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Physicochemical changes during the progressive ripening of mango (*Mangifera indica* L.) cv. Pusa Manohari under storage conditions

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ABSTRACT

Aim: *Pusa Manohari, a cultivar developed by the Indian Agricultural Research Institute (IARI), New Delhi, lacks comprehensive characterization regarding its physicochemical transformations during postharvest ripening under varied storage parameters. Consequently, this investigation was undertaken to elucidate the ripening kinetics of Pusa Manohari across a spectrum of storage conditions.*

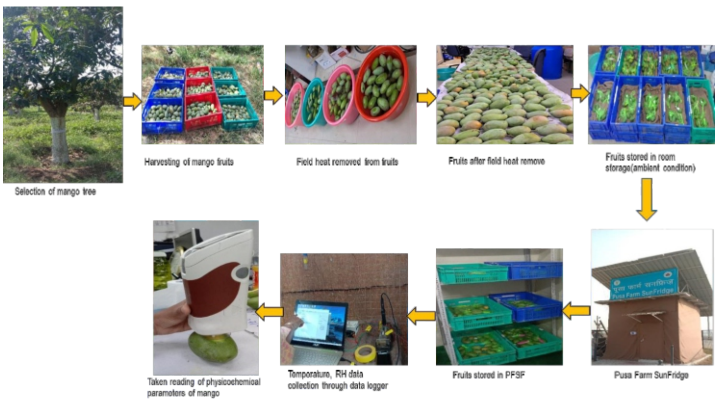
Methodology: *Mature Mangifera indica cv. Pusa Manohari fruits, harvested 103 days after flowering (DAF) from 20-year-old trees at the Division of Agricultural Engineering, ICAR-IARI, New Delhi, were subjected to postharvest storage under room storage (RS) and Pusa Farm SunFridge (PFSF) conditions.*

Results: *Total soluble solids (TSS) increased from 9 to 20 °Brix in mangoes stored under room storage (ambient conditions), and from 9 to 17 °Brix in those stored within a Pusa Farm SunFridge (PFSF). Fruit firmness exhibited a decline from 96 to 16 N over 18 days in ambient storage, and from 96 to 36 N over 35 days in PFSF. The respiration rate of room-stored mangoes initially decreased, followed by a subsequent increase after 5 days, reaching 306 mg CO_2 kg^{-1} hr^{-1} at 18 days. Conversely, mangoes stored in PFSF demonstrated a comparatively attenuated increase in respiration rate, attributable to the lower storage temperature.*

Interpretation: *This investigation elucidates the comprehensive physicochemical alterations occurring in mango fruit during ripening under controlled, variable temperature regimes.*

Keywords: *Physicochemical changes, mango fruit, storage.*

Graphical Abstract



Introduction

Mango is a major fruit crop in India, featuring many prominent varieties grown across different regions. As a climacteric fruit, mangoes experience a notable increase in respiration rate during the ripening process. It is crucial to enhance their post-harvest shelf life while preserving the quality of the fruit, given its significant value. 'Pusa Manohari' is a mango variety developed by the Indian Agricultural Research institute, New Delhi. 'Pusa Manohari,' a hybrid of 'Amrapali' and 'Lal Sundari,' is medium-sized (approximately 223-250 g) with a greenish-yellow peel and reddish shoulders. Its pulp is yellowish-orange, less fibrous, and has a total soluble solids (TSS) content of around 20-22 °Brix (Jayachandran and M. L. Meghwal, 2022) However, like many mango varieties, the 'Pusa Manohari' faces the challenge of a short shelf life at ambient temperatures. This rapid ripening process, while contributing to its flavor profile, limits its distribution and marketability (Waskar *et al.,* 1999). To address this, various post-harvest techniques have been explored, with temperature control emerging as a crucial factor. As established by research, lowering the temperature significantly slows down the metabolic processes within the fruit, effectively delaying ripening and extending shelf life. Pre-cooling to a range of 10-13°C has proven particularly beneficial, especially in hot climates or when transportation delays are anticipated (Hidalgo *et al.,* 1997). Refrigeration, as a broader technology, is widely employed to mitigate post-harvest deterioration across a spectrum of horticultural products. Despite the growing popularity of 'Pusa Manohari', there remains a notable gap in our understanding of its specific

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physicochemical changes during ripening, especially under varying temperature conditions. Consequently, a web initiative was undertaken to meticulously monitor these changes. This study aims to provide a comprehensive analysis of the ripening process in 'Pusa Manohari' mangoes, focusing on the dynamic interplay of temperature and physicochemical transformations. By elucidating these processes, we can develop optimized post-harvest handling strategies that ensure the preservation of this valuable mango variety's quality and extend its availability to consumers. This research allows for a detailed understanding of the progression of physicochemical changes in Pusa Manohari mangoes during progressive ripening.

