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RESEARCH ARTICLE

Pre-harvest bagging: Optimizing physical and quality attributes of banganapalli mango (*Mangifera indica* L.)

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Abstract

This study evaluates the effectiveness of various pre-harvest fruit bagging materials on the quality and development of the Banganapalli mango cultivar. The bagging materials tested included red/black double-layered bags, brown/black double-layered bags, single-layered brown paper bags, single-layered white paper bags, butter paper bags, agro-plastic sleeve bags, and a control (no bagging). Bagging treatments were applied 45 days after the fruit set. The results demonstrated that fruits bagged in brown/black double -layered bags significantly improved fruit retention (78.24%) and fruit weight (641.8 g), along with enhancements in fruit peel color, firmness, and key quality attributes such as total soluble solids (TSS) (17.72°Brix), TSS: acid ratio (60.17), ascorbic acid content (54.37 mg/100g), and beta-carotene content (12,687.25 µg/100g of pulp). The shelf life of these fruits extended to 16 days, with a notable reduction in fruit fly infestation and disease incidence (4.89%). Additionally, enzymatic activities such as catalase (14.9%), peroxidase (10.7%), and β-glucosidase (4.92%) were increased. These findings suggest that pre-harvest bagging is highly effective in enhancing fruit quality and resistance to biotic stresses, offering mango farmers a valuable strategy to produce superior-quality fruit and achieve higher returns in both domestic and international markets.

Keywords

bagging; disease incidence; fruit fly; fruit quality; mango; peel colour

Introduction

Mango (*Mangifera indica* L.), belonging to the Anacardiaceae family, is one of the most significant tropical fruits. It is often called the "King of Fruits" due to its popularity, flavor, and cultural importance. India is the leading producer and exporter of mangoes worldwide, with a cultivation area of 2,346.09 thousand hectares, yielding 20872.22 thousand metric tons, and a productivity rate of 8.90 metric tons per hectare during the 2022-2023 period (1). Mango is highly favored across India by people of all ages for its flavor, appealing color, and delicious taste. Due to its diverse agro-climatic conditions, India is home to over 1,000 mango cultivars, including Alphonso, Totapuri, Kesar, Bombay Green, Rajpuri, and Banganapalli, among the leading export varieties. The primary destinations for fresh mango exports from India include the United Arab Emirates (UAE) (33%), Nepal (24%), the United Kingdom (UK) (9%), Oman (7%), Qatar (6%), Bangladesh (6%), Saudi Arabia (3%), Bahrain (2%), Kuwait (2%), and United States of America (USA) (2%).

Recent climatic changes, including temperature fluctuation and abnormal rainfall, have adversely affected mango production and fruit quality (2). The external peel color is crucial for local and export markets, while internal attributes such as flavor, sweetness, texture, acidity, and shelf life are essential for international trade**.** These attributes are often compromised by harsh environmental conditions, resulting in fruits that fail to meet global export standards.

Mango is highly susceptible to various pests, particularly fruit flies, which pose a significant challenge to production and export, leading to considerable economic losses (3). Although pesticides are commonly used to control fruit flies, their overuse creates environmental hazards, fueling a growing demand for alternative, sustainable pest management methods (4). Pre-harvest fruit bagging is one alternative that has proven effective in protecting fruits from pests, disease infestations, and adverse climatic conditions. This method has been utilized to protect fruits from insect and disease occurrences, physiological abnormalities, and to improve fruit skin coloration for increased commercial value (5). It has been successfully applied to crops like pears, peaches, apples, and grapes in China, Australia, and Japan (6). In nations like Mexico, Chile, and Argentina, fruit bagging during growth and development is mandatory for export (7). Pre-harvest bagging of mangoes using materials such as brown and white paper, muslin cloth, and wavelength-selective (UV-transparent) plastics has been shown to significantly improve fruit length, weight, diameter, TSS, citric acid, reducing sugar, total sugar, and β-carotene content, compared to non-bagged fruits. However, to enhance the sustainability of this practice, the development and promotion of biodegradable bagging materials is essential (8). Fruit bagging is also recommended as an agricultural practice for reducing agrochemical residues (9) and extending the shelf life of mango fruits (10). This study aims to assess the impact of various bagging materials on the growth and quality of mango fruits.

Materials and Methods

This experiment was conducted on farmer's fields at Keelavadagarai, Periyakulam, Theni district, from March to June 2024. The orchard is located at 10° 12' N latitude and 77° 54' E longitude, with maximum and minimum temperatures of 35°C and 23°C, respectively. The average daily relative humidity from March to June is 68%, and the average annual rainfall is 828 mm. The soil type of the mango orchard is red loam. Irrigation water was applied at 14.92 liters per plant per day using a drip irrigation system. Fertilizers were applied through fertigation, including urea, phosphoric acid, muriate of potash, and magnesium sulfate.

The mango cultivar "Banganapalli" was selected for the study, and the fruits were bagged 45 days after the fruit set. The experiment followed a randomized complete block design (RCBD), consisting of seven treatments, and each replicated three times with ten fruits per treatment in each replication. The different bagging materials used in the study were as follows: T_1 - red/black double-layered bag (20 x 28 cm), T_2 - brown/black double-layered bag (18 x 28 cm), T_3 - single-layered brown paper bag, T_4 - single-layered white paper bag, T_5 - butter paper bag, T_6 - agroplastic sleeve bag, and T_7 - control (no bagging). Pre-harvest factors were recorded, such as the days required for harvesting and fruit retention. Physical and quality attributes were observed following standard procedures.

Fruit weight

The fruits were weighed individually using an electronic weighing balance (iScale i-02 weight capacity 30 Kg x 2g digital weighing machine) and recorded in grams.

Fruit length

The fruit length was measured using a Vernier caliper scale and recorded in centimeters.

Fruit circumference

The fruit circumference was measured using a thread and recorded in centimeters.

Fruit fly incidence

Visual fruits were inspected randomly across all treatments every five days during the 30 days preceding harvest to evaluate signs of fruit fly infestation. Infestation rates were calculated using the following formula:

$$\text{Infestation rate} = \frac{\text{Number of infested fruits}}{\text{Total number of sampled fruits}} \times 100$$

.....(Eqn.1)

Disease incidence

After harvest, the fruits were visually assessed for the severity of disease incidence every three days until the end of their shelf life, randomly across all treatments. The fruit was stored at ambient temperature (27℃). The percent disease incidence was calculated using the following formula:

$$\text{Percent disease incidence} = \frac{\text{Number of diseased fruits}}{\text{Total number of sampled fruits}} \times 100$$

.....(Eqn.2)

Fruit firmness

Firmness was recorded both at the harvest and ripening stages using a Digital Penetrometer (Model: GY-4, Sundoo Industries Co., Ltd., China).

Fruit colour

The fruit peel color was measured at harvest using an NS810 Portable High-Quality Spectrophotometer (3nh Shenzhen Threenh Technology Co., Ltd, China).

