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Assessment of ripening sachets for postharvest quality enhancement in Dashehari mango (*Mangifera indica* L.)

Karma Beer, Anil Kumar Verma, S.C. Ravi*, Alok Kumar Gupta, Vishambhar Dayal and Akath Singh[1]

*ICAR- Central Institute for Subtropical Horticulture, Lucknow (UP) – 226101, India. *E-mail: ravi.sc@icar.gov.in*

Abstract

Understanding the essential role of ethylene release in the long-distance transportation of climacteric fruits, like mangoes, is crucial. This study aimed to investigate the relationship between ethylene release and the postharvest ripening of mangoes. The research employed innovative ripening sachets to control the ripening process, specifically focusing on extending shelf life and enhancing quality. Dashehari mangoes exposed to ripening sachets releasing 100 ppm of ethylene exhibited improved quality attributes. The 6th day post-treatment recorded the highest total soluble solids (TSS) at 17.37 °B and the lowest acidity at 0.23%. Ascorbic acid content and firmness were measured at 22.50 mg 100 gm^{-1} and 2.63 kg cm^{-2}, respectively. Polygalacturonase activity in mango pulp (11.80,08.56 U mL^{-1} min^{-1}) and peel (34.00, 20.30 U mL^{-1} min^{-1}) peaked on the 4th and 6th day, respectively. The peel colour L* value increased from 2nd to 6th day after treatment, whereas the a* and b* values increased from 2nd to 4th day and the a* and b* values gradually decreased on 6th day in all the treatments except T_4. The study suggests that ripening sachets have the potential to effectively regulate mango ripening and preserve fruit quality for an extended period.

Key words: Mango, ripening, postharvest quality, shelf life, phenolic compounds and HPLC.

Introduction

The mango, often called the "King of Fruits" in India due to its delightful taste and medicinal properties, holds significant agricultural importance. Cultivated across 23.12 lakh hectares, it contributes 40.48% to the world's mango production, with exports to over 40 countries. The Dashehari mango, particularly favoured in Northern India for its taste, high yield potential, and quality fruits, is harvested in July amid hot and humid weather. Harvesting at the green mature stage is preferred for better taste, although hardness, low soluble solids, and high acidity are associated with this stage.

The ripening process involves a cascade of metabolic activities, inducing chemical changes, increased respiration, modifications to structural polysaccharides softening the fruit, chlorophyll degradation, and carotenoid biosynthesis. Excessive softening during ripening poses a risk of fruit spoilage. Fruits significantly increase respiration and ethylene production at ambient temperatures after the third to fourth day postharvest, limiting consumer acceptance and postharvest shelf life (Narayan *et al.*, 1996).

Various methods have been employed to stimulate mango ripening postharvest. Traditionally, calcium carbide salt was widely used in India due to its cost-effectiveness (Siddiqui and Dhua, 2010). However, gas emissions from calcium carbide compromise taste and overall fruit quality—moreover, health risks associated with carbide led to its prohibition under the Prevention of Food Adulteration legislation. The safer alternative involves ethylene gas, but limited infrastructure availability restricts its widespread adoption. Ethephon treatments and controlled temperature regimes are gaining recognition for inducing fruit ripening (Singh *et al.*, 2012; Jawandha *et al.*, 2015).

Ethylene, an endogenous hormone, plays a pivotal role in natural fruit ripening and poses no health risks to consumers. Ripening sachets containing externally applied ethylene have been designed to facilitate safe fruit ripening. Unfortunately, commercially available ripening sachets often incorporate talcum powder and other fillers containing heavy metals, posing health risks (Herianus *et al.*, 2003). To ensure consistent mango ripening, the Central Institute for Subtropical Horticulture in Lucknow has created a ripening sachet utilizing readily available plant materials and a precise quantity of ethylene. This research compares safe ripening with the sachet free from inert materials containing heavy metals, addressing health hazards associated with conventional sachets.

This study explores safety concerns associated with ripening sachet use and investigates changes in acidity, vitamin C, and total soluble solids (TSS) levels during artificial ripening with sachets.

Materials and methods

Mature green mangoes were harvested from the ICAR- CISH, Lucknow research farm for evaluation. The fruits were de-sapped, washed, and then placed in ten-kilogram capacity CFB boxes for both control and treated fruits.

Methodology for ripening sachet development: The ripening sachet was developed using plant materials as the filler and was adequately soaked with a quantified amount of Type-A solution. A similar process was followed for the Type-B solution. After that, they were dried per the protocol developed by ICAR-CISH, Lucknow. The standard quantity of Type-A and Type-B compositions were mixed and adequately wrapped in a sachet weighing 2.0 g. One sachet was used for the ripening of 5.0 kg of mango. Accordingly, the treatments were designed to ensure

the safe ripening of the fruits. The ripening sachet development protocol is easy and economical it can be reproduced easily.