Material and Methods

Fruit material

The cvs. 'Pusa Manohari' mangoes were selected for this study. Five mango trees of each cultivar were selected with good vigor and similar crown size, approximately 20 years of age, located at ICAR-Indian Agricultural Research Institute, New Delhi, and labeled as 'experimental trees'.

Fruit harvesting and initial preparation

The first sampling (initial harvest) was conducted 103 days after flowering (13 June 2023) for Pusa Manhori. At the initial stage, the fruits had fully developed cheeks and outgrown shoulders. Mango fruits were harvested in the early morning hours using a mango fruit picker (a long wooden stick with a blade and shade net bag fixed at the end) from selected experimental trees; the stems were trimmed to 2 cm, and then fruits were transported immediately to the laboratory. In the laboratory, fruits were immersed in water (27 ± 5 °C) for an hour to rapidly remove field heat and achieve ambient temperature. Afterwards, fruits were sorted for uniform size and freedom from mechanical damage and air-dried for 20 minutes. Each mango was then labeled, weighed using an analytical balance (SF-400C digital scale, Baijnath Premnath, India) and randomly assigned to various experiments described in the following sections.

Collection of samples

To study the physico-chemical changes during the progressive ripening of mango, 'Pusa Manohari' fruits (6 replications) were harvested and kept in room storage (RS) storage and Pusa Farm SunFridge (PFSF). Six mangoes were taken out from the store every 4-5 days to study the maturity characteristics during storage. The total number of Pusa Manohari mangoes studied in storage experiments was 200, respectively.

Storage conditions

We stored mangoes in two places first was mango stored in room storage (30 ± 5 °C and 50 ± 5% RH) and Second was Pusa Farm SunFridge (PFSF) (12 ± 5 °C and 80-85 % RH). The temperature and humidity of the ambient and PFSF were monitored using data loggers to record wet and dry bulb temperatures as described by Chopra et al. (2015).

Determination of physicochemical analysis/fruit quality attributes

The total soluble solids (TSS) were determined by a hand refractometer (Erma, Tokyo, Japan) having a range of 0 to 32 °Brix and a resolution of 0.2 °Brix (Karuna et al., 2015).

Unripe fruit juice was extracted by crushing the middle part of mango fruit using a pestle and mortar.

Ripe fruit juice was extracted using squeezed mango pulp. Around 2-3 drops of clear juice were used, and observations were expressed as °Brix at 30 ± 5 °C.

Fruit firmness was measured at the middle positions of the fruit. A penetrometer (Model GY-3, Erma instrument, India) with a capacity of up to 12 kg/cm^2, fitted with a 5-mm dia probe, was used. The probe was allowed to penetrate the peel to a depth of 1.5 cm, and the corresponding force (N) required to penetrate this depth was determined (Jha et al., 2010).

Mango fruit respiration rate (RR) was measured using a handheld infrared gas analyzer (CEM GD-3803, CEM Instruments, India) with a linear range of 0 to 9999 $\mu L\ L^{-1}\ CO_2$. A mango and the CO_2 analyzer were both placed into a transparent 8-L plastic airtight container, and readings were taken at 7-minute intervals for 15 minutes. The CO_2 emission rate was calculated as $mg\ CO_2 kg^{-1}\ hr^{-1}$.