Shelf life of fruits

The shelf life in days was determined by observing the period from harvest until the fruit spoiled.

Physiological loss in weight

The physiological loss in weight was assessed at four-day intervals by weight basis and expressed in percentage:

$$\text{Physiological loss in weight} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Final weight}} \times 100$$

.....(Eqn.3)

Biochemical attributes

Total Soluble Solids (brix): A portable RHS hand refractometer measured the fruits' TSS.

Titrable acidity

A known volume of liquid sample pulp was titrated with 0.1 N NaOH using phenolphthalein as an indicator. A known quantity was blended with 20–25 mL of distilled water for solid samples, transferred to a 100 mL volumetric flask, and filtered. An aliquot of 10 mL extract was titrated with the 0.1 N NaOH solution. The determination was carried out according to the standard protocol (11).

$$\text{Acidity} = \frac{\text{Burette reading x N of NaOH x 0.067}}{\text{Weight of sample}}$$

.....(Eqn.4)

Ascorbic acid (mg/100g)

The ascorbic acid content of pulp was estimated (11).

$$\text{Ascorbic acid} = \frac{\text{Titre x dye equivalent x dilution}}{\text{Weight of sample}} \text{ x } 100$$

.....(Eqn.5)

Total sugars

After acid hydrolysis of a defined sample with 35% hydrochloric acid and subsequent neutralization with sodium hydroxide, the filtrate was titrated against standard Fehling's solution (Fehling's A and B) to a brick-red endpoint, using methylene blue as the indicator. The determination was performed according to a standardized protocol (12).

$$\text{Total sugars} = \frac{\text{Burette reading x weight of sample x 50 (filtrate taken)}}{\text{100 x 100 (volume made) x 0.05 (Glucose value) x 250}}$$

.....(Eqn.6)

Reducing sugars

A known weight of the sample (5 g) was mixed with 22% potassium oxalate and 45% lead acetate to precipitate extraneous materials and remove the lead from the solution. The resulting lead-free extract was then used to estimate reducing sugars by titrating against standard Fehling's solution (Fehling's A and B) to a brick-red endpoint, using methylene blue as an indicator. The determination was carried out according to a standardized protocol (12).

$$\text{Reducing sugars} = \frac{100 \times 0.05\,(\text{Glucose value}) \times 25}{\text{Burette reading} \times \text{Weight sample}}$$

.....(Eqn.7)

Beta carotene (µg/100 g of pulp)

One gram of the sample was macerated with 10 mL of a 3:2 mixture of petroleum ether and acetone (comprising 300 mL petroleum ether and 200 mL acetone), then centrifuged. The supernatant was collected and diluted to 50 mL with the same petroleum ether and acetone mixture. The absorbance was measured at 450 nm using a UV spectrophotometer. The determination was carried out according to a standardized protocol (13).

$$\text{Beta carotene} = \frac{3.857 \times \text{O.D} \times \text{volume made up} \times 100}{\text{Weight of sample} \times 1000}$$

.....(Eqn.8)

Enzymatic activities

Total amylase (µg/min/g)

To prepare the enzyme extract, 2 g of the sample was macerated with 10 mL of 0.2 M phosphate buffer containing 0.1% calcium acetate (0.1 g calcium acetate in 100 mL distilled water). The mixture was centrifuged at 5000 rpm for 10 minutes, and the supernatant was collected as the enzyme extract. The reaction mixture consisted of 0.5 mL phosphate buffer, 0.3 mL of 0.5% starch solution (0.5 g starch dissolved in 100 mL distilled water), and 1 mL of enzyme extract. The mixture was incubated at 37°C for 1 hour. To terminate the reaction, 1 mL of dinitro salicylic acid (DNS) reagent was introduced, and the absorbance was quantified at 540 nm utilizing a UV spectrophotometer. A standard maltose curve (20 mg/100 mL) was used to calculate the amylase activity, and it was quantified using the standard methodology (14).

β glucosidase (µg/min/g)

The reaction mixture was prepared by combining 1 mL of enzyme extract with 1 mL of 5 mM p-Nitrophenyl-β-D-glucopyranoside (0.0375 g dissolved in 25 mL of 200 mM phosphate buffer). The mixture was incubated at 45°C for 10 minutes with shaking. The reaction was terminated by adding 1 mL of 2 M Na_2CO_3 (21.18 g dissolved in 100 mL distilled water) and thoroughly mixing the solution. Absorbance was measured at 410 nm, and a standard curve was created using para-nitrophenol. The enzyme activity was estimated following a standardized protocol (15).

Polygalacturonase (µg/min/g)

Phosphate buffer was used for enzyme extraction to assess polygalacturonase activity. The reaction mixture consisted of 1 mL of enzyme extract, 0.2 mL of 0.2 M sodium acetate buffer at pH 5.0, and 0.3 mL of a 1% pectin solution (1 g pectin dissolved in 100 mL distilled water). The mixture was incubated at room temperature for 1 hour. The reaction was stopped by heating the mixture in a boiling water bath (100 °C), then adding 1 mL of dinitrosalicylic acid (DNS) reagent and another 5 minutes of boiling. After cooling, the absorbance was measured at 540 nm using a blank prepared similarly but without the enzyme extract (using two test tubes for the two cuvettes). A standard curve was constructed using D-galacturonic acid as the standard. The assay measured the reducing groups released from polygalacturonic acid (16, 17).

Catalase (activity/min/g)

The enzymatic activity of catalase in the sample was measured by recording the absorbance of hydrogen peroxide at 240 nm. A decrease in absorbance over time indicated the reduction of hydrogen peroxide (H_2O_2) to water and oxy-

gen through catalase. For the analysis, a 3 mL reaction mixture was prepared, consisting of 1.5 mL of phosphate buffer, 0.5 mL of hydrogen peroxide (H_2O_2) (775 µL of 30% H_2O_2 diluted in 100 mL of distilled water), and 50 µL of the enzyme, with the volume adjusted to 3 mL using distilled water. Hydrogen peroxide was added last, as the reaction begins immediately upon its addition. The decrease in absorbance at 240 nm was recorded at 30-second intervals for 1 minute using a UV spectrophotometer. Catalase activity was determined using a standardized protocol (18) and was calculated using a specific formula.

$$\text{Catalase} = \frac{2.3}{\text{time(secs)}} \times \log\frac{A1}{A2} \times \frac{10\times1000}{50} \times \frac{60\times1}{2}$$

.....(Eqn.9)

Peroxidase (ΔA/min/g)

Peroxidase activity was measured using the O-dianisidine method (19). In this method, the enzyme activity in the sample is determined by the oxidation of O-dianisidine upon the addition of H_2O_2, which is catalyzed by the peroxidase enzyme. The resulting increase in absorbance is recorded at 430 nm. For the analysis, a reaction mixture was prepared containing 3.5 mL of phosphate buffer, 0.2 mL of enzyme extract, 0.1 mL of freshly prepared O-dianisidine (1 mg O-dianisidine dissolved in 1 mL methanol), and 0.2 mL of H_2O_2 (0.14 mL of 30% H_2O_2 diluted in 100 mL distilled water). The mixture was well mixed, and hydrogen peroxide was added last after positioning the cuvette in the spectrophotometer. The increase in absorbance at 430 nm was measured at 30-second intervals for 3 minutes using a UV spectrophotometer.

$$\text{Peroxidase} = \frac{\Delta A/\text{min}\times10\times1}{0.2\times2}$$

.....(Eqn.10)

Statistical analysis

Data were analyzed for multiple comparisons using analysis of variance (ANOVA) and evaluated with the Least Significant Difference (LSD) test at a significance level of $p \leq 0.05$, using the 'Grapes' statistical software, Version 1.1.0.

