Effect of Various Post-Harvest Techniques on Banana (Musa spp.) Cultivar Quality

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A comparative study was conducted to evaluate the efficacy of four different post-harvest treatments (T0 (Control), T1: Fruit kept in perforated polyethylene bag, T2: Fruits kept in colour polythene bag, and T3: Fruits treated with aloe-vera gel assisted with gibberellic acid (GA3) on the quality attributes and shelf life of two economically important banana cultivars, G-9 (V1) and Bombay (V2), over a 24-day storage period. The study showed that post-harvest treatments had not worked the same way for both cultivars. Each variety responded differently, with a clear trade-off between keeping the fruit firm and slowing down the biochemical changes tied to ripening. T3 stood out for reducing weight loss in both varieties, resulting in a weight reduction of approximately 10.5%. That showed strong peel protection against water loss. However, once you look at ripening, the situation changes: in V1, T3 showed increased sugar levels rapidly, giving the highest sugar and TSS values, while in V2 showed lower sugar development. By contrast, T2 slowed ripening visually in V1 and kept TSS values in a better range for V2. However, the shelf-life assessment revealed a critical limitation: while V1 maintained a 12-day shelf life across all treatments, the V2 (Bombay) variety proved highly sensitive to T1 and T2, which unexpectedly reduced its marketed shelf life to only 9 days. This result highlights the challenges of applying uniform treatments across varieties. The varying results highlight the challenge of applying a single technique to all varieties: T3 is the most effective at delaying weight loss; however, its inconsistent effects on sugar development indicate the necessity of treatment plans specific to each variety, striking the correct balance between reducing transpiration and directing ripening.

Keywords: Postharvest, edible coating, shelf-life, polyethene packing, banana varieties, Aloe-Vera gel, gibberellic acid.

Introduction:

Bananas (Musa spp.) rank among the most popular and extensively cultivated fruits globally. Asia plays a major role in their production, as the crop thrives in tropical, subtropical, and even arid to semi-arid environments when sufficient water is available. More than a thousand distinct varieties are currently grown across these regions. Bananas serve as both a staple food and a valuable export commodity. In Pakistan, particularly in Sindh province, they are transported overland to neighboring countries such as Afghanistan and Iran. Global banana production is estimated at around 50 billion tons, with Cavendish bananas accounting for nearly half of the total yield[1]. In Pakistan, bananas are among the most widely consumed fruits, particularly in Sindh, where their production surpasses that of many other locally grown fruits. Because of their high production, bananas remain affordable and are available throughout the year. Nutritionally, they provide a rich source of carbohydrates and moderate amounts of protein, along with essential vitamins such as B and C, and vital minerals including potassium and magnesium. In Pakistan, banana cultivation spans approximately 85,990 acres, with Sindh province accounting for nearly 87% of the total production. Within Sindh, the dwarf Cavendish variety dominates, contributing about 95% of the overall output. The banana's nutritional value, affordability, and adaptability have made it an essential component of rural economies and agricultural food security. This occurs as a result of its ability to withstand the severe conditions of varying temperatures and winds[2].

The perishable nature of bananas makes post-harvest losses a major concern, creating serious challenges for growers, traders, and the overall supply chain in Pakistan. In contrast, developed countries experience significantly lower post-harvest losses, ranging from only 5–25%[3],[4]. Even though it accelerates upmarket readiness, ripening with smoke induction is another frequent problem in the postharvest chain that degrades and produces uneven ripening, which leads to texture disintegration and a drop in consumer appeal[5].

Banana post-harvest handling is the focus of intensive research worldwide, ranging from chemical and biological treatments to temperature control and modified atmosphere packaging. Growth regulators (gibberellic acid, or GA_3), edible coatings (aloe vera gel), and packaging (polyethylene) are being investigated among these solutions to increase shelf life, reduce fruit respiration, and maintain fruit texture. Pakistan, like many other developing nations, loses an estimated 25–50% of its fruit production annually, amounting to nearly Rs. 1,156 million in value. In contrast, developed countries experience significantly lower post-harvest losses, ranging from only 5–25%[3],[4].

This variation in banana cultivars is vast and hence raises important questions. These questions include whether a single treatment strikes a balance between metabolic control and physical preservation, as well as how different banana varieties respond to the same treatment. Although limited comparative research exists in Pakistan, where local varieties such as G-9 (Grand Naine) and Bombay dominate the market, available studies indicate that post-harvest responses are often variety-specific. Growers run the risk of using methods that could increase the shelf life of one cultivar while decreasing the marketability of another if they are unaware of this[6].

This study compared four post-harvest techniques (control storage, perforated polyethylene bags, colored polythene bags, and aloe vera gel with GA_3) on two banana cultivars, G-9 and Bombay, to address the identified gaps. The objective is to evaluate both physical parameters (weight loss, moisture content, pulp-to-peel ratio) and biochemical variations (dry matter, total soluble solids, total sugar, pH) over a 24-day storage period. The study found that certain treatment-cultivar combinations offered balanced benefits for shelf life, ripening control, and fruit quality[7].