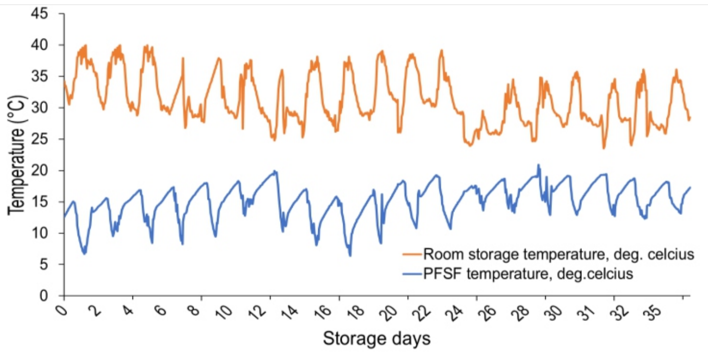
The pulp color and peel color of the mango were measured by using a colorimeter (AMT 599 Mini scan XE plus, USA). Before measuring the color of the fruit, the colorimeter was calibrated using white and black calibration tiles provided with the instrument. The color values were recorded in the form of L*, a*, and b*. L* indicates the lightness coefficient and ranges from 0-100 (black to white); a* and b* indicate color ranges from green to red and blue to yellow as the value changes from negative to positive. The color was measured at the equator of each fruit.

Data processing

There were three replications for each experiment, with each replication representing a differing source tree. For each replication, we determined the rate of change for each parameter following harvest using a linear curve fit. For the respiration rate, we fitted the respiratory data to a 3rd degree polynomial identified the day when the maximum respiration rate was reached, and determined the days from harvest. If the maximum respiration rate appeared to be between analysis dates, we extrapolated values. The data in the figures represent the average of the three replications.

Statistical analysis

The change in physiochemical parameters (i.e., TSS, firmness, color, and the day of reaching maximum respiration rate) for the experiments was used for statistical analysis. Univariate analysis was carried out using a statistical package IBM SPSS Statistics V20 (IBM Corp., Armonk, NY), and Tukey's Honest Significant Difference (HSD) test was used to compare treatments at $p = 0.05$.



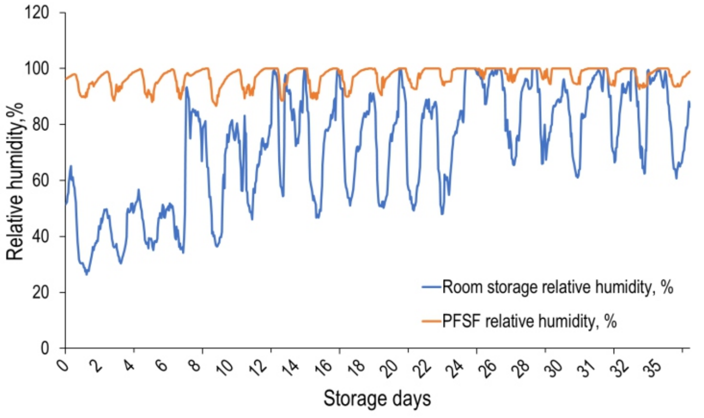


Figure 1. Temperature (upper graph) and relative humidity (lower graph) in the Pusa Farm SunFridge (FSF) refrigerated storage and in the laboratory for the duration of the experiments (13 June to 1 July 2023) in New Delhi, India. Average FSF temperature and RH were 15.7 ± 3.1 °C and 97.1 ± 3.2%, respectively; average ambient temperature and RH were 31.0 ± 3.8 °C and 76.0 ± 20.2%, respectively.

Result and Discussion

Total soluble solids

Total Soluble Solids (TSS) in mangoes primarily comprise soluble sugars, organic acids, vitamins, and pigments. Fig. 1 illustrates the changes in TSS of mangoes (Pusa Manohari cultivar) during ripening under two different storage conditions: room storage and Pusa Farm SunFridge (PFSF). The rate of TSS increase was faster for mangoes stored at room temperature compared to those stored in PFSF. Specifically, mangoes stored at room temperature exhibited an increase in TSS from 9 to 20 °Brix, while those stored in PFSF showed an increase from 9 to 17 °Brix (Table 1, Figure 2). The slower rate of TSS increase in mangoes stored in PFSF is attributed to the lower storage temperature, which slows down the ripening process (Ayele and Bayleyegn, 2017).

The rate of increase of TSS in 'Pusa Manohari' stored at lower temperatures in the PFSF was significantly lower than that of mangoes stored in ambient. The use of low temperatures to slow ripening by metabolic suppression is well-known and constitutes a common commercial practice (Ayele et al., 2012, Karithi, 2013, Hailu, 2016).

