR-Central Institute for Subtropical Horticulture (CISH), Lucknow India during 2023 and 2024. The site is located at 26 °91' N and 80° 78' E coordinates at an altitude of 123 m amsl. Experimental site experiences humid subtropical climate (Cwa) with the annual rainfall of ~900 mm, average relative humidity of 71.6% and average maximum, minimum and mean temperature of 32.7 °C, 19.2 °C and 25.4 °C respectively. The site is characterized by hot summer during May-June, well defined winter season (December – February) and rainy season (July to mid-September). The soils of the site are silty clay loam in texture, neutral in reaction (pH 7.) low in organic carbon content (0.43%), medium in available nitrogen (267.20 kg ha^{-1}) available phosphorus (18.65 kg ha^{-1}) and potassium (163.47 kg ha^{-1}).

Experiment was conducted on 10-year-old healthy and uniform trees of 'Dashehri' planted at a spacing of 5 × 5 m. Thirty trees were selected for experimentation. All the trees were uniformly fertilized

(N500:P250:K600 g/plant) and irrigated with drip system during the fruit development. Fruits were harvested at five different dates which were considered as treatments. The experiment was laid out in randomized block design with three replications each comprised two plants. In each tree of 'Dashehri', 60 floriferous shoots, representing all the four sides were tagged at full bloom. The flowering stage of mango corresponds to the phenological stage 615 which signifies opening of more than 50% flowers in panicles (Rajan *et al*. 2011).

Fruits were harvested at 90, 95, 100, 105 and 110 days after full bloom (DAFB) from the experimental mango plot of CISH, Lucknow in 2023 and 2024. All the fruits were harvested along with the peduncle (25-30 mm) to avoid sap exudation. Fruits were brought to the fruit analysis laboratory for sorting, cleaning, packing and physico-chemical analysis. Under each replication of a treatment 60 fruits were packed in ventilated CFB boxes using paper cushioning material and kept at 25±1 °C for ripening. Physico-chemical analysis of fruits was performed at 0, 2, 4, 6, 8 and 10 days of harvesting. In order to study the changes in physico-chemical attributes, 30 fruits were randomly selected from each treatment (10 fruits per replication) at each ripening period.

Heat unit

Heat unit accumulation at different harvest time was worked out on the basis of average temperature prevailed between full bloom and fruit harvest, and base temperature. Considering the climatic preference of mango a base temperature of 10 °C was considered and heat unit accumulation was worked out in degree days (Lemos *et al*., 2018). Data on temperature and rainfall were obtained from the meteorological unit of CISH, Lucknow and presented in Figure 1.

$$GDD = \sum (t=1)^n \{(Tmax + Tmin)/2\}-T_b$$

where: GDD is the growing degree days; Tmax is the daily maximum air temperature (°C); Tmin is the daily minimum air temperature (°C); T_b is the base temperature (°C) and n is the number of days between full bloom and fruit harvest.

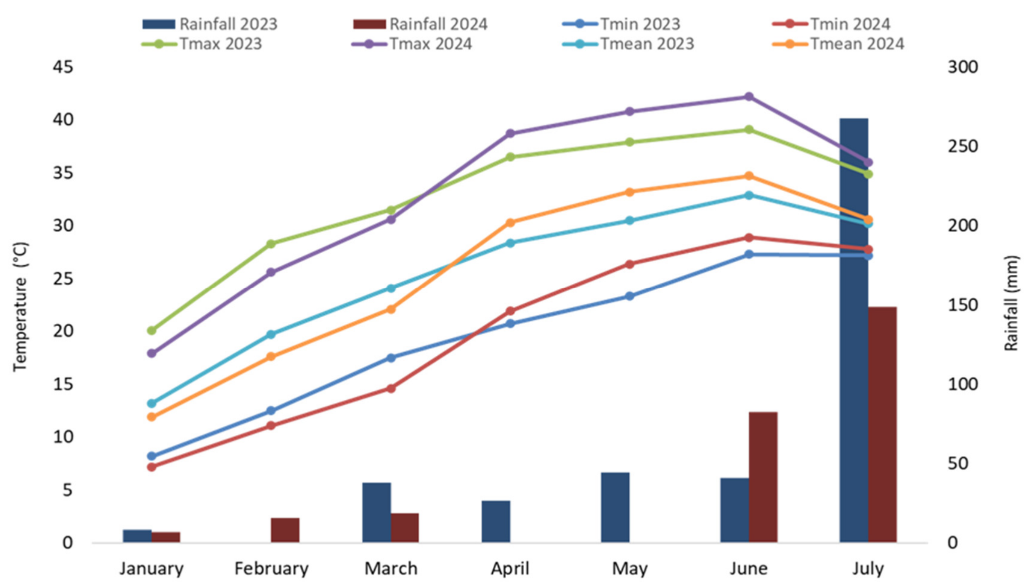

Figure 1. Meteorological data during the study period

Physical attributes

Dry matter content in fruits was estimated on the basis of the difference between initial fruit weight and oven dried fruit weight, and expressed in percentage.

$$\text{Dry matter (\%)} = [(W_i - W_o)/W_i] \times 100 \quad (1)$$

Where, Wi and W_o are initial and oven dried fruit weight (g), respectively.