Results and Discussion

Influence of pre-harvest fruit bagging on pre-harvest parameters of mango cv. Banganapalli

The study's results demonstrated that different bagging treatments significantly influenced fruit retention and the days required to harvest after bagging. The highest fruit retention was observed in fruits bagged with T_2 (78.24%), while the lowest was recorded in T_6 (67.27%). T_2 showed a 14.20% increase compared to the non-bagging treatment (68.51%) (Table 1). These outcomes align with previous research, which reported that bagging increases the fruit retention rate (20). Pre-harvest fruit bagging provides a physical shield that protects the fruit from pests and birds, reducing their impact. This also decreases ethylene production in the fruit, allowing it to remain on the tree longer.

Consequently, the number of marketable fruits increases, ultimately boosting fruit yield. Additionally, the number of days required for harvest was reduced in T_2 (67 days), representing an 11.84% reduction compared to the control (76 days) (Table 1). These results are consistent with an earlier study, which found that bagging reduces the days required for harvesting (21).

Influence of pre-harvest fruit bagging on fruit weight, fruit length, and circumference of mango cv. Banganapalli

Pre-harvest fruit bagging significantly influenced mangoes' weight, length, and circumference. Fruits bagged with T_2 exhibited the highest fruit weight (641.8 g), while the lowest weight was observed in T_6 (606.9 g). In T_2, fruit weight increased by 5.14% compared to the control (Table 1). These findings support previous research indicating that bagging can modify the microenvironment, leading to physiological and biochemical changes in fruits, which may ultimately increase fruit weight (22-25). Different bagging systems can alter the microclimatic conditions

Table 1. Effect of pre-harvest fruit bagging on pre-harvest parameters, fruit weight, fruit length and circumference, fruit peel color at harvest stage, fruit fly incidence of mango cv. Banganapalli

Treatments	Fruit retention (%)	Days to harvest after bagging (Days)	Fruit weight (g)	Fruit length (cm)	Fruit circumference (cm)	L*	a*	b*	Fruit fly Incidence (%)
T_1	74.36	68.5	636.1	13.8	31.7	58.47	13.74	47.45	0
T_2	78.24	67	641.8	13.3	32.4	59.62	14.07	48.62	0
T_3	70.54	69.5	621.2	12.8	28.7	54.26	-6.89	37.21	5.68
T_4	66.32	72.5	608.4	11.7	27.3	51.78	-7.34	32.67	7.29
T_5	69.58	73.5	623.9	12.9	29.6	53.67	-6.54	35.74	6.25
T_6	67.27	75.5	606.9	12.2	27.8	50.9	-7.28	28.89	7.58
T_7	68.51	76	610.4	12.5	28.1	49.31	-6.14	25.71	13.47
F-Test	S	S	S	S	S	S	S	S	S
CD (5%)	5.49	4.03	33.55	1.24	2.38	4.92	1.01	3.12	0.73
SE	2.52	1.85	16.08	0.60	1.14	2.26	0.467	1.43	0.34

Significant at a 5 percent level. T1- red/black double-layered bag, T2- brown/black double-layered bag, T3- single layered brown paper bag, T4- single-layered white paper bag, T5- butter paper bag, T6- agroplastic sleeve bag, T7- control (no bagging). L- Lightness, a*- Colour position between green and red, b*-Colour position between blue and yellow.

around the fruit surface, potentially influencing fruit weight (26). Fruit length and circumference were also significantly affected by bagging treatments. The highest fruit length was observed in T_1 (13.8 cm), while the lowest was found in fruits bagged with T_4 (11.7 cm) (Table 1). These results align with an earlier study, which reported that in date palm cv. Rothana, bagging with kraft paper, increased fruit length compared to the control (27). Fruit circumference was significantly greatest in T_2 (32.4 cm), while the lowest was observed in T_4 (27.3 cm) (Table 1). These outcomes are consistent with previous research which showed that bagging enhances fruit circumference (28). Bagging during specific developmental stages may improve fruit physiology, thus positively affecting the growth and size of the fruit (29). Larger fruits are often perceived by consumers as being of higher quality, with size being associated with better flavor and nutritional benefits. This preference for larger fruits can significantly influence purchasing decisions in the marketplace. Both domestic and international markets typically set size standards for fruits, with larger fruits receiving higher grading classifications and commanding premium prices. Therefore, fruit size plays a critical role in determining market value (30).

Influence of pre-harvest fruit bagging on fruit peel color of mango cv. banganapalli at harvest stage

The L* value was significantly higher in T_2, showing an increase of over 20.9% compared to the control (Table 1). The a* value of the fruit peel was markedly higher in fruits bagged with T_2 (14.07), while the lowest value was observed in the control fruits (-6.14) (Table 1). T_2 also exhibited an increase of approximately 89.1% in the b* value compared to the control (Table 1). These findings are consistent with earlier studies (31, 32).

Pre-harvest bagging affects the metabolism of chlorophyll, carotenoids, and anthocyanins due to the light modulation around the fruit surface by different types of bags. Increased light penetration through transparent bagging materials enhances photosynthesis, which helps sustain or elevate chlorophyll levels in the fruit skin, potentially delaying chlorophyll degradation. Conversely, when opaque bagging materials reduce light penetration around the fruit, the rate of photosynthesis decreases, leading to lower chlorophyll levels in the fruit skin. In response to these lower light conditions, the plant reallocates resources to synthesize carotenoids and anthocyanins, enhancing the fruit peel's color (33, 34).

Influence of pre-harvest fruit bagging on fruit firmness, physiological loss in weight, shelf life, fruit fly, and disease incidence of mango cv. Banganapalli

Pre-harvest fruit bagging significantly influenced fruit firmness, physiological loss in weight (PLW), shelf life, fruit fly incidence, and disease incidence in mangoes. At the harvest stage, T_2 treatment increased fruit firmness by 24.78% compared to the control fruits (Fig. 1A). At the ripening stage, T_2 enhanced firmness by 12.8% compared to the non-bagging treatments (Fig. 1B). These findings are consistent with previous research, which reported increased firmness due to bagging (35, 36). Fruit firmness is key in assessing fruit maturity and shelf life (7). Physiological loss in weight (PLW) was reduced in fruits bagged with T_2. Compared to the control, T_2 reduced PLW by 36.5 % relative to the non-bagging treatment (Fig. 1C), supporting an earlier study (37). Since PLW directly affects shelf life, reducing weight loss extends the fruit's longevity and quality.