The novelty of this study is that it examines several post-harvest methods. Including various packaging techniques on two locally prominent banana varieties (G-9 and Bombay) under controlled storage conditions, as well as applying edible coating with aloe vera gel assisted with GA_3. There were not many studies in Pakistan that evaluated this combined approach, and none that compared the responses of different varieties directly. By undertaking this, this research supports variety-specific preservation tactics as opposed to using general techniques.

Materials and Methods:

The present laboratory experiment was conducted at the Laboratory of the Department of Farm Structures and Postharvest Engineering, Faculty of Agricultural Engineering and Technology, Agriculture University, Tandojam (Plate-1), during the period May to June 2024.

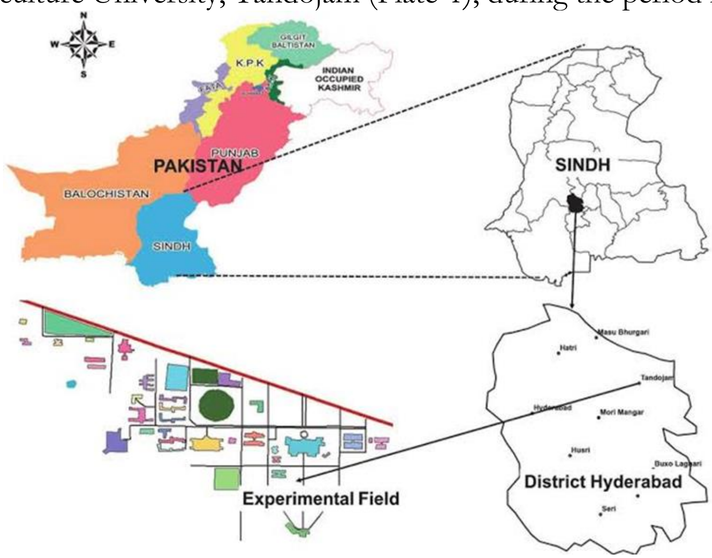

Plate 1. Layout of experiment site[25].

Experimental Arrangement:

The two-factor experiment was conducted using a completely randomized design (CRD) with three replications. The banana samples were collected from Rizvi Agricultural Farm, District Tando Allahyar, Sindh, Pakistan. Mature fruits of the banana were harvested. Two types of post-harvest factors were considered in the study: varieties and post-harvest methods, both treated as post-harvest techniques.

Factor A: Two different varieties of banana:

V1: Grand Nine (G-9)

V2: Bombay

Factor B: Different post-harvest methods:

There were eight (4) different post-harvest methods examined (T_1 to T_3). T_0 was considered as a control method.

T_0: Control open space (ambient temperature).

T_1: Fruit kept in a perforated polyethylene bag.
T_2: Fruits kept in a colored polythene bag.
T_3: Fruits treated with aloe vera gel assisted with gibberellic acid (GA3).

In the morning hours, six bunches from each variety were harvested and immediately transported to the Department of Farm Structures and Postharvest Engineering (FS&PE), Faculty of Agricultural Engineering and Technology (FAET), Sindh Agriculture University (SAU), Tandojam. The bunches were carefully handled during transport to prevent injury and were subsequently stored in the FS&PE laboratory under appropriate storage conditions. Immediately after collecting, the bunches were pre-cooled by the fan to remove the field heat. From each bunch of every cultivar, the upper and lower one to two hands were removed to obtain experimental units of uniform size. Mature banana fruits, physically similar fruits of approximately more or less uniform size, shape, and color, were selected. A total of 30 hands, each consisting of 8 fingers, were carefully selected from each variety for use in the experiment. The skin of banana fruits was cleaned with the help of soft tissue paper just before setting. All laboratory standards were strictly followed during the experiment to ensure that the results remained free from contamination and error.

Observation:

Fruits used in the experiment were observed at 3-day intervals for a total of 24 days. Data was collected on weight loss, physical and chemical changes, and root-ness of the fruits. In the experiment, the following parameters were studied:

External fruit characters:

Banana fruit, a versatile and widely consumed fruit, exhibits distinct external characteristics that vary depending on the cultivar and ripeness stage. The fruits were first evaluated for external characteristics such as shape, size, and peel thickness. Changes in peel color during storage were monitored by comparing the pericarp color with a standard color chart[8].

Total weight loss (%):

The initial weight of each banana bunch was recorded using a top balance. The bunches were then stored, and percentage weight loss was determined at regular intervals of three days (0, 3, 6, 9, 12, 16, 18, 21, and 24 days) using the following formula (1):

$$Weight\ loss\ (\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100 \ldots\ldots\ldots \quad (1)$$

Pulp to peel ratio:

During storage, the pulp-to-peel ratio can change slightly due to factors like water loss and ripening. As the fruit ripens, the peel may become thinner, and the pulp may increase in weight relative to the peel. However, the overall change in the ratio is usually not significant.