Post-harvest weight loss (PWL) of fruits was determined on the basis of the difference in initial and final weight of the fruits and expressed in percentage.

$$\text{PWL (\%)} = [(W_i - W_f)/W_i] \times 100 \quad (2)$$

Where, W_i and W_f are initial and final fruit weight (g), respectively.

Firmness of fruits was measured with the digital handheld fruit hardness tester (Lutron FR5120) using 3 mm tip. The maximum force required to insert the tip inside the fruit was recorded and expressed in Newton (N).

Color attributes

Color characteristics of peel and pulp was measured with a color spectrophotometer (3nh-CR8) in the CIE *Lab* space using L^* (lightness), a^* (redness), and b^* (yellowness) coordinates. L^* represents lightness or luminosity, a^* is an indicative of redness and b^* represents the degree of yellowness. The instrument was set up at D65 as illuminate, 10° observer angle and ϕ8mm aperture, and calibrated with standard white and black background. Color attributes were measured at five different spots marked on each fruit and values for L^*, a^* and b^* coordinates were averaged.

Chemical attributes

Soluble solids content (SSC) was determined with the help of handheld digital refractometer and expressed in °Brix. Acidity of fruits was estimated by titration method (0.1N NaOH) using phenolphthalein as an indicator and expressed in percentage citric acid (AOAC 2000). The ratio between SSC and acidity (SSC/acid) was also estimated. Sugar content in the fruit samples was quantified colorimetrically by anthrone method (Yemm and Willis, 1954). The absorbance of the reaction mixture was measured at 630 nm and the sugar content in the sample was quantified with the standard curve of D-glucose and expressed in g $100g^{-1}$. β-carotene content in fruits was spectrophotometrically estimated following the protocol of Biswas *et al*. (2011). Samples were extracted in the chilled acetone followed by the centrifugation for 10 minutes (10000 rpm). Thereafter supernatant was collected in a test tube, and the compound was re-extracted. Pooled supernatant was filtered and the absorbance of the extract was measured at 449 nm wavelength. The content of β-carotene in fruit samples was quantified with the help of the standard curve of β- carotene and expressed in μg g^{-1}.

Sensory attributes

The sensory quality of fruits was determined by using nine-point Hedonic scale (Nicolas *et al*., 2010). A panel of 5 judges was made based on their consistency and reliability of judgment. Panelists were asked to score the samples (9-extremely desirable and 1-extremely undesirable) on the basis of aroma, taste, flavour and overall appearance. The average score of the panelists was considered to assess the sensory quality of fruits at different ripening periods.

Data analysis

Descriptive statistics was used to calculate the mean, standard deviation, range and coefficient of variation for heat unit, firmness, dry matter content, soluble solid contents (SSC), acidity and SSC/acid ratio with respect to the harvesting time. The strength and direction of the relationship between the harvest time and maturity indices was performed using Pearson's correlation coefficient. The analysis of variance (ANOVA) was carried out to assess the significant differences among means of various studied parameters. The mean value was compared using Tukeys' HSD test ($P \leq 0.05$). Principal component analysis (PCA) was done by using XLSTAT statistical software.

Results and Discussion

Analysis of the variation in fruit maturity indicators

In fruit crops heat unit accumulation, fruit firmness, dry matter content, soluble solids content (SSC), acidity and SSC/acid ratio are considered as important maturity indices. Hence an attempt was made to study the range of deviation in maturity indices in relation to harvest time through descriptive statistics. In 'Dashehri', heat unit ranged 1788 - 2256 °days during the period of harvesting (Table 1). Daily accumulation of heat units during fruit maturation was 23.40 °days. Lemos *et al*. (2018) also studied the heat unit accumulation in mango and reported that 3173 heat units are accumulated between flower bud swelling and fruit maturation. Fruit firmness of 'Dashehri' varied from 21.45 to 54.34N during harvest period. It was observed that fruit firmness was narrowly differed at different harvest time. Dry matter content varied from 16.64 to 20.52% during the harvest period. Data clearly demonstrated that dry matter varied marginally at different harvest time.

Soluble solids content (SSC) and SSC/acid ratio demonstrated an increasing trend with the degree of fruit maturation, whereas acidity exhibited a decreasing trend. There was a significant variation in the range of SSC (8.54 - 14.23 °Brix), acidity (0.62 - 1.87%) and SSC/acid ratio (4.40 - 22.41) during fruit maturation of 'Dashehri' indicating a perceptible change in the chemical composition of fruits during ripening.