Treatments details: The study included four treatments, *viz.*, T_1- Mango fruits packed and sealed in CFB boxes without any treatments (Control), T_2- Mango fruits packed and sealed in CFB boxes with ethylene ripening sachet (50 ppm), T_3- Mango fruits packed and sealed in CFB boxes with ethylene ripening sachet (100 ppm), T_4- Mango fruits packed and sealed in CFB boxes with ethylene ripening sachet (200 ppm). Each treatment was replicated thrice by using the CRD (completely randomized design). The treatments were designed to assess the effective ethylene concentration for ripening the fruit, determine whether it will be effective for its ripening, and maintain the postharvest quality of the fruit.

The data was collected on the 1st day (pre-treatment) and then on the 2nd, 4th, and 6th days after ripening. The fruits' physiological and biochemical aspects were recorded, including phenolic compounds, total soluble solids (TSS), acidity, fruit firmness, and physiological weight loss. The L*, a*, and b* values were assessed based on the Royal Horticulture Society (RHS) colour chart to determine the color of the mango peel. This involved referencing the colour chart to obtain the corresponding values for accurate color representation for L*, a*, and b*.

Phenolic compounds analysis: Analysis of phenolic compounds was performed through HPLC. The phenolic compounds were determined by using the protocol by Bhattacherjee *et al.* (2011).

Sample collection and pre-treatment: The fruit was washed with water, dried between clean scientific tissue paper layers and peeled with a stainless steel knife for biochemical analysis. Each fruit sample was dried at 60°C to determine moisture until constant weight was achieved. The dried samples were then homogenized and powdered in a grinder. The powdered samples were labelled correctly and stored in plastic bags at low temperatures for further analysis.

Statistical analysis: This study employed a Completely Randomized Design (CRD) as the research design. To identify notable differences ($P < 0.05$) among element means, one-way and two-way analysis of variance (ANOVA) were conducted, depending on the data's nature. Following this, Tukey's HSD (honestly significant difference) test was utilized to compare means within the ANOVA results.

Results

TSS and titratable acidity: The treatment T_3 recorded the highest TSS at 17.37 °B on the 6th day, followed by T_4 at 16.42 °B. On the 2nd, 4th day and 6th day, the highest TSS was detected in treatment T_3 (14.66 °B), T_4 (16.42 °B) and T_2 (15.63 °B), respectively (Table 1), the lowest Total Soluble Solids (TSS) was observed in treatment T_1 (12.16 °B). The analysis revealed that treatment T_1 had the greatest acidity levels (0.66 %, 0.58 %, and 0.45 %) on the 2nd, 4th, and 6th day, respectively. Treatment T_4 exhibited the lowest acidity levels (0.35, 0.25 and 0.24 %) followed by T_3 (0.44 %, 0.35 % and 0.23 %) on the 2nd, 4th, and 6th day of storage, respectively (Table 1).

Physiological weight loss: The impact of the treatment on the physiological reduction in mango weight is illustrated in Fig. 1. The treatment T_4 exhibited the most physiological weight loss on the second day (4.83 %), followed by T_3 (3.89 %). In contrast, the control group had the lowest weight loss. On the fourth day after storage, the treatment T_4 had the highest physiological weight loss (7.18 %), followed by T_3 (6.64 %) and the control group (7.09 %). On the 6th day of treatment, the maximum physiological weight loss was observed in treatment T_4 with a percentage of 9.14 %, followed by treatment T_3, which had a weight loss percentage of 9.11 %. The control group had the lowest weight loss percentage *i.e.,* 8.90 %.

Table 1. Effect of ripening sachet on TSS (°B) and titratable acidity (%) of mango

Treatment	TSS (°B)			Titratable Acidity (%)		
	2nd Day	4th Day	6th Day	2nd Day	4th Day	6th Day
T_1	12.16^{e}	14.48^{c}	16.38^{b}	0.66^{a}	0.58^{b}	0.45^{c}
T_2	12.59^{e}	13.52^{d}	15.63^{b}	0.68^{a}	0.45^{c}	0.36^{d}
T_3	13.55^{d}	15.67^{b}	17.37^{a}	0.44^{c}	0.35^{d}	0.23^{e}
T_4	14.66^{c}	15.71^{b}	16.42^{b}	0.35^{d}	0.25^{e}	0.24^{e}

Note: TSS and titratable acidity on day one was 6.30 ^{0}B and 2.31 %, respectively. Data with different alphabets as superscripts indicates a significant difference at P=0.05.