T_2 also enhanced the shelf life of fruits by 10.3 % compared to the control (Fig. 1D). These results are consistent with previous research (38), which showed that

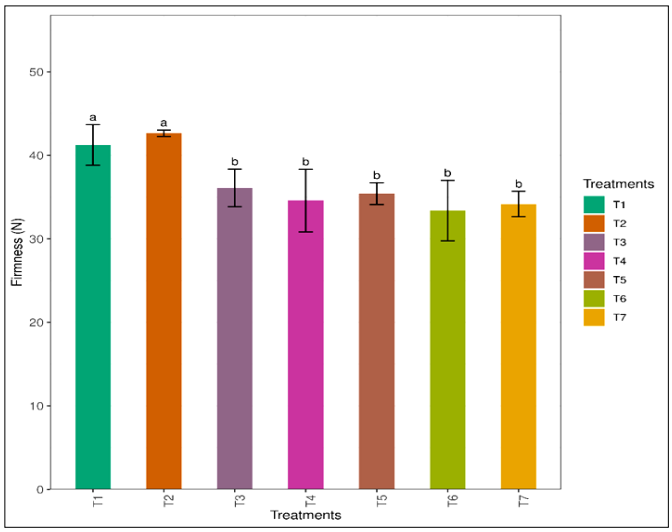

Fig. 1A. Firmness at harvest stage.

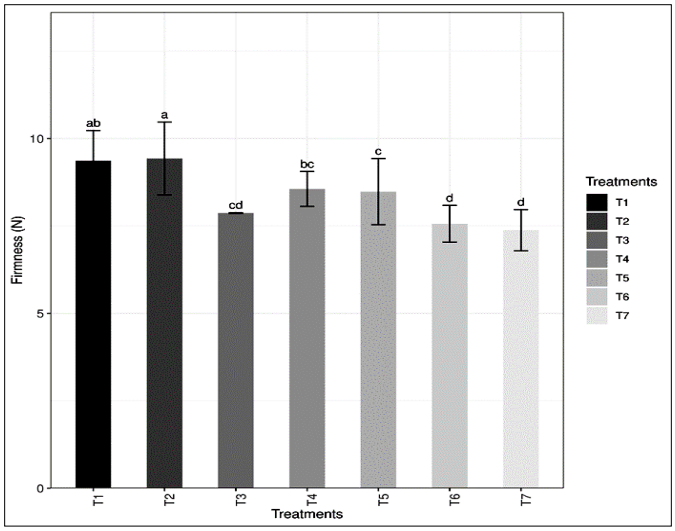

Fig. 1B. Firmness at the ripening stage.

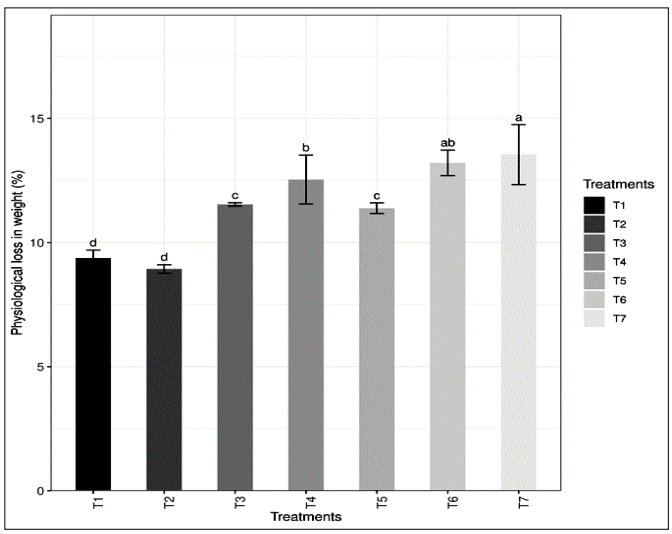

Fig. 1C. Physiological loss in weight.

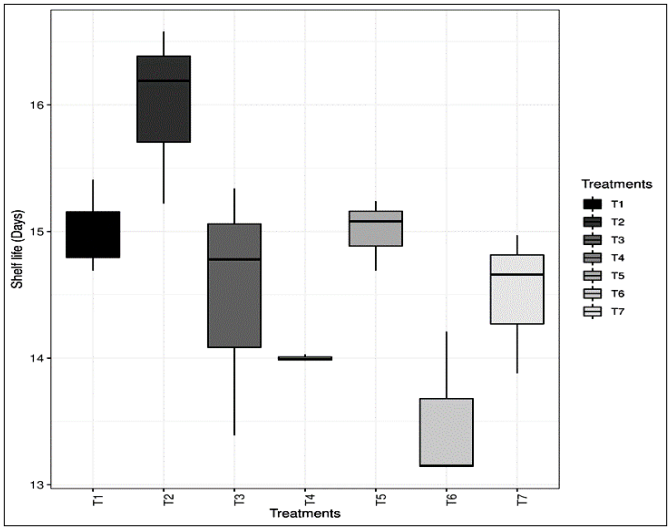

Fig. 1D. Shelf life.

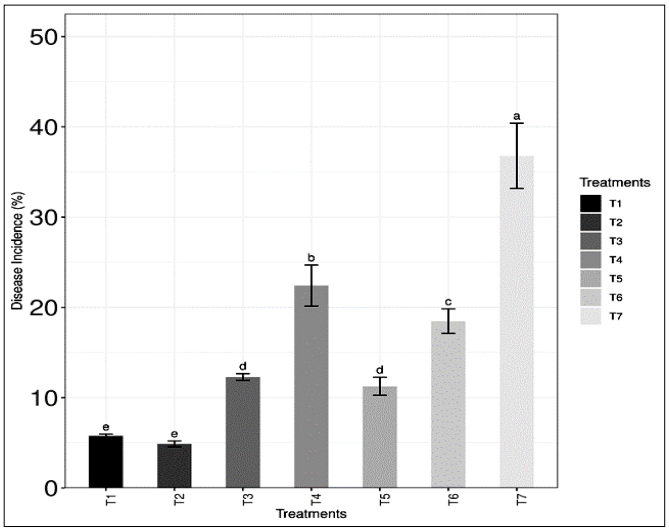

Fig. 1E. Disease Incidence.