Heat unit accumulation, fruit firmness, dry matter content, soluble solids content (SSC), acidity and SSC/acid ratio of 'Dashehri' (Table 1) demonstrated low standard deviation (SD) as well as coefficient of variation (CV) at each harvest time indicating low degree of data dispersion and less variability around the mean. It other words, all the six maturity indices may be considered as stable attributes in defining harvest time. Hence it may be construed that heat unit accumulation, fruit firmness, dry matter content, SSC, acidity and SSC/acid ratio are reliable indicator in explaining degree of fruit maturation in 'Dashehri'. Wongmetha *et al*. (2015) also reported that mango fruit should be harvested after physiological maturity when fruit attains the maximum value of firmness, TSS, and minimum acidity level.

Correlation analysis between harvest time and fruit maturity indices demonstrated significant relationship (Table 2). Heat unit, soluble solids content and SSC/acid ratio showed significant positive correlation with the harvest time, whereas fruit firmness, acidity and dry matter content demonstrated significant negative correlation. Data clearly demonstrate that harvest time can be a reliable index in explaining heat unit accumulation, firmness, dry matter content, soluble solids content, acidity and SSC/acid ratio of mango at fruit maturation.

Table 1. Variation analysis of the fruit quality indices of mango var. 'Dashehri'

Attributes	Statistical parameter	Days after full bloom (FAFB)				
		90	95	100	105	110
Heat unit (°days)	Mean	1788.45	1914.55	2036.37	2138.81	2256.45
	SD	11.58	15.74	11.46	12.84	12.14
	Range	1769 - 1795	1891 - 1932	2019 - 2048	2118 - 2152	2239 - 2274
	CV	0.64	0.82	0.56	0.6	0.53
Firmness (N)	Mean	54.34	50.32	43.67	33.62	21.45
	SD	1.76	1.13	0.99	0.87	1.11
	Range	52.14 - 57.34	48.66 - 51.62	42.29 - 45.32	32.65 - 35.37	20.38 - 23.44
	CV	3.23	2.24	2.26	2.58	5.17
Dry matter (%)	Mean	20.52	19.37	18.56	17.78	16.64
	SD	0.42	0.31	0.29	0.28	0.25
	Range	21.24 - 19.88	18.89 - 19.87	18.45 - 19.12	17.53 - 18.11	16.21 - 16.89
	CV	2.04	1.61	1.56	1.57	1.51
SSC (°Brix)	Mean	8.54	10.57	11.38	13.16	14.23
	SD	0.34	0.24	0.32	0.31	0.27
	Range	7.91-9.12	10.12- 10.92	10.89-11.91	12.68-13.59	13.88-14.52
	CV	3.98	2.27	2.81	2.36	1.9
SSC/acid ratio	Mean	4.4	6.75	8.97	15.52	22.41
	SD	0.19	0.21	0.19	0.3	0.37
	Range	4.19-4.93	6.35 - 7.11	8.61-9.15	15.27-16.21	22.03-23.14
	CV	4.32	3.11	2.12	1.93	1.65

SD: Standard deviation; CV: Coefficient of variation

Table 2. Correlation analysis between harvest time and maturity indices of mango (n=150)

Maturity index	Pearson correlation coefficient (r)	Standard error	P-value	Significance level
Heat unit	0.988	15.94	<0.0001	0.01
Firmness	-0.978	0.352	<0.0001	0.01
Dry matter	-0.967	0.145	<0.0001	0.01
SSC	0.958	0.277	<0.0001	0.01
Acidity	-0.972	0.061	<0.0001	0.01
SSC/acid ratio	0.936	0.204	<0.0001	0.01

DAFB: Days after full bloom; SD: Standard deviation; CV: Coefficient of variation

Color attributes

Consumers invariably prefer those mango fruits which possess peel color because they relate it to the characteristic taste and flavor of the well-ripe fruit (Subedi *et al.*, 2007). Changes in the peel and pulp color attributes (*L*, *a** and *b**) of 'Dashehri' (Figure 2) were studied during the ripening period. The peel *L* value varied differently with the harvest time during the ripening. Fruits harvested early demonstrated lower *L* value which indicated the appearance of dull peel color. On the other hand, there was a gradual increase in the *L* value during ripening period when 'Dashehri' was harvested between 95-100 DAFB. In late harvested fruits, there was a sharp decline in the *L* value after 6-8 days of ripening period. The *a** and *b** color coordinates of peel increased gradually during the ripening process. However, the intensity of both the color coordinates increased with the delay in harvesting indicating the manifestation of yellow coloration due to the breakdown of chlorophyll and development of carotenoids. Early harvested fruits exhibited lower *a** and *b** values representing suboptimal color breakdown. Gianguzzi *et al.* (2021) also reported that the most noticeable change in the mango at maturation is the depletion in green color collaborated with the enhancement in *a** value due to an increase in the carotenoid content. Kapoor *et al.* (2022) reported that the regulation of carotenoid biosynthetic pathway during fruit ripening is mediate through cellular signaling by plant growth hormones, enzymes and environmental stimuli such as light.