Ascorbic acid: No significant differences were noted in the amounts of ascorbic acid across the different treatments. Treatment T_1 had the highest concentration of ascorbic acid at 21.50 mg 100 gm^{-1} on the 2nd day, followed by treatment T_2 at 17.77 mg 100 gm^{-1}. On the fourth day, treatment T_1 exhibited the maximum concentration of ascorbic acid at 21.22 mg 100 gm^{-1}, while treatment T_3 had a little lower quantity at 18.84 mg 100 gm^{-1}. On the sixth day, a comparable trend was seen as on the fourth day, wherein T_1 exhibited the highest concentration of ascorbic acid at 22.50 mg 100 gm^{-1}, followed by T_3 at 19.32 mg 100 gm^{-1} (Table 2).

Fruit firmness: Treatment T_3 had the greatest fruit firmness of 3.74 kg cm^{-2} on the second day, followed by T_2 with a hardness of 3.48 kg cm^{-2} (Table 2). The control group (T_1) exhibited the lowest firmness of 3.35 kg cm^{-2}. The maximum fruit firmness was observed on the 4th and 6th day in treatment T_2, with values of 3.33 and 2.75 kg cm^{-2}, respectively. Subsequently, T_3 was administered, resulting in measurements of 3.25 and 2.63 kg cm^{-2} on the 4th and 6th day, respectively.

Table 2. Effect of ripening sachet on ascorbic acid (mg 100 gm^{-1}) and fruit firmness (kg cm^{-2}) of mango

Treatment	Ascorbic Acid (mg 100 gm^{-1})			Fruit Firmness (kg cm^{-2})		
	2nd Day	4th Day	6th Day	2nd Day	4th Day	6th Day
T_1	21.50^{a}	21.22^{ab}	22.50^{a}	3.35^{ab}	2.77^{d}	1.33^{e}
T_2	17.77^{cd}	16.91^{de}	18.63^{cd}	3.48^{ab}	3.33^{ab}	2.75^{d}
T_3	15.54^{e}	18.84^{cd}	19.32^{bc}	3.74^{a}	3.25^{bc}	2.63^{d}
T_4	15.49^{e}	17.09^{de}	18.52^{cd}	2.85^{cd}	1.37^{e}	1.02^{e}

Ascorbic acid and fruit firmness on day one was 18.89 mg 100 g^{-1} & 4.44 kg cm^{-2}, respectively. Data with different alphabets as superscripts indicates a significant difference at P=0.05

Sensory quality: The sensory quality of the treatments after

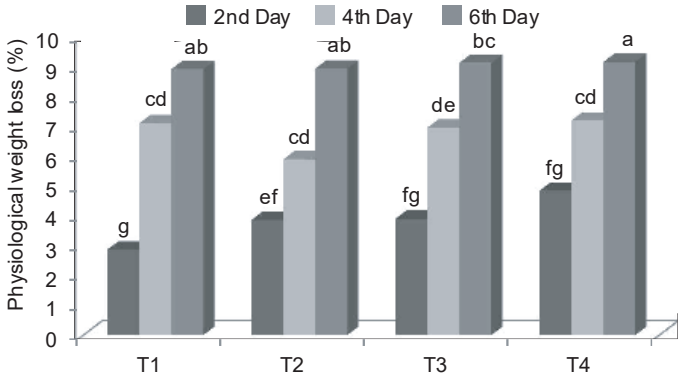

Fig. 1. Physiological weight loss of mango across the treatments

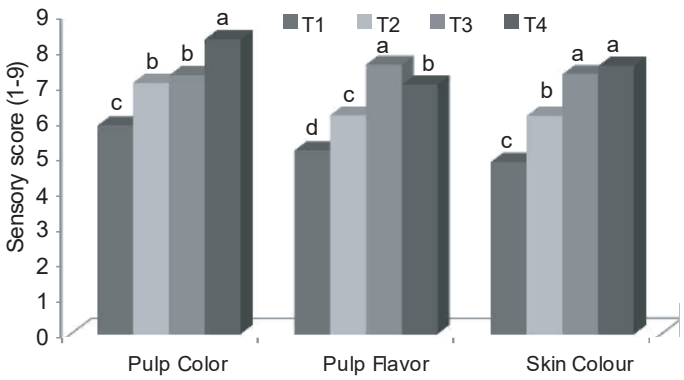

Fig. 2. Sensory evaluation of mangoes ripened using ripening sachet

6th day of ripening is depicted in Fig. 2. Treatment T_4 received the best sensory scores for peel color, pulp colour followed by treatment T_3 and while the best pulp flavour was found in treatment T_3 followed by T_4, while the significantly lowest scores was received for all of these features in control treatment (T_1).