Moisture content (%):

From each treatment and replication, 5 g of banana pulp were weighed into a Petri dish and placed in an electric oven at 105°C for 24 hours until a constant weight was achieved. The dishes were then cooled, reweighed, and finally, the percentage moisture content of banana pulp was calculated using Equation (2) [9]. Finally, the percentage moisture content of banana pulp was calculated using the following formula:

$$Moisture\ content\ (\%) = \frac{wet\ weight - dry\ weight}{wet\ weight} \times 100 \ldots\ldots\ldots \quad (2)$$

Dry matter (%):

Dry matter content was determined as the portion of banana pulp that remained after moisture removal. The pulp samples were oven-dried following the standard procedure, and the dry matter percentage was calculated using Equation (3).

$$Dry\ matter\ content\ (\%) = 100 - Moisture\ content\ (\%) \ldots\ldots\ldots \quad (3)$$

Total soluble solids (TSS) content of banana pulp (%Brix):

Total soluble solids (TSS) represent the dissolved solids in banana pulp, mainly sugars, acids, and minerals. TSS was measured using a refractometer, which determines the refractive index of the pulp juice and directly provides values in °Brix. The sugar content was then estimated from the refractometer reading, and the TSS percentage was calculated using Equation (4).

$$\text{TSS}\ (\%) = \text{Reading of refractometer}\ (\%) \times 0.8 \ldots\ldots\ldots \quad (4)$$

Total sugar content of banana pulp:

The total sugar content of banana pulp was estimated from the TSS values obtained with the refractometer. Using the standard formula (5), the sugar concentration of the pulp was calculated in relation to the total soluble solids reading.

% Total sugar content=Fehling's solution ×100×Dilution (5)

pH of banana pulp:

Banana pulp samples were prepared by mashing the fruit and extracting the juice, which was then analyzed for acidity. A pH meter was calibrated with standard buffer solutions, and the electrode was immersed in the prepared pulp juice to record the pH values.

Shelf life:

The shelf life of banana fruits under different post-harvest treatments was determined by counting the number of days taken to reach full ripeness while maintaining optimum market and eating quality.

Statistical analysis:

The collected data were statistically analyzed to find out the variation resulting from experimental treatments following the F-test variance tests. The significant difference between the pair of means was compared by the LSD test at 5% level of probability[10].

Result & Discussion:

Total Weight Loss (%):

Figure 1 shows the effect of various post-harvest treatments on the total weight loss (%) of two banana varieties, G-9 (V1) and Bombay (V2), over a 24-day storage period. In all treatments and varieties, weight loss increased progressively throughout storage. For variety V1, the untreated control (T0) exhibited the highest final weight loss (12.76%), whereas treatment T3 resulted in the lowest (10.98%), showing its superior effectiveness. T1 (11.44%) was close to T3, while T2 (12.51%) was similar to the control. Similarly, for variety V2, the control (T0) ended at 11.51%, while T3 again produced the lowest weight loss (10.52%). In contrast, T2 (12.7%) and T1 (12.44%) performed inferior to the control, suggesting variety-specific responses. Varietal comparison showed that V2 generally had lower initial losses than V1, though by Day 24, both varieties experienced similar cumulative losses, ranging between ~11–13%. Across both varieties, weight loss followed a linear increase with storage time, and T3 was consistently the most effective treatment.

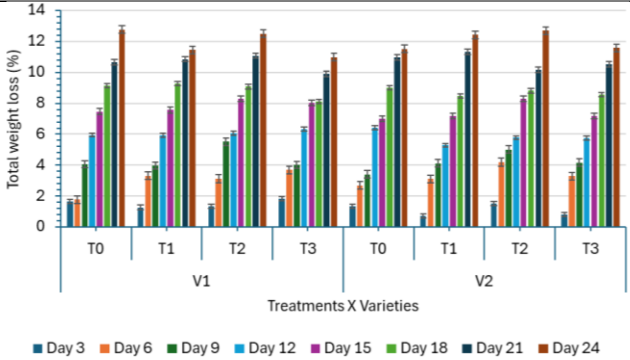

Figure 1. Total weight loss (%) of banana varieties (G-9 and Bombay) under the different postharvest treatments during storage.

Pulp to peel ratio:

Figure 2 presents the pulp-to-peel ratio, an inverse indicator of peel thickness and a measure of ripening stage, which generally decreased over the 24-day storage period for both V1 and V2 across all treatments. Figure 2 showed that the decreasing trend reflected a continuous reduction in the proportion of pulp relative to the peel. For V1, T3 maintained the highest ratio across storage, while in V2, the control (T0) finished highest and T3 lowest, indicating variety-specific differences, meaning that the T3 treatment was less effective or detrimental in maintaining the pulp-to-peel ratio in this variety. In summary, post-harvest treatments had a differential impact on the two varieties, with T3 being highly beneficial for V1 but detrimental for V2.