Changes in the *L*, *a** and *b** color attributes of pulp in relation to harvest time and ripening period are presented in Figure 2. There was a gradual decline in *L* values during the ripening period irrespective of harvest time. Reduction in the *L* values of pulp during the ripening process may be attributed to the development of color pigments such as carotenoids and concomitant decrease in the luminosity. Fruits harvested at different dates showed significant variation in *a** and *b** color attributes of pulp which are indicative of the intensity of red and yellow color, respectively. The intensity of yellow coloration in the pulp of 'Dashehri' was moderately high as it was evident with the higher *b** value. It was observed that during the ripening process the relative increase in the *b** value was more than *a** values. The *a** and *b** value of early harvested fruits was significantly less than the fruits harvested later. In early harvested fruits, *a** value increased by ~7 times during the ripening period, whereas fruits harvested 95-100 DAFB showed ~6 times increase. Fruits harvested later, demonstrate ~3 times increase in the *a** value. In 'Dashehri' temporal increase in *a** value during the ripening period was relatively less indicating low intensity of red coloration in the pulp harvesting. It was evident that late harvested fruits (110 DAFB) attained *a** maxima after 4 days of ripening period followed by gradual reduction. On the other hand, fruits harvested between 95-100 DAFB showed continuous increase in *a** during ripening and attained maxima after 8-10 days. This indicates sequential progression in the ripening process as well as the extension in the shelf life of fruits. Variation in the *b** color coordinate (yellowness) of fruits harvested at different dates also demonstrated the pattern of *a** during the ripening process. However, the values of *b** coordinate were significantly high. The average value of *b** color coordinate was ~3 times higher than the value of *a** color coordinate. Data indicated that fruit harvested later attained *b** maxima after 4 days of ripening period followed by gradual reduction. On the other hand, fruits harvested between 95-100 DAFB showed continuous increase in *b** during ripening and attained maxima after 8-10 days indicating gradual advancement in the ripening process which facilitates extended shelf life of fruits. Kour *et al.* (2018) also reported an increase in pulp color attributes of 'Dashehri' with the delay in harvesting period. They further reported that the rate of ripening was rapid in late harvested fruits as compared to early harvested fruits.