Fig. 1. Influence of pre-harvest bagging on physiological loss in weight, firmness, shelf life, and disease incidence in mango cv. Banganapalli. T1- red/black double-layered bag, T2- brown/black double-layered bag, T3- single-layered brown paper bag, T4- single-layered white paper bag, T5- butter paper bag, T6- agroplastic sleeve bag, T7- control (no bagging).

fruit bagging significantly influences shelf life. The bagging treatments notably reduced fruit fly incidence. No fruit fly incidence was observed in either T_1 or T_2 treatments, while the non-bagging treatments had a 13.47% incidence (Table 1). These findings align with earlier studies (39, 40), which reported that bagging reduces fruit fly infestation. Pre-harvest fruit bagging creates a physical barrier between the fruit and the external environment, preventing fruit flies from accessing the fruit (41). T_2 also significantly reduced disease incidence by 86.7% compared to the non-bagging treatment (Fig. 1E). These observations confirm previous research findings which concluded that fruit bagging reduces disease incidence (42). Pre-harvest fruit bagging can alter the microclimatic conditions around the fruit surface, influencing factors such as temperature, light, and relative humidity. This modification can inhibit the growth of certain pathogens and, in turn, reduce disease incidence.

Influence of pre-harvest fruit bagging on enzymatic activities of mango cv. Banganapalli

The research indicated that pre-harvest fruit bagging significantly affected enzymatic activities. The different bagging treatments notably influenced peroxidase activity. At the harvest stage, T_2 treatment resulted in a 21.1% increase compared to the non-bagging treatment (Fig. 2A). At the ripening stage, T_2 further enhanced peroxidase activity by 10.7% relative to the control (Fig. 2B). Catalase activity was also markedly affected by the bagging materials. T_2 increased catalase activity by 18.95% at the harvest stage compared to the non-bagging treatment (Fig. 2C). At the ripening stage, T_2 enhanced catalase activity by 14.9% compared to the control fruits (Fig. 2D). These findings align with previous research which demonstrated that bagging increases peroxidase and catalase activities in apples (43, 44). The antioxidant enzymes, such as peroxidase and catalase, play a crucial role in maintaining fruit quality, mitigating oxidative stress, and protecting fruits from pathogens (45).

Polygalacturonase activity was not significantly affected by the bagging treatments at either the harvest or ripening stages (Table 2). Polygalacturonase is vital for fruit ripening as it degrades the middle lamella, leading to fruit softening (46). This enzyme indirectly influences the shelf life of fruits. The bagging treatments at the harvest stage significantly impacted amylase activity. T_2 increased amylase activity by 10.23% compared to the control fruits (Table 2). Amylase is a key enzyme that converts starch to sugar during ripening, enhancing the sweetness of the

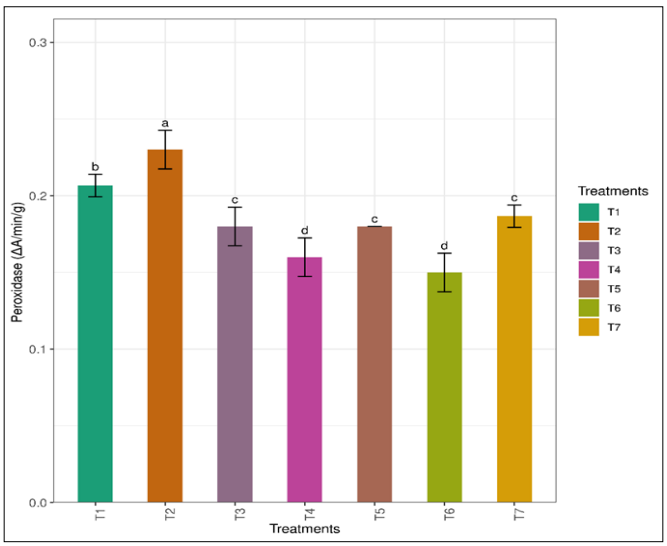

Fig. 2A. Peroxidase at harvest stage.

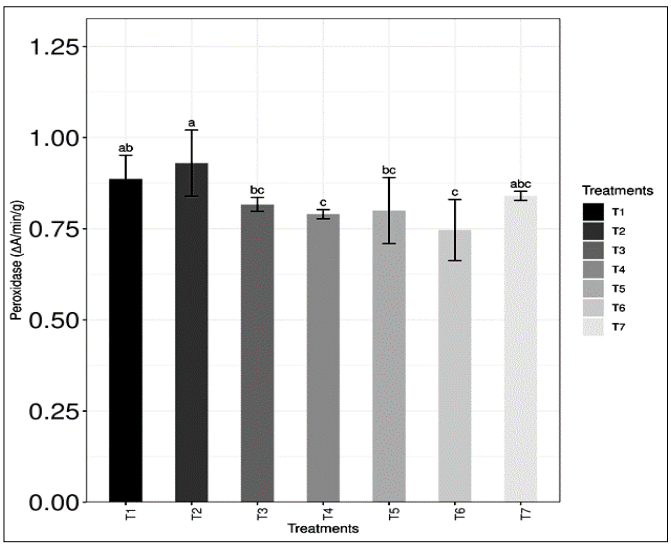

Fig. 2B. Peroxidase at ripening stage.

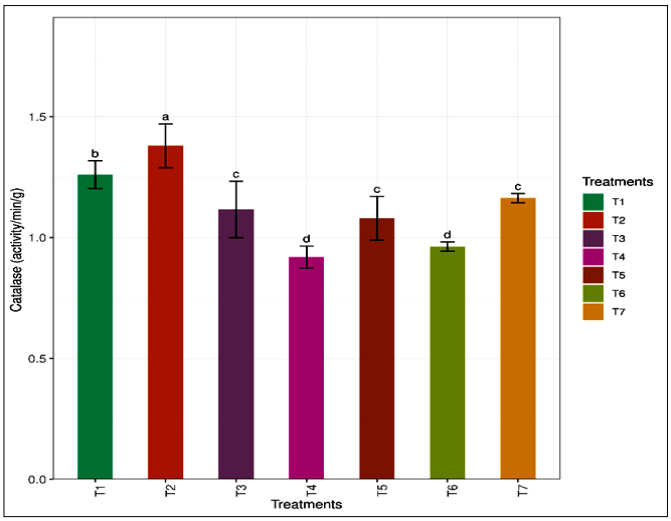

Fig. 2C. Catalase at harvest stage.

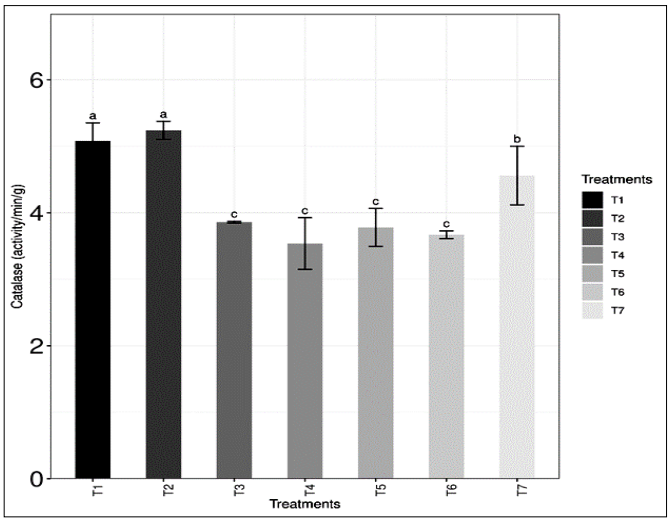

Fig. 2D. Catalase at ripening stage.