Moisture Content (%):

The moisture content of the banana fruit decreased consistently throughout the 24-day storage period for both varieties (V1 and V2) and all post-harvest treatments; a trend generally correlated with ripening and weight loss. Figure 3 showed that variety V1 maintained a significantly higher overall moisture content than V2. For V1, the T3 treatment was the most effective in moisture preservation, maintaining the highest content (89.12 to 75.88%) on Day 24. Conversely, the T0 (Control) treatment for V1 resulted in the lowest final moisture content (68.11%). For variety V2, the T2 treatment was the most effective, maintaining the highest final moisture content (72.39%) on Day 24, while the T0 and T1 treatments led to the lowest final values, both finishing near 66%. Overall, the T3 treatment was highly successful in moisture retention for V1, while the T2 treatment performed best for V2.

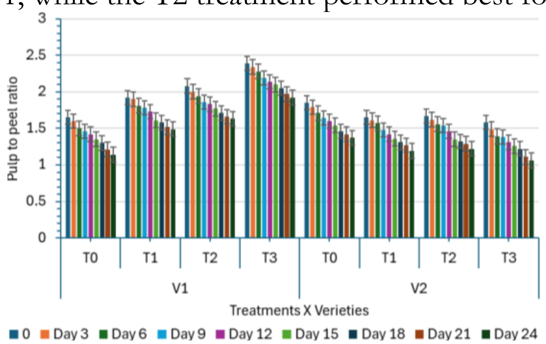

Figure 2. Pulp to peel ratio of banana varieties (G-9 and Bombay) under the different postharvest treatments during storage.

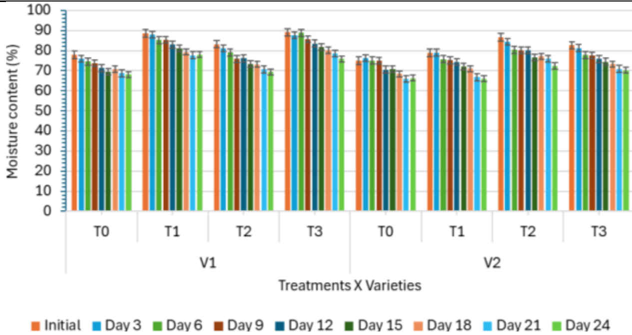

Figure 3. Moisture content (%) of banana varieties (G-9 and Bombay) under the different postharvest treatments during storage.

Dry Matter (%):

The dry matter content of the banana fruit increased progressively throughout the 24-day storage period for both varieties (V1 and V2) across all post-harvest treatments, a trend inversely related to moisture loss and starch-to-sugar conversion during ripening. Figure 4 showed that variety V2 consistently maintained a higher overall dry matter content compared to V1. For V1, the T0 (Control) treatment, despite having the highest initial content (22.1%), also showed the highest final dry matter (31.89%) on Day 24, suggesting a rapid advancement of ripening and moisture loss. Conversely, the T3 treatment for V1 resulted in the lowest final dry matter (24.12%), indicating it was the most effective treatment for slowing the metabolic changes. For V2, treatment T1 produced the highest final dry matter (33.93%), while T2 resulted in the lowest (27.61%).

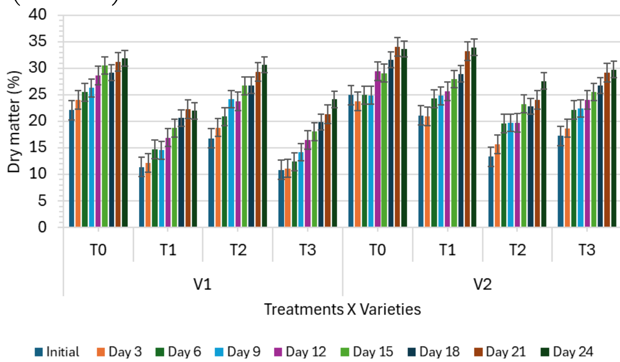

Figure 4. Dry matter (%) of banana varieties (G-9 and Bombay) under the different postharvest treatments during storage.

Total Sugar Content (%):

Figure 5 showed the total sugar content (TSC) for all treatments and varieties, which increased consistently throughout the 24-day storage period, reflecting the typical hydrolysis of starch into simple sugars during ripening. Variety V1 maintained consistently higher total sugar content than V2 across all treatments. In V1, treatment T3, which started with the highest initial TSC (23.64%), also recorded the highest final TSC (30.93%) on Day 24, indicating that this treatment significantly accelerated the ripening process. The V1 control (T0) had a lower initial value (15.06%) and a considerably lower final TSC (21.51%). In contrast, for V2, all treatments, including the control, resulted in much lower final TSC, clustering between 18.13% (T3) and 20.48% (T0).

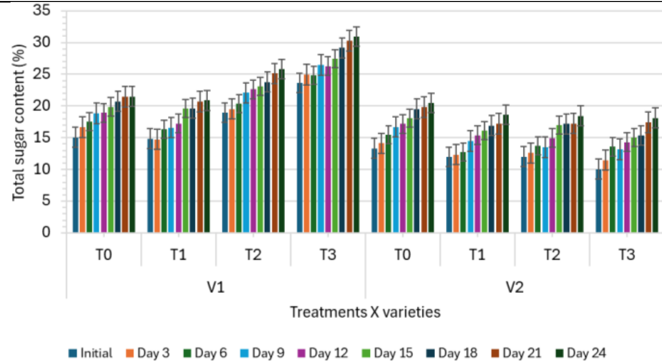

Figure 5. Total sugar content (%) of banana varieties (G-9 and Bombay) under the different postharvest treatments during storage.