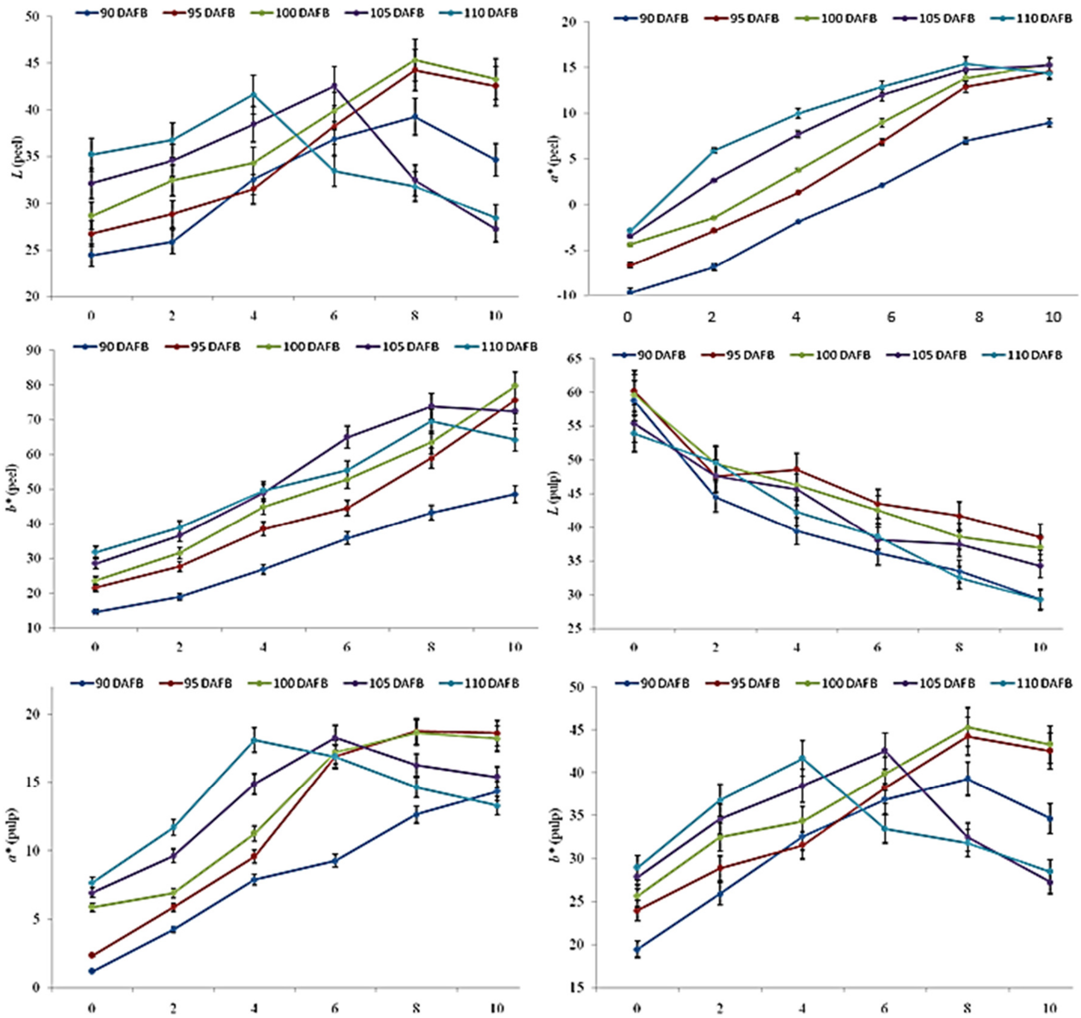

Figure 2. Color attributes of mango variety 'Dashehri' during ripening

Physical attributes

A significant change in the fruit firmness, post-harvest weight loss (PWL) and dry matter content was observed during the ripening period (Figure 3). Fruit firmness decreased with the progression of fruit ripening and minimum firmness was recorded at the end of the ripening period. Similar trend was also observed in dry matter content. On the other hand, post-harvest weight loss increased with the progression of the ripening period and maximum loss in fruit weight was recorded at the end of the ripening period. Maximum reduction in fruit firmness (~80%) was observed when fruits were harvested early, whereas minimum reduction in fruit firmness (~71%) was observed when fruits were harvested between 95-110 DAFB. The reduction in the fruit firmness during ripening period was also significantly high when harvesting was delayed. It can be inferred that at harvesting a fruit firmness range of 43.67 – 50.32 N may be optimized for 'Dashehri' (Table 1). Reduction in fruit firmness during ripening is associated with the softening of peel and pulp which is brought about by the enzyme-induced cell wall disassembly. Degradation in cell wall is mediated with the activity of polygalacturonase, pectin methylesterase, pectate lyase, β-galactosidase and cellulose enzymes which are encoded by ripening related genes (Goulao and Oliveira, 2008; Paniagua *et al*., 2014).