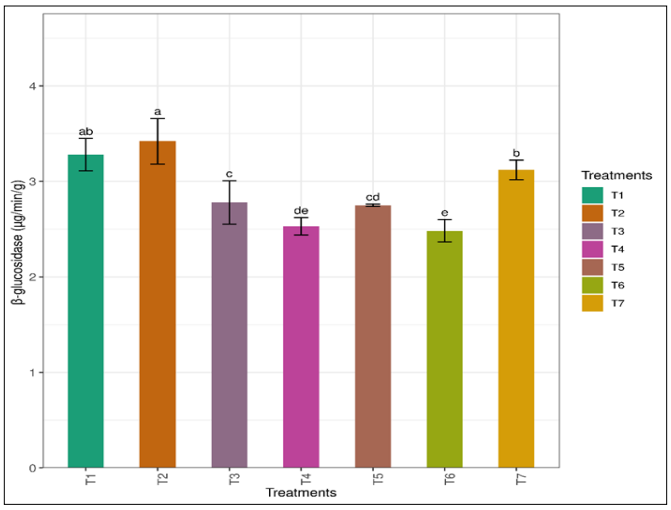

Fig. 2E. β-glucosidase at harvest stage.

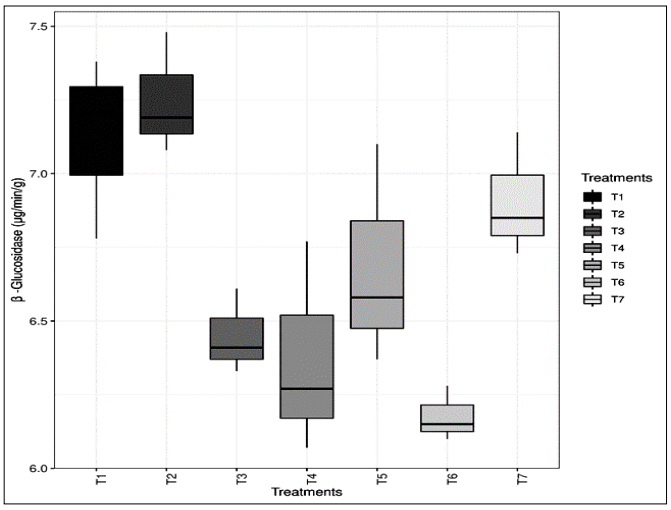

Fig. 2F. β-glucosidase at ripening stage.

Fig. 2. Influence of pre-harvest bagging on enzymatic activities of mango cv. banganapalli at harvest and ripening stage. T1- red/black double-layered bag, T2- brown/black double-layered bag, T3- single-layered brown paper bag, T4- single layered white paper bag, T5- butter paper bag, T6- agroplastic sleeve bag, T7- control (no bagging).

Table 2. Effect of pre-harvest fruit bagging on sugars, beta carotene, polygalacturonase, and amylase activities of mango cv. Banganapalli

Treatments	At harvest stage					At ripening stage				
	Total sugar (%)	Reducing sugars (%)	Beta carotene (µg/100g 0f pulp)	Polygalac-turonase (µg/min/g)	Amylase (µg/ min/g)	Total sugar (%)	Reducing sugars (%)	Beta carotene (µg/100g of pulp)	Polygalac-turonase (µg/min/g)	Amylase (µg/min/g)
T_1	3.74	2.56	331.24	51.35	7.65	12.71	4.78	12468.25	132.61	21.08
T_2	3.79	2.6	334.17	53.48	8.29	13.12	4.84	12687.47	138.79	22.56
T_3	3.59	2.38	315.36	48.71	6.84	12.56	4.67	11475.39	125.67	20.68
T_4	3.54	2.44	310.14	46.57	6.53	11.96	4.56	11346.78	124.18	19.89
T_5	3.68	2.37	313.42	47.12	6.95	12.62	4.71	11563.92	127.91	20.92
T_6	3.65	2.45	312.78	45.84	6.48	12.28	4.52	11278.94	124.36	19.76
T_7	3.7	2.47	314.43	50.36	7.52	12.65	4.63	11453.76	129.48	21.05
F-Test	NS	NS	NS	NS	S	NS	NS	S	NS	NS
CD (5%)	NS	NS	NS	NS	0.60	NS	NS	848.32	NS	NS
SE	2.20	0.131	0.108	2.77	0.27	0.58	0.14	389.35	5.79	0.89

*Significant at a 5 percent level. T1- red/black double-layered bag, T2- brown/black double-layered bag, T3- single-layered brown paper bag, T4- single-layered white paper bag, T5- butter paper bag, T6- agroplastic sleeve bag, T7- control (no bagging).

fruit. However, amylase activity was not notably affected by the bagging treatments at the ripening stage (Table 2). β-glucosidase activity was significantly influenced by the bagging treatments. T_2 improved β-glucosidase activity by 9.61% compared to the control fruits at the harvest stage (Fig. 2E). At the ripening stage, T_2-treated fruits exhibited a

4.92% increase in β-glucosidase activity compared to the non-bagging treatment (Fig. 2F). β-glucosidase plays a major role in improving fruit flavor and aroma by releasing volatile compounds (47).

Influence of pre-harvest fruit bagging on biochemical attributes of mango cv. Banganapalli

The different bagging treatments significantly affected TSS. Fruits bagged in T_2 showed an 11.5% increase in TSS at the harvest stage compared to the control (Fig. 3A). At the ripening stage, T_2-treated fruits exhibited a 10.68% increase in TSS compared to the non-bagging treatment (Fig. 3B). These results are consistent with previous studies which indicated that bagging enhances TSS content in fruits by promoting sugar accumulation (48). Titrable acidity was also significantly influenced by the bagging treatments. At the harvest stage, T_2 reduced acidity by 7.82% compared to the non-bagging treatment (Fig. 3C). At the ripening stage, T_2 decreased acidity by over 30.95% compared to the control (Fig. 3D). These findings align with previous research which showed that bagging significantly reduces acidity in guava (22). Ascorbic acid content was notably affected by the bagging treatments. Fruits bagged in T_2 exhibited an 11.91% increase in ascorbic acid at the harvest stage compared to the control (Fig. 3E). At the ripening stage, T_2-treated fruits had a 14.20% higher ascorbic acid content than the non-bagging treatment (Fig. 3F). These results are consistent with earlier studies which demonstrated that bagging increases the ascorbic acid content in fruits (24).