Total Soluble Solids (TSS):

The Total Soluble Solids (TSS), a key indicator of sugar content and ripeness, increased consistently across all post-harvest treatments and both varieties (V1 and V2) over the 24-day storage period. Figure 6 showed that variety V1 generally maintained higher total soluble solids (TSS) than variety V2. In V1, treatment T3, which started with a high initial TSS (14.78 °Brix), reached the highest final TSS (19.95 °Brix) on Day 24, indicating that this treatment significantly enhanced ripening-related accumulation of soluble solids. The T0 (Control) treatment for V1 finished with the lowest final TSS (13.22∘Brix). Similarly, for Variety V2, the T2 treatment produced the highest final TSS (18.11∘Brix), while the T0 (Control) produced the lowest (13.21∘Brix). Overall, treatments T2 and T3 consistently resulted in a greater final TSS accumulation compared to the control, though the most effective treatment was variety-dependent (T3 for V1 and T2 for V2).

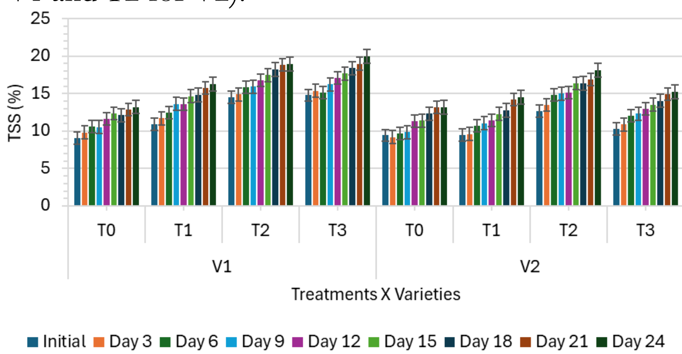

Figure 6. Total soluble solids (%) of banana varieties (G-9 and Bombay) under the different postharvest treatments during storage.

pH:

Figure 7 showed that the pH of the banana fruit decreased consistently across all treatments and varieties (V1 and V2) over the 24-day storage period, which is characteristic of organic acid accumulation during ripening. Variety V1 maintained a significantly higher overall pH than V2. In V1, treatment T3, which started with the highest initial pH (6.32), remained the most effective at buffering acid accumulation, recording the highest final pH (5.11) on Day 24. Conversely, the T0 (Control) and T1 treatments for V1 resulted in the lowest final pH values (4.18 and 3.95). V2 showed a more rapid decrease, with all treatments converging to final values between 3.54 and 3.77. The T0 (Control) treatment for V2 resulted in the highest final pH (3.77), while the T1 treatment resulted in the lowest (3.54). Overall, the T3 treatment was the most successful in slowing the drop in acidity for V1, while the treatments had a negligible differential effect on the final, highly acidic pH of V2.

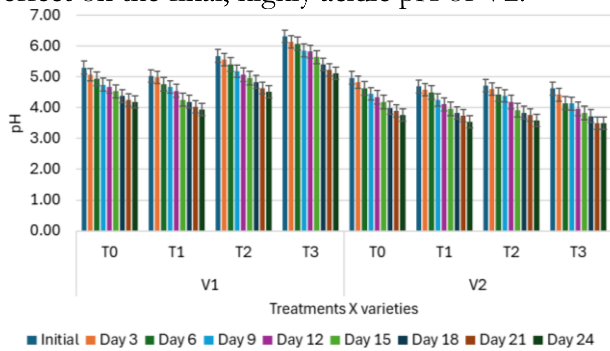

Figure 7. pH of banana varieties (G-9 and Bombay) under the different postharvest treatments during storage.

Shelf Life and Visual Deterioration:

Table 1 showed that the G-9 variety maintained a consistent shelf life of 12 days across all treatments (T0 to T3). However, T2 was the only treatment that successfully delayed ripening for G-9, with fruits only reaching a yellowish-green stage by Day 12, whereas T0, T1, and T3 resulted in full deterioration (yellowish to black). In contrast, the Bombay variety showed a more variable response; its maximum shelf life of 12 days was achieved by the control (T0) and T3, while treatments T1 and T2 reduced shelf life to only 9 days, indicating an early onset of quality loss independent of full color development.

Table 1. Determine the shelf-life (days) of different varieties of banana fruits under various treatments for a 24-day storage period.