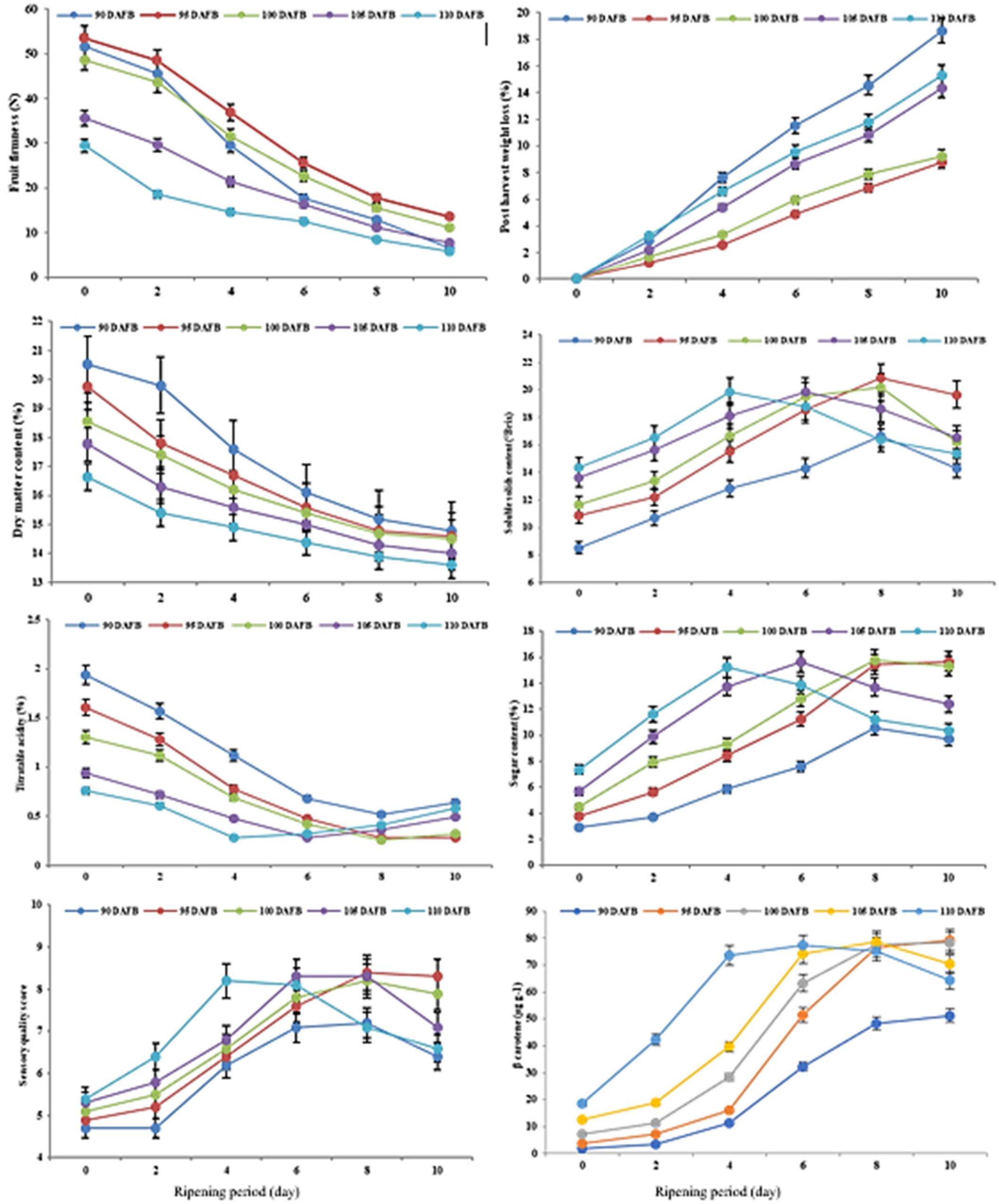

Figure 3. Changes in physico-chemical attributes of mango var. 'Dashehri' during ripening period
DAFB: Days after full bloom

Physiological weight loss (PWL) of fruits increased with the progression of fruit ripening (Figure 3). The PWL was significantly high (>16%) when fruits were harvested at early maturation stages (90 DAFB). It was observed that harvesting of fruits between 95 - 110 DAFB caused minimal PWL (~9%) even after 10 days of ripening period. PWL was relatively more when harvesting of fruits was delayed. Our findings are in agreement with the results of Dick et al (2009) who reported that late harvesting of mango fruits enhances

PWL. Similar result was also reported in apple and plum (Guerra and Casquero, 2008; Musacchi and Serra, 2018).

Dry matter content demonstrated a linear decline with the advancement in the ripening period (Figure 3). However, the rate of decline in the dry matter content during the ripening period was higher in those fruits which were harvested late. Dry matter content decreased by ~17% and ~21%, respectively in early and late harvested fruits of 'Dashehri'. Fishman and Genard (1998) observed that dry matter is a very important quality index of mango, as it is linked to the carbohydrate content in the fruit, which imparts typical taste to fruit. It can be deduced that at harvesting the range of dry matter content in 'Dashehri' should be 18.56 - 19.35% for ensuring best fruit quality (Table 1).

Chemical attributes

Soluble solids content (SSC) showed a gradual increase with the ripening process (Figure 3). It is evident that early harvested fruits of 'Dashehri' (190 DAFB) exhibited relatively low SSC during ripening. On the other hand, fruits harvested from second maturation stage onwards attained maximum level of SSC during the ripening process. However, there was a temporal variation in attainment of SSC maxima. Fruits harvested between 95-100 DAFB showed gradual increase in SSC and maximal value was attained after 8 days of ripening period. On the other hand, late harvested fruits attained maximal SSC just after 4 days of ripening period followed by the gradual reduction. It can be inferred that for ensuring best fruit quality of 'Dashehri', optimized range of SSC at harvest should be 10.57 – 11.38 °Brix (Table 1).

Changes in the sugar content of mango during the ripening process followed the trend of SSC. In early harvested fruits sugar content was significantly lower than the fruits harvested between 95-100 DAFB. Fruits harvested between 95-100 DAFB showed gradual increase in sugar content and maximal value was attained after 8 days of ripening period (Figure 3). However, in late harvested fruits (110 DAFB) maximal sugar content was attained even after 4 days of ripening period.

Acid content in fruits was marked by gradual reduction during the ripening period. It was evident that the acid content in the early harvested fruits was significantly higher (2 times) than the late harvested fruits (Figure 3). With the ripening process, acid content reduced by about 4-5 times. The reduction in acid content was linked with the concomitantly increase in the SSC/acid ratio. Hence, it can be deduced that at harvesting the range of SSC/acid ratio in Dashehri should be 6.75 - 8.97 for obtaining quality fruit (Table 1). Dick *et al*. (2009) also reported that mango var. Kent harvested at 100 days after flowering developed better sugar content and pulp color than those of the fruit harvested earlier. Accumulation of sugar content in mango is associated with the enzymatic breakdown of starch. Castrillo *et al*. (1992) observed that the activity of sucrose phosphate synthase, amylase and acid invertase increased significantly during ripening which was linked with increase in sugar content. Low sugar content in early harvested fruits may be due to lower activity of starch degrading enzymes.

β-carotene is one of the most vital biochemical compositions of mango as it reflects the vitamin content and nutritional value of fruits. In early harvested fruits of 'Dashehri' β-carotene content was significantly low throughout ripening period (Figure 3). In such fruits, β-carotene content was ~40% lower than the fruits harvested later. Fruits harvested between 95-100 DAFB showed gradual increase in β-carotene content and maximal value was attained after 8 days of ripening period. On the other hand, in late harvested fruits, highest β-carotene content was attained after 6 days of ripening period followed by the gradual reduction. β-carotene is the predominant carotenoid in mango which determine the bioavailability and stability of fruit color as well as nutritional properties. The biosynthesis of β-carotene is regulated by genes. Yungyuen *et al.* (2021) studied the expression of carotenoid biosynthesis genes and the accumulation of pigment. They reported that in mango peel and pulp, the expression of carotenoid biosynthesis genes (*MiPSY*, *MiZDS*, *MiLCYb*, and *MiZEP*) rapidly increased during fruit maturation and ripening. Poor exhibition of peel and pulp coloration in early harvested mango fruits might be due to the low expression of carotenoid biosynthesis genes.