An increase in TSS is primarily due to the hydrolysis of starch into soluble sugars, including sucrose, glucose, and fructose. Ripe mangoes with a TSS of 18 to 22 °Brix are generally considered good to excellent by consumers (Markoo et al., 2019). However, reported TSS ranges in various studies vary widely, from as low as 8 °Brix to as high as 25 °Brix (Cosme et al., 2017; Gill et al., 2017; Begum et al., 2023; Jha et al., 2010). These variations reflect the diverse preferences and quality standards associated with mangoes across different regions and consumer groups.

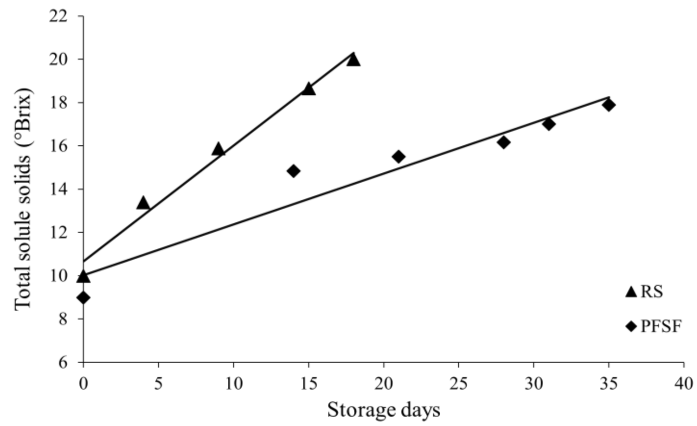


Figure. 2 Changes in total soluble solids of mango cv. Pusa Manohari during the progression of ripening under room storage and Pusa Farm SunFridge.

Fruit Firmness

Fruit firmness is primarily determined by cell wall composition, including moisture content, cellulose, hemicellulose, pectin, lignin, and glycoproteins. It is a crucial maturity/quality indicator in mangoes. Mango firmness can vary across the fruit. At harvest, the top portion is generally firmer than the bottom (Jha et al., 2010). The firmness of stored mangoes of 'Pusa Manohari' declined over the study period. Mango stored in room storage showed a faster decrease in firmness compared to PFSF stored mango. Firmness of mango stored in room storage decreased from 96 to 16 N over 18 days, while mango stored in PFSF showed a decrease in firmness from 96 to 36 N over 35 days (Table 1, Fig. 3). Reported firmness values in literature vary widely (110-19 N) across studies (Cosme et al., 2017; Gill et al., 2017; Begum et al., 2023). The firmness loss reflects ripening processes, such as cell wall degradation and softening of tissues (Cosme et al., 2017; Begum et al., 2023). During maturation and ripening, mangoes undergo physical and biochemical changes, including cell wall hydration and increased intercellular spaces. Enzymes catalyze the breakdown of starch and non-starch components (cellulose, hemicellulose, pectin, lignin), contributing to fruit softening. (Cosme et al., 2017; Schouten et al., 2018).

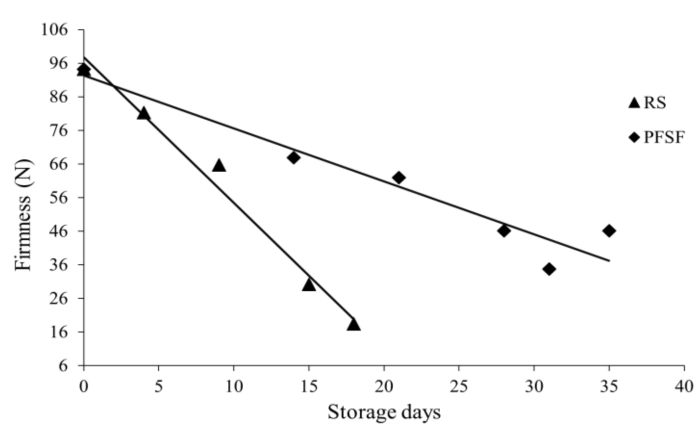


Figure. 3 Changes in firmness of mango cv. Pusa Manohari during the progression of ripening under room storage and Pusa Farm SunFridge.