Variety	Treatment	Shelf Life (Days)	Ripening Stage Reached	Notes on Deterioration
G-9	T0	12	Yellowish black	Deteriorated by day 12
	T1	12	Yellowish black	Similar to control
	T2	12	Yellowish green	Delay in ripening observed
	T3	12	Yellowish black	No improvement in shelf life
Bombay	T0	12	Fully ripe (yellow, black)	Deteriorated after day 12
	T1	9	Yellowish green	Early deterioration from day 12
	T2	9	Yellowish green	Deterioration begins on day 12
	T3	12	Yellowish black	Slightly extended shelf life

Discussion:

Total Weight Loss (%):

Weight loss increased linearly in all banana samples due to continuous respiration and transpiration, a typical post-harvest trend. Treatment T3 was the most effective across both varieties, achieving the lowest final losses and showing strong protection against transpiration and reducing moisture transfer. Conversely, the control (T0) for V1 and, unexpectedly, T2 for V2 resulted in the highest weight loss, highlighting the variety-specific adverse effects of some treatments on peel integrity. The effectiveness of T3 in mitigating this primary source of market loss is crucial for extended storage[11],[12].

Pulp-to-Peel Ratio:

The pulp-to-peel ratio decreased consistently, reflecting the continuous ripening process where moisture loss from the pulp exceeds that from the peel, causing the peel to appear relatively thicker. For V1, T3 maintained the highest ratio throughout storage, while in V2, the control ended with the highest ratio and T3 the lowest, highlighting clear varietal differences, indicating a differential impact on moisture migration and cell wall breakdown. This parameter strongly emphasizes the variety-specific influence of the post-harvest environment on fruit composition[13],[14].

Moisture Content (%):

The moisture content decreased progressively throughout storage, directly correlating with the observed weight loss. Treatment T3 was the most effective in preserving moisture in V1, while the control for V1 resulted in the lowest final moisture. For V2, T2 was the most effective, whereas T0 and T1 led to the lowest final moisture values. Overall, T3 was highly successful in moisture retention for V1, while T2 performed best for V2, indicating that the structural properties and respiratory metabolism of the cultivars respond uniquely to the applied post-harvest barrier. Treatments that maintain a high moisture content directly contribute to a more acceptable texture and prolonged freshness[9], [15].

Dry Matter (%):

Dry matter content increased due to the concentration effect caused by moisture loss and the breakdown of starch into soluble sugars. Treatment T3 was the most effective at delaying dry matter accumulation in V1, indicating a reduction in metabolic rate despite its weight-loss prevention ability. Conversely, T0 resulted in the highest final dry matter for V1, suggesting rapid ripening and desiccation. For V2, T2 resulted in the lowest final dry matter, further illustrating the need for variety-specific treatment optimization[16],[17].

Total Sugar Content (%):

Total Sugar Content (TSC) increased significantly, a definitive indicator of ripening where complex starch is hydrolyzed into simple sugars. Treatment T3 significantly accelerated sugar conversion in V1, despite its physical preservation role, suggesting an enhancing effect on key ripening enzymes. Conversely, T3 resulted in the lowest TSC for V2, demonstrating its inhibitory effect on sugar accumulation in this specific cultivar. This disparity reveals that T3's primary function is a variety-dependent modulator of the ripening cascade, not a simple preservative[18],[19].

pH:

The pH decreased (acidity increased) across all samples due to the synthesis and accumulation of organic acids during ripening. Treatment T3 was the most effective at buffering this pH drop in V1, indicating a slowdown in the acid production pathway. However, V2 exhibited a more rapid and severe pH drop, with all treatments resulting in highly acidic final values. The pH profile confirms the more acidic nature and potentially faster ripening progression of the Bombay (V2) cultivar compared to G-9 (V1)[20],[21].

Total Soluble Solids (TSS):

TSS increased continually, mirroring the Total Sugar Content and serving as a reliable measure of ripeness and sweetness. Consistent with TSC results, T3 accelerated TSS accumulation in V1, but T2 produced the highest final TSS in V2, outperforming T3. The T0 control consistently resulted in the lowest final TSS for both varieties, suggesting that all active treatments enhance the solubilization of fruit solids. The different performance of T3 and T2 across varieties highlights the differential effect on starch-degrading enzymes[20],[22].

Shelf Life and Visual Deterioration:

The shelf-life assessment demonstrated clear varietal differences in response to treatments. V1 maintained a 12-day shelf life across the board, with T2 successfully delaying ripening colour change (yellowish green) compared to the quick deterioration observed in T0, T1, and T3. Conversely, V2 proved sensitive: while T0 and T3 maintained 12 days, treatments T1 and T2 unexpectedly reduced the shelf life to 9 days, suggesting an acceleration of senescence or quality loss not tied to full colour development. This observation is critical, as a reduction in actual market shelf life negates any potential quality benefits[23],[24].