Sensory quality (SQ) of fruits is one of the most important attributes for ascertaining consumer preference as it takes into account the color, texture, flavor, appearance and overall quality. Sensory quality of 'Dashehri' improved significantly throughout the ripening period when fruits were harvested between 95-100 DAFB (Figure 3). On the other hand, fruits harvested late exhibited significant increase in sensory quality only up to 4 days of ripening period thereafter a significant reduction in the SQ was observed. Early harvested fruits demonstrated gradual increase in the SQ; however, their relative scores were less. The increase in sensory quality score during ripening process is attributed to appearance of color, reduction in fruit firmness and acid content and concomitant increase in SSC and sugars. Sensory quality of fruits was also considered as an indicator of shelf life. It was evident that harvesting of 'Dashehri' between 95-100 DAFB demonstrated relatively longer shelf life (10 days). On the other hand, early (90 DAFB) and late harvested 'Dashehri' (105-110 days) demonstrated short shelf life due to high rate of PWL and low sensory quality. Saranwong *et al.* (2004) also observed that mangoes harvested at later stage ripened well and lead to better eating quality than the mangoes harvested at early stage. Kour *et al.* (2018) also observed enhanced sensory quality of 'Dashehri' when fruits were harvested at later than the fruits harvested at early stage.

Jelly seed is considered as one of the major physiological disorders in commercially important mango varieties in India as it severely affects the fruit quality and market value of 'Dashehri' (Krishna *et al*., 2020). It was evident that the incidence of jelly seed was pronounced in late harvested fruits (Figure 4). Data revealed that late harvested fruits (110 DAFB) had high incidence of jelly seed (>17%), whereas early harvested fruit were free from jelly seed incidence. High incidence of jelly seed in late harvested fruits might be associated with the enhanced respiration rate and seed activity due to its recalcitrant nature (Krishna *et al*. 2020). Harvesting time exhibited significant positive correlation with the jelly seed incidence (0.887), hence in order to ensure quality fruit production, harvesting should be performed between 95-100 DAFB. Singh *et al*. (2011) also observed jelly seed disorder in 'Dashehri', 'Amrapali', 'Langra' and 'Bombay Green' and reported that the intensity of jelly seed disorder increased with fruit maturity and storage time. Shivashankar *et al*. (2019) reported that precocious behavior of seed germination and enhanced activity of pectinolytic enzymes in mango pulp triggers jelly seed incidence.

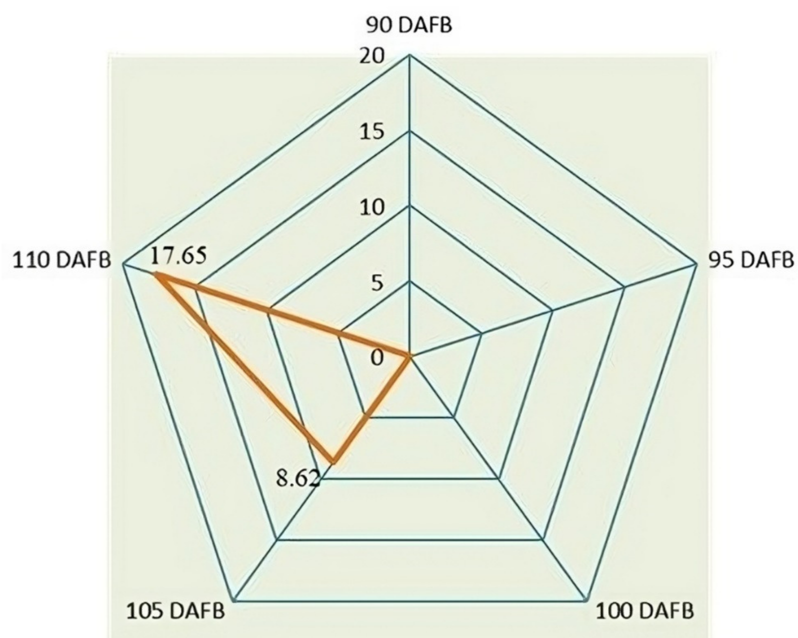

Figure 4. Influence of harvest time on jelly seed incidence in mango var. 'Dashehri'
DAFB: Days after full bloom

Principal component analysis

To decipher the relationship among harvest time and fruit quality attributes of 'Dashehri', PCA was performed (Figure 5).