The different bagging treatments significantly influenced the TSS to acid ratio. T_2 improved the TSS to acid ratio by over 20.7% compared to the control at the harvest stage (Fig. 3G). At the ripening stage, T_2-treated fruits showed a 54.7% increase in the TSS to acid ratio compared to the non-bagging treatment (Fig. 3H). These findings are in agreement with previous research which indicated that bagging enhances the TSS to acid ratio (49). Neither total nor reducing sugars were significantly impacted by the bagging treatments at either the harvest or ripening stages (Table 2). However, beta-carotene content was not significantly affected by the bagging treatments at the harvest stage (Table 2). At the ripening stage, T_2 increased beta-carotene by 10.77% compared to the control fruits (Table 2). These findings confirm the conclusions of past research which suggested that bagging improves beta-carotene content in mangoes (44).

Correlation analysis

The Correlation results show positive and negative relationships among the physical parameters, biochemical attributes, enzymatic activities at the ripening stage, and the shelf life of mango fruits. A positive correlation was observed between fruit weight, fruit length, fruit circumference, shelf life, firmness, and the activities of enzymes such as peroxidase, catalase, polygalacturonase, amylase,

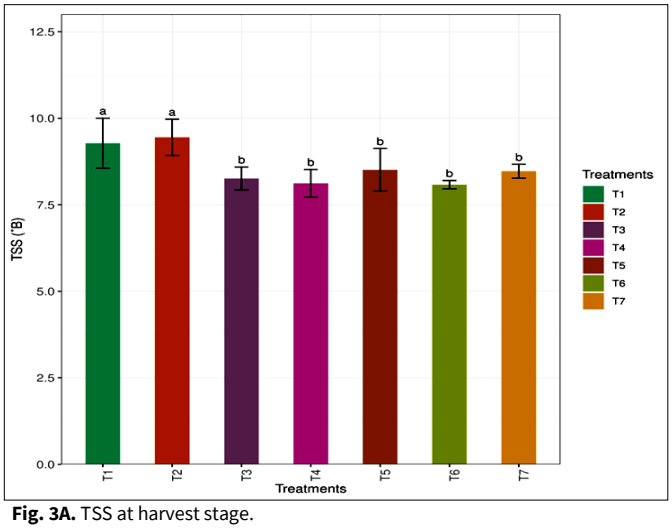

Fig. 3A. TSS at harvest stage.

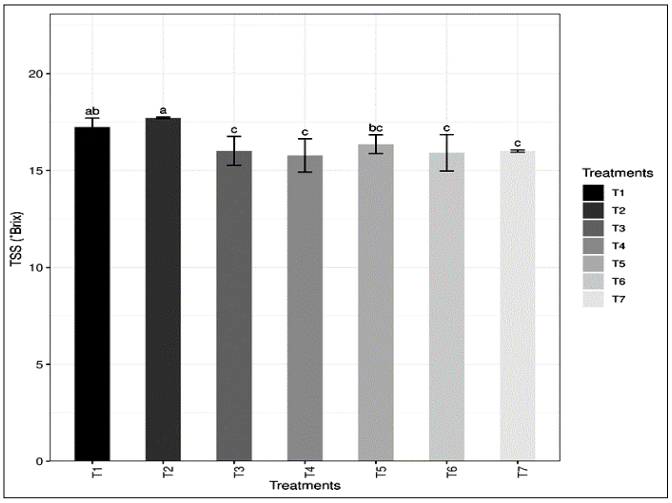

Fig. 3B. TSS at ripening stage.

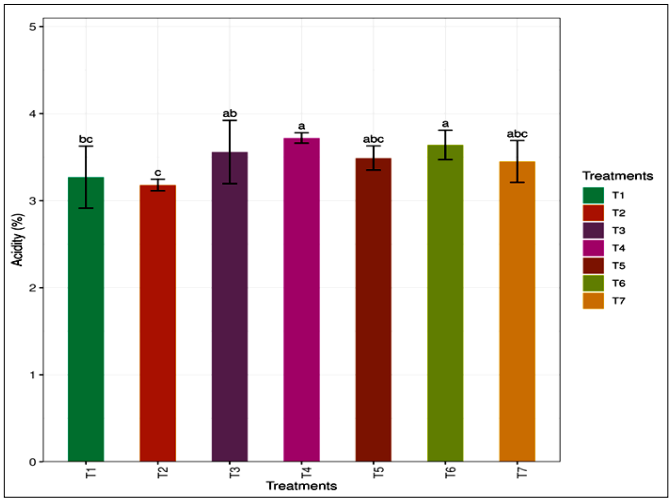

Fig. 3C. Acidity at harvest stage.

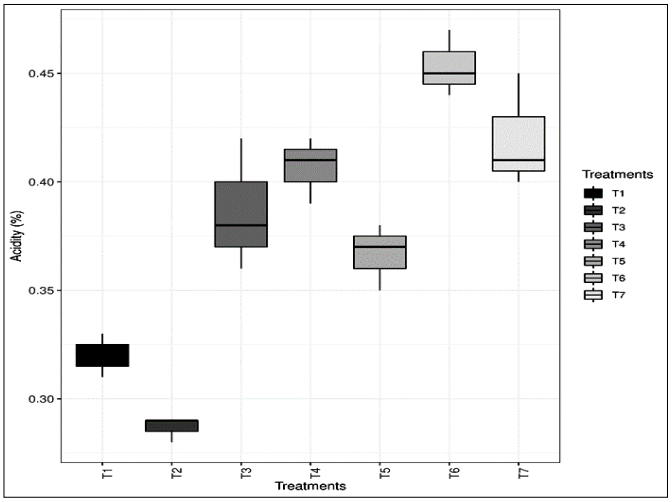

Fig. 3D. Acidity at ripening stage.

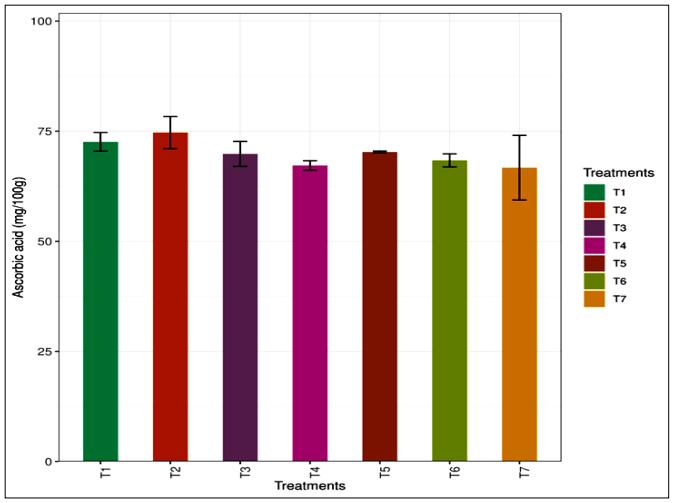

Fig. 3E. Ascorbic acid at harvest stage.