Conclusion:

The present research clearly establishes that the successful preservation of banana quality post-harvest is highly contingent upon the specific variety and the targeted quality parameter. Across all metrics, the efficacy of the treatments proved to be non-universal. Treatment T3 emerged as the dominant strategy for maintaining physical integrity, demonstrating its superior ability to form a protective barrier against moisture loss by achieving the lowest cumulative weight loss in both V1 and V2 (10.52% for V2) and thereby maximizing moisture retention. However, this preservation came with a significant trade-off in metabolic control: T3 accelerated the ripening process in V1, evidenced by the highest final Total Sugar (30.93%) and TSS (19.95∘Brix). Conversely, Treatment T2 showed greater success in delaying metabolic change for specific outcomes, being the most effective at visually postponing ripening in V1 (reaching only yellowish to green by Day 12) and minimizing final dry matter accumulation in V2. Shelf-life assessment reinforced the variety dependence: V1 consistently held a 12-day shelf life, while the V2 (Bombay) variety was detrimentally sensitive to T1 and T2, which unexpectedly reduced its shelf life to a mere 9 days. In conclusion, effective post-harvest management requires a dual focus on variety and specific treatment goal, as the best barrier treatment (T3) can also be the fastest ripening accelerator.

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Author Contributions: Mian Noor Hussain Asghar Ali designed and planned the research, performed statistical analyses, interpreted the results, prepared the manuscript, supervised the entire study, and provided overall guidance. Wajid Hussain Soomro and Manzoor Ali Magsi collected the data, prepared the illustrations. Shakeel Hussain Chattah, Mashooque Ali Talpur, and Zaheer Ahmed Khan contributed to the assistance in research planning and methodology, development, reviewing manuscripts, and interpretation of results. Ain-ul-Abad Syed and Naseer Ahmed Abbasi carried out proofreading to ensure accuracy and clarity.

Conflict of Interest:

The authors assert that they have no conflicts of interest to declare.

Data Availability Statement:

The data can be obtained from the corresponding author upon a reasonable request.

Ethics Approval:

Not applicable to this paper.

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References:

[1] Food and Agriculture Organization (FAO), "Banana facts and figures," 2019, [Online]. Available: https://www.fao.org/economic/est/est-commodities/oilcrops/bananas/bananafacts/en/

[2] Agribusiness Support Fund (ASF), "ASF Helps Commercial Banana Growers in Sindh Improve Quality and Profitability," 2023, [Online]. Available: https://agribusiness.org.pk/success-stories/usaid-helps-commercial-banana-growers-in-sindh-improve-quality-and-profitability/

[3] M. Amiruzzaman, "Postharvest handling and processing of fruits and vegetables," *Kitchen Gard. Homestd. Product. Act.*, p. 22, 1990, [Online]. Available: https://scholar.google.com/scholar_lookup?title=Postharvest+handling+and+processing+of+fruits+and+vegetables&author=M.+Amiruzzaman&publication_year=1990

[4] S. E. S. A. Khader, "Effect of gibberellic acid and Vapor Gard on ripening, amylase and peroxidase activities and quality of mango fruits during storage," *J. Hortic. Sci.*, vol. 67, no. 6, pp. 855–860, Jan. 1992, doi: 10.1080/00221589.1992.11516318.

[5] S. Janghu, V. Kumar, and A. K. Yadav, "Post-Harvest Management of Fruits and Vegetables," *Curr. Perspect. Agric. Food Sci. Vol. 7*, pp. 125–148, Feb. 2024, doi: 10.9734/BPI/CPAFS/V7/7984E.

[6] R. Solórzano, H. A. Ramírez Maguiña, L. Johnson, C. Ureta Sierra, and J. Cruz, "Current Progress in Microbial Biocontrol of Banana Fusarium Wilt: A Systematic Review," *Agron. 2025, Vol. 15, Page 619*, vol. 15, no. 3, p. 619, Feb. 2025, doi: 10.3390/AGRONOMY15030619.

[7] T. Al Rifat, S. F. T. Boni, M. S. Hossain, S. M. S. Rahman, and M. Z. Mahmud, "Effect of Aloe Vera Gel Coating and Different Conventional Packaging Materials on Shelf Life Extension of Banana," Aug. 2024, doi: 10.21203/RS.3.RS-4892454/V1.

[8] J. Zhuang *et al.*, "Assessment of External Properties for Identifying Banana Fruit Maturity Stages Using Optical Imaging Techniques," *Sensors 2019, Vol. 19, Page 2910*, vol. 19, no. 13, p. 2910, Jul. 2019, doi: 10.3390/S19132910.

[9] M. N. H. Asghar Ali, J. Peng, J. Bi, J. Yi, and Y. Y. Zhao, "Title: Effects of Instant Controlled Pressure Drop (DIC) Drying on the Texture and Tissue Morphology of Fruits and Vegetables," *Int. J. Food Eng.*, vol. 14, no. 7–8, Jul. 2018, doi: 10.1515/IJFE-2018-0153/MACHINEREADABLECITATION/RIS.

[10] A. A. G. Kwanchai A. Gomez, "Statistical Procedures for Agricultural Research," John Wiley & Sons,. Accessed: Mar. 24, 2025. [Online]. Available: https://books.google.com.pk/books/about/Statistical_Procedures_for_Agricultural.html?id=PVN7_XRhpdUC&redir_esc=y

[11] M. Al-Dairi, P. B. Pathare, R. Al-Yahyai, H. Jayasuriya, and Z. Al-Attabi, "Postharvest quality, technologies, and strategies to reduce losses along the supply chain of banana: A review," *Trends Food Sci. Technol.*, vol. 134, pp. 177–191, Apr. 2023, doi: 10.1016/J.TIFS.2023.03.003.