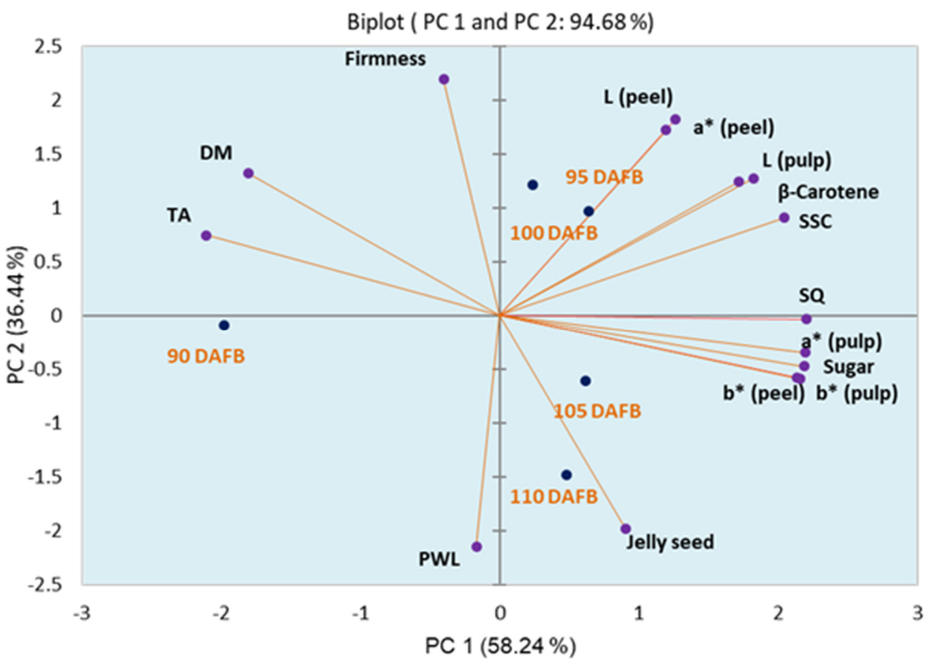

Figure 5. Principal Component Analysis (PCA)–biplot based on the variance in fruit quality attributes under different harvest time of mango var. 'Dashehri'

The PCA results illustrated that first two principal components (PC 1 and PC 2) accounted for more than 94% of total variation. The observations on PCA biplot (harvest time) clearly demonstrated spatial variation. Harvesting of fruits at 95 DAFB and 100 DAFB exhibited their proximity, whereas 110 DAFB was distantly positioned along the PC 2 axis. 90 DAFB and 105 DAFB were also separately placed along the PC 1 axis. It is evident from PCA that harvest time has significant impact on fruit quality attributes. Fruit quality attributes (variables) exhibited spatial variation on PCA biplot. Sensory quality (SQ), soluble solids content (SSC), sugar content, color attributes and β-carotene content have large positive loadings on PC1. Therefore, this component emphasizes vital quality attributes of mango. On the other hand, post-harvest weight loss (PWL) and jelly seed (JS) incidence have large negative loading on PC 2 indicating the undesirable attributes of fruit quality. The bi-plot exemplifies the proximity of SQ, SSC, sugar content, color attributes and β-carotene content, and farness of jelly seed and PWL with of 95 DAFB and 100 DAFB signifying the optimized time of harvesting of 'Dashehri'. The bi-plot also demonstrates the proximity of jelly seed and PWL with late harvested fruits (110 DAFB) indicating the negative impact of late fruit harvest. It is also evident that fruit firmness and dry matter content were negatively associated with jelly seed incidence and PWL demonstrating their significance in determining optimum harvest time.

PCA is widely used to examine the interrelations among a set of variables by reducing dimensionality of a dataset. Nowicka *et al.* (2019) identified the most the attractive peach cultivators on the basis of fruit quality variables using PCA model. Weber *et al.* (2024) also ascertained a relationship between quality attributes and fruit maturation stages of cape gooseberry using PCA.

Conclusions

Harvesting of fruits at optimum maturity is the key to ensure better fruit quality and market value. Results clearly exhibited that harvest time is a reliable index in explaining fruit firmness, dry matter content, soluble solids content, acidity and SSC/acid ratio of 'Dashehri' at maturation. In subtropical region of north India, 'Dashehri' should be harvested between 95-100 DAFB in order to ensure better fruit quality, enhanced shelf-life, minimal post-harvest weight loss and jelly-seed free fruits. Since soluble solids content, acid content, fruit firmness, dry matter, heat unit accumulation and SSC/acid ratio are considered important maturity indices for mango, we quantified their optimal range for 'Dashehri' at harvesting under subtropical climatic conditions of north India. Moreover, optimal range of heat unit accumulation in 'Dashehri' (1914 - 2036 °days) was also quantified. Optimization of harvest time for mango in subtropical region of north India will have significant impact on quality fruit production and market value of mango.

Authors' Contributions

KK: Conceptualization; Writing- original draft; Editing. DK: Investigation. KKS: Methodology. SKD: Writing- review. DS: Data analysis. AS: Editing. NSS; Investigation. PLS; Editing; DK: Methodology.

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

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

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