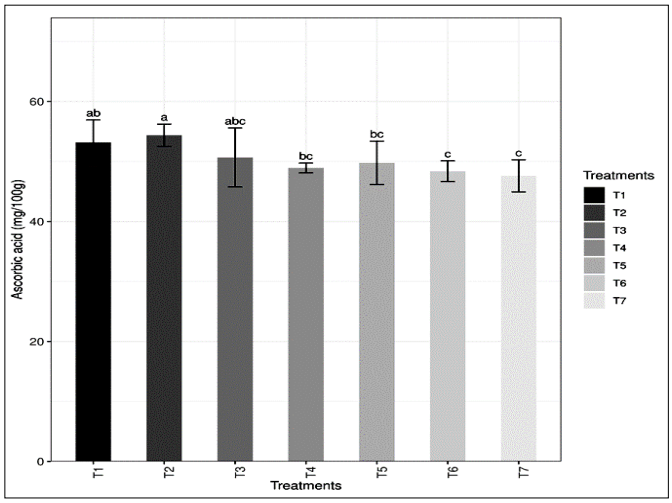

Fig. 3F. Ascorbic acid at ripening stage.

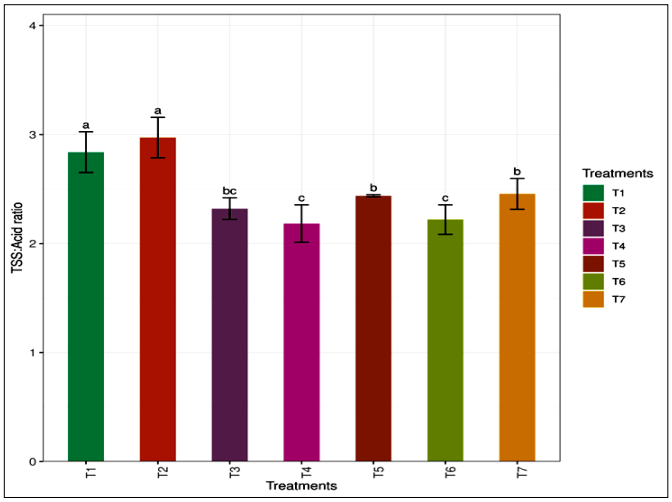

Fig. 3G. TSS: acid ratio at harvest stage.

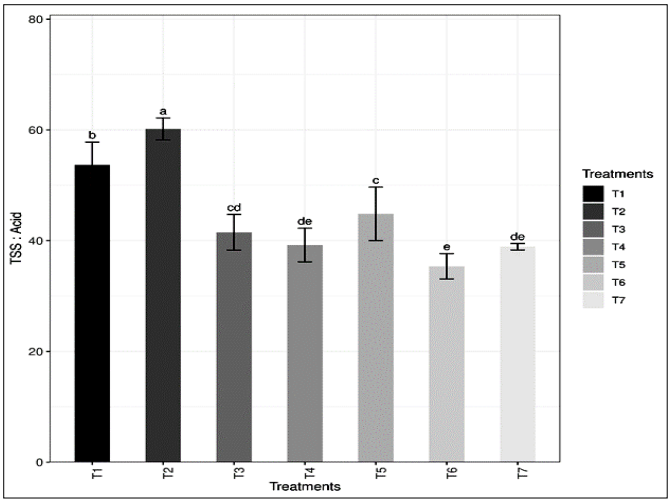

Fig. 3H. TSS: acid ratio at ripening stage.

Fig. 3. Influence of pre-harvest bagging on biochemical attribute in mango cv. banganapalli at harvest and ripening stage. T1- red/black double-layered bag, T2- brown/black double-layered bag, T3- single-layered brown paper bag, T4- single-layered white paper bag, T5- butter paper bag, T6- agroplastic sleeve bag, T7- control (no bagging).

and β-glucosidase. Additionally, there was a positive correlation with TSS, ascorbic acid, TSS: acid ratio, total sugars, reducing sugars, and beta carotene. In contrast, these variables negatively correlated with physiological weight loss, disease incidence, fruit fly incidence, and acidity (Fig. 4)

Conclusion

This study established that pre-harvest fruit bagging modified the microclimatic conditions surrounding the fruit surface, creating an advantageous environment for fruit growth and development. The technique proved successful in enhancing both fruit quality and shelf life. The brown/black double-layer bag yielded the most favorable outcomes across all parameters among the various bagging treatments. Therefore, the brown/black double-layer bag is recommended for mango farmers in India, as it results in superior fruit quality and extended shelf life, enabling farmers to secure lucrative returns in both domestic and export markets. Future studies could explore optimizing bagging techniques for different conditions, assess the long-term environmental impacts, and examine consumer preferences for bagged fruits. Overall, this research lays a solid foundation for improving sustainable practices in mango farming.

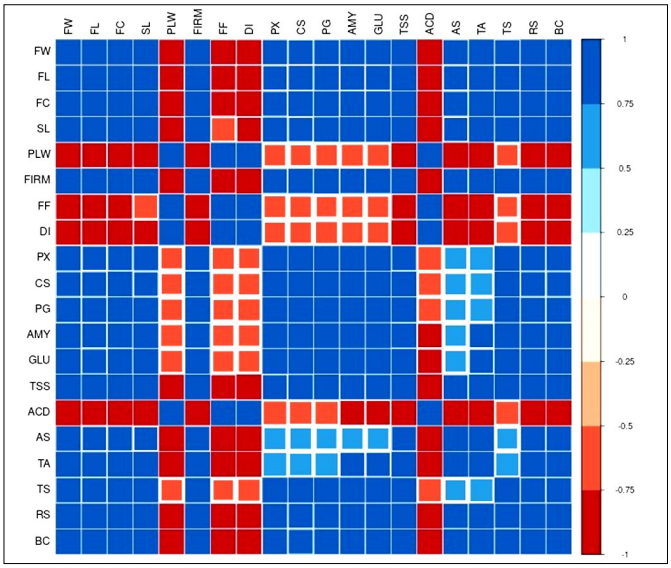

Fig. 4. This correlogram provides a comprehensive overview of the interactions among various variables related to mango fruit quality. It highlights the key factors influencing fruits' overall quality and shelf life. FW- Fruit weight, FL- Fruit length, FC- Fruit circumference, SL- Shelf life, FIRM- Firmness, PX- Peroxidase, CX- Catalase, TSS- Total soluble solids, AS- Ascorbic acid, TA - TSS: Acid ratio, TS- Total sugars, RS- Reducing sugars, BC- Beta carotene, PLW- Physiological loss in weight, DI- Disease incidence, FF- Fruit fly incidence, ACD- Acidity, PG- Polygalacturonase, AMY- Amylase and GLU- β-Glucosidase.

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Authors' contributions

MV, IM and PS contributed to conceptualizing and supervising the research design and experimental planning. MV and KAS carried out the experiment, data collection, and analysis. AS^1 and AS^2 imposed the experiment. KAS and IM helped with the statistical analysis. All authors read and approved the final version(AS^1 stands for A Senthil and AS^2 stands for A Suganthi).

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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