[12] M. Xia *et al.*, "Impact of packaging materials on bruise damage in kiwifruit during free drop test," *Acta Physiol. Plant.*, vol. 42, no. 7, pp. 1–11, Jul. 2020, doi: 10.1007/S11738-020-03081-5/METRICS.

[13] O. Article, S. Anjum, and S. Sundaram, "COMPARATIVE STUDY ON NUTRIENT COMPOSITION AND FUNCTIONAL CHARACTERISTICS OF TROPICAL FRUITS WITH EMPHASIS ON BANANA FRUIT PEEL," *Int. J. Pharm. Pharm. Sci.*, pp. 25–35, May

2022, doi: 10.22159/IJPPS.2022V14I5.44144.
[14] S. Ghafoor and Azizuddin, "Empirical comparison of changes in the peel and pulp of Cavendish basrai banana ripening under various stored stages," *Pakistan J. Agric. Sci.*, vol. 55, no. 4, pp. 853–862, Dec. 2018, doi: 10.21162/PAKJAS/18.3808.
[15] N. E. Cerquera, E. Pastrana, and J. K. Castro, "DETERMINATION OF THE DRYING VARIABLES FOR DEHYDRATION OF BANANA PULP SHEETS (Musa paradisiaca L.)," vol. 12, no. 1, 2017, Accessed: Oct. 05, 2025. [Online]. Available: www.arpnjournals.com
[16] J. Zhang *et al.*, "Nutrient and dry matter accumulation in different generations of banana at different growth stages," *Rev. Zhang, C Wang, Z Fang, B Li, P Christie, X LiFruits, 2019•revues.cirad.fr*, 2019, doi: 10.17660/th2019/74.2.4.
[17] S. R. Fatemeh, R. Saifullah, F. M. A. Abbas, and M. E. Azhar, "Total phenolics, flavonoids and antioxidant activity of banana pulp and peel flours: influence of variety and stage of ripeness," *Int. Food Res. J.*, vol. 19, no. 3, pp. 1041–1046, 2012.
[18] J. Marriott, M. Robinson, and S. K. Karikari, "Starch and sugar transformation during the ripening of plantains and bananas," *J. Sci. Food Agric.*, vol. 32, no. 10, pp. 1021–1026, Oct. 1981, doi: 10.1002/JSFA.2740321011.
[19] Z. A. Salih, A. Siddeeg, R. TATaha, M. Bushra, A.-F. Ammar, and A. O. Ali, "Physicochemical and Functional Properties of Pulp and Peel Flour of Dried Green and Ripe Banana (Cavendish)," 2017. Accessed: Oct. 05, 2025. [Online]. Available: https://www.researchgate.net/publication/322292115_Physicochemical_and_Functional_Properties_of_Pulp_and_Peel_Flour_of_Dried_Green_and_Ripe_Banana_Cavendish
[20] R. Bazaz, W. N. Baba, F. A. Masoodi, and S. Yaqoob, "Effect of some preservation techniques on quality parameters and antioxidant properties of banana pulp during storage," *J. Food Meas. Charact.*, vol. 12, no. 1, pp. 661–673, Mar. 2018, doi: 10.1007/S11694-017-9679-Y/METRICS.
[21] C. de O. Vogado *et al.*, "Enrichment of Probiotic Fermented Milk with Green Banana Pulp: Characterization Microbiological, Physicochemical and Sensory," *Nutr. 2018, Vol. 10, Page 427*, vol. 10, no. 4, p. 427, Mar. 2018, doi: 10.3390/NU10040427.
[22] M. M. Ali and R. B. Janius, "PREDICTION OF TOTAL SOLUBLE SOLIDS AND PH IN BANANA USING NEAR INFRARED SPECTROSCOPY," *J. Eng. Sci. Technol.*, vol. 13, no. 1, pp. 254–264, 2018.
[23] I. Fernando, J. Fei, R. Stanley, H. Enshaei, and A. Eyles, "Quality deterioration of bananas in the post-harvest supply chain- an empirical study," *Mod. Supply Chain Res. Appl.*, vol. 1, no. 2, pp. 135–154, Dec. 2019, doi: 10.1108/MSCRA-05-2019-0012.
[24] S. H. Othman, N. A. Abdullah, N. Nordin, N. N. Abdul Karim Shah, M. Z. Mohd Nor, and K. F. Md Yunos, "Shelf life extension of Saba banana: Effect of preparation, vacuum packaging, and storage temperature," *Food Packag. Shelf Life*, vol. 28, p. 100667, Jun. 2021, doi: 10.1016/J.FPSL.2021.100667.
[25] A. A. SIYAL, S. A. SOOMRO, and A. G. SIYAL, "Performance of Pitcher Irrigation with Saline Water under High Evapotranspiration Rates," *J. Chinese Soil Water Conserv.*, vol. 46, no. 1, pp. 61–69, Mar. 2015, doi: 10.29417/JCSWC.201503_46(1).0007.