Table 1. Evaluation of physicochemical changes during varying storage conditions

Variety	Storage condition	Storage days	TSS, ºBrix	Firmness, N	L* (Pulp color)	a* (Pulp color)	b* (Pulp color)	L* (Peel color)	a* (Peel color)	b* (Peel color)	RR, mg CO_2 $kg^{-1}hr^{-1}$
Pusa Manohari	RS	0	9±0.12	94.25±0.37	80.05±0.56	-4.69±0.68	40.74±0.92	51.18±0.67	-15.52±1.01	25.20±2.56	194.42±11.90
	RS	4	10±0.14	81.26±1.78	67.26±0.67	-10.5±0.87	36.09±0.49	48.38±0.90	-16.10±0.97	28.29±1.23	200.21±9.45
	RS	9	16±0.15	65.76±0.41	81.06±0.78	-0.46±0.36	52.19±0.76	50.34±0.65	-13.27±1.04	22.70±1.67	184.68±10.45
	RS	15	19±0.12	30.16±0.45	49.08±0.34	6.49±0.67	47.59±0.86	50.64±0.85	-13.11±0.59	38.97±0.67	278.55±10.67
	RS	18	20±0.18	18.43±0.34	59.79±0.23	12.50±0.63	51.73±0.34	49.42±1.20	-7.65±0.78	27.83±0.45	325.89±10.98
	PFSF	0	9±0.16	94.25±0.56	80.05±0.14	-4.69±0.08	40.74±0.56	51.18±1.45	-15.52±0.80	25.20±0.88	194.42±11.45
	PFSF	14	15±0.20	67.86±0.89	77.44±0.67	-1.18±0.65	43.14±0.45	51.11±0.32	-14.55±0.96	28.53±0.43	100.89±12.56
	PFSF	21	16±0.16	61.99±1.23	78.23±0.45	2.35±0.34	50.76±0.32	47.85±0.56	-13.70±1.07	29.89±0.56	328.44±15.89
	PFSF	28	16±0.21	46.08±0.45	74.55±0.37	5.49±0.15	56.62±0.19	49.35±0.43	-10.34±0.49	31.80±0.67	287.99±13.78
	PFSF	31	17±0.20	34.77±0.75	69.85±0.56	8.13±0.19	56.06±0.49	52.46±0.78	-12.99±0.67	32.31±0.87	257.00±10.45
	PFSF	35	18±0.18	32.87±0.37	73.69±0.67	5.83±0.56	57.14±0.38	50.40±0.83	-15.97±0.87	35.22±0.70	347.10±11.47

Data represented in the Mean ± standard deviation

Respiration rate

The respiration rate reflects the rate of sugar and stored resource utilization within the fruit and significantly influences fruit physiology. Fruit respiration is crucial for various physiological processes, including development, ripening, enzyme synthesis, pigment formation, aroma and flavor development, and the loss of astringency. The respiration rate of mangoes stored at room temperature initially decreased; however, after 5 days, it began to increase. After 18 days of storage, the respiration rate had risen to 306 mg CO_2 kg^{-1} hr^{-1} (Table 1, Fig. 4). In contrast, mangoes stored in PFSF experienced a slower increase in respiration rate compared to those stored at room temperature, likely due to the lower storage temperature. This indicated that mangoes stored at low temperatures have a slower rate of increase in respiration rate than mangoes stored at room storage. Previous studies have reported a wide range of RR values in mangoes, from 5.37 to 23.77 ml CO_2 kg^{-1} hr^{-1} (Begum et al., 2023), 248.72 to 348.38 mg CO_2 kg^{-1} hr^{-1}(Karuna et al., 2017) and 36.92 to 74.24 mg CO_2 kg^{-1} hr^{-1} (Cosme et al., 2017), highlighting the variability in RR across cultivars and experimental conditions.

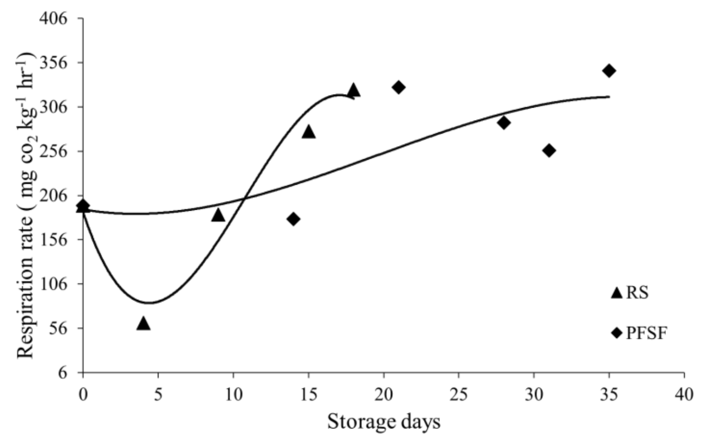


Figure. 4 Changes in respiration rate of mango cv. Pusa Manohari during the progression of ripening under room storage and Pusa Farm SunFridge.