Polygalacturonase activity: The effect of a ripening sachet on the activity of Polygalacturonase (U mL^{-1} min^{-1}) in mango peel and pulp is displayed in Table 3. It was observed that the polygalacturonase activity reduced from the first day to the sixth day. The most significant activity level was observed in the peel and pulp of the mango on the first day. The second day of the experiment showed the highest polygalacturonase activity in the mango peel in treatment T_4 (76.30 U mL^{-1} min^{-1}), followed by T_3 (75.00 U mL^{-1} min^{-1}), while the lowest activity was observed in the control group T_1 (38.20 U mL^{-1} min^{-1}). In mango peel on the 4th and 6th day, maximum polygalacturonase activity was observed in treatment T_3 (34.00 and 20.30 U mL^{-1} min^{-1}), respectively. The polygalacturonase activity trend in the mango pulp was equal to that in the mango peel. The highest level of polygalacturonase activity was observed on the second day in Treatment T_4, with a recorded value of 69.30 U mL^{-1} min^{-1}, followed by Treatment T_3, which had a polygalacturonase activity of 57.50 U mL^{-1} min^{-1}. The lowest activity was found in treatment T_2 with a 39.70 U mL^{-1} min^{-1} value. In mango pulp, on the 4th and 6th day, maximum polygalacturonase activity was observed in treatment T_3 (11.80 and 08.56 U mL^{-1} min^{-1}), respectively. The treatment T_3 exhibited the maximum polygalacturonase activity on the 4th and 6th day, both in the peel and pulp. Conversely, the treatment T_4 showed the lowest activity.

Table 3. Effect of ripening sachet on polygalacturonase (U mL^{-1} min^{-1}) activity in mango peel and pulp

Treatment	Mango Peel			Mango Pulp		
	2nd Day	4th Day	6th Day	2nd Day	4th Day	6th Day
T_1	38.20^{bc}	25.00^{d}	12.20^{fg}	40.50^{c}	8.02^{d}	7.48^{d}
T_2	43.50^{b}	21.40^{de}	13.70^{fg}	39.70^{c}	9.22^{d}	7.33^{d}
T_3	75.00^{a}	34.00^{c}	20.30^{de}	57.50^{b}	11.80^{d}	8.56^{d}
T_4	76.30^{a}	16.60^{ef}	9.72^{g}	69.30^{a}	7.82^{d}	6.30^{d}

Note: Polygalacturonase (U mL^{-1} min^{-1}) activity in mango peel and pulp on day one was 285.70 and 177.92, respectively. Data with different alphabets as superscripts indicates a significant difference at P=0.05.

Phenolic compounds: The effect of a ripening sachet (100 ppm) on the phenolic compounds in both the peel and pulp of mangoes is presented in Table 4. The phenolic content in raw mango peel and pulp is higher than in ripe mango peel and pulp, except for chlorogenic acid, which is highest in mango pulp. The phenolic compound concentration (µg g^{-1}) in mangoes ripened by ripening-sachet was not significantly different from the control treatment. The average concentration of phenolic compounds, including gallic acid, catechin, epicatechin, caffeic acid, and *p*-coumeric acid, was highest in the unripe mango peel and pulp. However, after treatment, the ripe mango peel and pulp showed a reduced concentration of these phenolic compounds. The average concentration of chlorogenic acid was lower in the peel and higher in the pulp of raw and ripe mangoes (treated mangoes).

Table 4. Effect of ripening on phenolic compound (µg g^{-1}) in mango ripened through ripening-sachet 100 ppm

Phenolic compound	Raw Mango		Ripe Mango	
	Peel	Pulp	Peel	Pulp
Gallic acid	820.52^{a}	95.20^{c}	723.37^{b}	73.19^{d}
Chlorogenic acid	456.21^{b}	524.93^{a}	379.10^{d}	410.63^{c}
Catechin	2776.68^{a}	322.37^{c}	2274.90^{b}	268.22^{d}
Epicatechin	209.63^{b}	58.58^{c}	239.36^{a}	60.06^{c}
Caffeic acid	0.82^{a}	0.54^{c}	0.65^{b}	0.32^{d}
p-coumeric aid	2419.08^{a}	30.04^{c}	2241.26^{b}	20.30^{c}

Data with the different alphabet as superscript indicates a significant difference at P=0.05.

Peel Color: In Table 5, mango peel colour, *i.e.* L*, a* and b* are presented for different treatments. These values correspond with Royal Horticulture Society colour chart.

The L*, a* and b* value for treatment T_1 and T_2 on 2nd, 4th day and 6th after treatment corresponds with RHS colour chart code (140A and 140D), (151D and 151C) and (154D and 154C), respectively.

The L*, a* and b* value for treatment T_3 and T_4 on 2nd, 4th day and 6th after treatment correspond with RHS colour chart code are (140C and 140B), (151B and 151A) and (154B and 154A), respectively.

Table 5. Effect of ripening sachet on L*, a* and b* value of mango peel

	Day	T_1	T_2	T_3	T_4
L*	2nd	57 (140 A)	82	77	67
	4th	80	78	73	69
	6th	89	87	84	81
a*	2nd	-44 (140 A)	-19	-31	-36
	4th	-9	-8	-4	-2
	6th	-9	-10	-11	-13
b*	2nd	46 (140 A)	22	32	43
	4th	63	69	69	52
	6th	40	52	67	58

Discussion

The total soluble solids (TSS) content of mango fruits exhibited an increasing trend during the ripening process, peaking at the end of the ripening period at room temperature. This increase was observed up to the 6th day of ripening, after which a slight decline occurred. The change in TSS content is a natural phenomenon associated with hydrolytic changes in carbohydrates during storage (Kishore *et al.*, 2011). The observed rise in TSS during fruit ripening can be attributed to the increased activity of enzymes responsible for the hydrolysis of starch into soluble sugars (Zhong *et al.*, 2006). These findings align with the results of Baloch and Bibi (2012), who noted a high TSS during the ripening process, and Ahmad *et al.* (2001), who observed greater TSS in bananas kept at higher temperatures compared to lower temperatures.

The titratable acidity (TA) of Dashehari mango fruit displayed a linear decline with the advancement of the ripening period during storage. This decline may be attributed to the utilization of substrates for respiration (Medlicott and Thompson 1985), consistent with the findings of Gill *et al.* (2015), who reported a continuous decrease in the titratable acidity of mango fruits during ripening.

The shift in mango peel color is attributed to the breakdown of chlorophyll, resulting in the disappearance of the green hue. As the ripening progresses, the peel transitions from dark green to bright yellow, signifying alterations in chlorophyll levels that gradually reveal the carotenoid pigments in unripe mango fruits. The ethylene-induced ripening process accelerates color changes, shifting from dark (green) to redness, with further intensification observed during storage. Notably, mangoes subjected to ethylene gas treatment exhibited higher values of L*, a*, and b* than those not exposed. This observation aligns with similar findings reported by Doreyappy-Gowda *et al.* (2001), Kittur *et al.* (2001), and Gaikwa *et al.* (2006) in their studies on mango fruit.

Naturally ripened mangoes exhibited higher ascorbic acid values. This increase may be due to the extended time taken by the mangoes to ripen on the tree, allowing more starch to convert into ascorbic acid. Additionally, ethylene may suppress the action of ascorbic acid synthesis (Thapa *et al.*, 2017). Majagi *et al.* (2018) reported higher levels of ascorbic acid in naturally ripened mangoes than in artificially ripened ones, suggesting that the prolonged ripening period allows more starch to be converted into ascorbic acid.

The decline in firmness observed during ripening may be attributed to an increase in the activity of polygalacturonase and cellulase (Zoghbi, 1994). Mangoes ripened in temperature-controlled chambers retained more firmness than at room temperature. However, after the 6th day, the treated fruit exhibited undetectable firmness as the pulp became very soft, indicating over-ripening.

Physiological weight loss in fruits is likely due to transpiration, respiration, and various biochemical changes occurring in mango fruits (Thinh *et al.*, 2013). Ripening at room temperature resulted in significantly greater weight loss than controlled temperature ripening, consistent with the findings of Waskar and Masalkar (1997), who reported a faster increase in physiological weight loss at room temperature.

The sensory quality of fruit in treatment T_2 was superior to other treatments, and it improved in fruits ripened at room temperature up to the 6th day, after which it started to decline.

Mango fruits contain various phenolic substances, and the concentrations of these may vary between varieties and geographical regions. Ripening processes may affect the formation of these phenolic substances. The increase in phenolic content in ethylene-ripened fruits compared to naturally ripened ones was reported by Campuzano *et al.* (2018).

The study provides valuable insights for developing safe ripening sachets without acetylene gas, and ethylene gas at 100 ppm is recommended for ripening purposes. The developed sachet has the potential for safe ripening with good postharvest quality for safe consumption that will benefit consumer health. This study is a foundation for future research on safe ripening methods for mango fruits.

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