Peel and pulp color

The change in peel and pulp color of mango was evaluated for L*, a*, b* parameters (Table 1, Fig. 5). Mango stored in PFSF and room storage it was shown that there are no changes happened in L* value of peel color (Fig.5.a). L* value of the pulp of mango was stored in PFSF and room storage was decreased over storage days but the rate of decreased in L* value was faster in room storage (80 to 55) compared to PFSF (80 to 75) storage. The a* value of the pulp of PFSF stored mangoes increased slowly from -5 to 5 and a* value of the pulp of room storage mangoes increased faster (9 to 10) compared to PFSF mangoes. The a* value (-16 to -10) of the peel of mango stored in PFSF increased slowly over storage days, a* value of pulp of mango stored in room storage there is no changes (Fig. 5.b).

The rate of increase in b* value of the pulp color was higher the peel color of the mango as shown in fig. 5.C. The b* value of the pulp color of the mango stored in room storage was increased from 40 to 50 over 35 days, and b* value of the peel color of the mango was 25 to 30 over 18 days. The b* value of the pulp color of the mango stored in PFSF was increased from 40 to 55 over 35 days, and b* value of the peel color of the mango was 25 to 30 over 18 days. The change in color of mango reflects the synthesis of carotenoid and other pigments and the concurrent degradation of chlorophyll (Gill et al., 2015; Nambi et al., 2015; Kour et al. 2018; Begum et al., 2023).

A study conducted by (Nambi et al., 2015) demonstrated that the maturation of Alphonso and Banganapalli mangoes was accompanied by a decrease in pulp lightness (L*), attributable to the internal color transition from white to yellow. Specifically, the L* value of the pulp decreased from 76.96 to 56.38 for Alphonso mangoes and from 91.24 to 73.28 for Banganapalli mangoes. In contrast, the L* value of the peel increased, rising from 49.21 to 64.55 for Alphonso mangoes and from 51.70 to 70.51 for Banganapalli mangoes. Peel a* values significantly increased during maturation, rising from -9.80 to 29.07 in Alphonso and from -10.95 to 16.45 in Banganapalli mangoes. Similarly, peel b* values also exhibited a substantial increase, progressing from 32.46 to 62.15 in Alphonso and from 27.74 to 48.81 in Banganapalli.

kour et al., 2018 reported that the L* value for the pulp of Dussehri mango decreased from 80.16 to 63.196. In contrast, the a* value increased from 12.98 to 22.29, and the b* value rose from 48.68 to 65.81.

Similarly, Begum et al. 2023 observed that for the Gopalbhog mango, the L* value of the peel diminished from 55.82 to 44.42. The a* value of the peel increased from -10.75 to 2.64, while the b* value went up from 27.10 to 32.42.

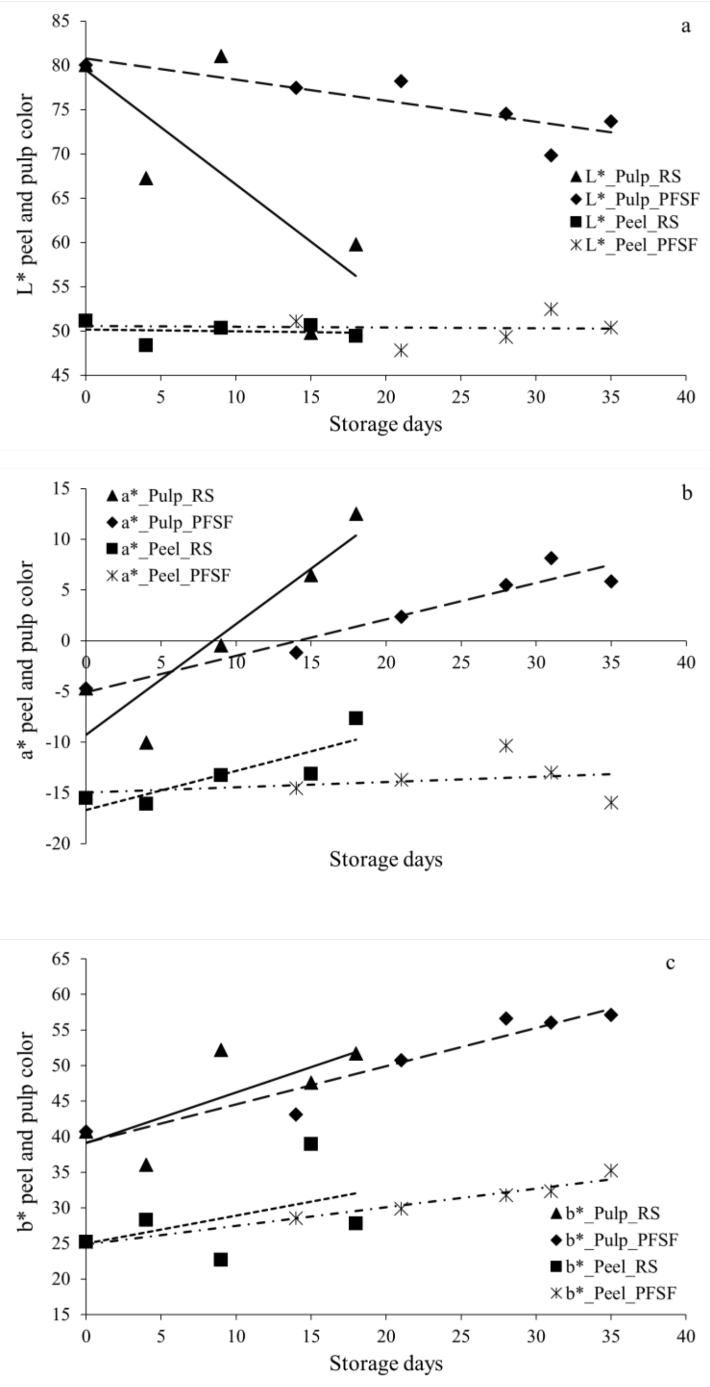


Figure. 5 Changes in fruit color (a) L* peel and pulp color, (b) a* peel and pulp color, (c) b* peel and pulp color of mango cv. Pusa Manohari during the progression of ripening under room storage and Pusa Farm SunFridge.

Conclusion

This study investigated the impact of varying temperature conditions on the physicochemical changes during the progressive ripening of mango (Mangifera indica L.) cv. Pusa Manohari, specifically examining total soluble solids (TSS), respiration rate, firmness, and color. Significant variations in these quality parameters were observed across different storage durations within the PFSF and room storage. The results demonstrate a clear temperature-dependent ripening dynamic. Mangoes stored at lower temperatures exhibited a significantly slower rate of physicochemical change compared to those stored at room storage conditions. Specifically, the PFSF environment effectively decelerated the increases in TSS, respiration rate, and color development, while maintaining higher firmness over extended storage periods. This retardation of ripening processes directly translates to a potential extension of the fruit's shelf life by over three weeks when maintained above the chilling injury threshold. While low-temperature storage offers a substantial advantage in delaying ripening, the potential for quality defects necessitates careful monitoring and optimization. Nevertheless, this study confirms that controlled low-temperature storage, particularly within a PFSF, is a critical postharvest strategy for preserving the quality and extending the marketability of mango cv. Pusa Manohari.

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Authorship & Contributorship
Nile Shubhangi Gorakhnath: Methodology, Investigation, Analysis, Writing-original draft, conceptualization; Sangeeta Chopra: Conceptualization, Investigation, Analysis, Instrumentation, Supervision, Writing-editing, and review; Devinder Dhingra: Conceptualization, Investigation, Analysis, Supervision, Writing-editing, and review; P. K. Sahoo: Supervision, Review; Rouf Ahmad Parray: Supervision, Review; Manish Srivastava: Supervision, Raw Material, Guidance; Mrinmoy Ray: Analysis; Shivani Nagar: Methodology, Analysis; Randolph Beaudry: Supervision, validation.

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