International Journal of Advanced Biochemistry Research 2025; SP-9(12): 697-708

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(12): 697-708
www.biochemjournal.com
Received: 08-09-2025
Accepted: 13-10-2025

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Influence of osmotic dehydration on physico-chemical changes and storage quality of banana slices in Kamalapur Red and Grand Naine varieties

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DOI: https://www.doi.org/10.33545/26174693.2025.v9.i12Si.6581

Abstract
This study investigated the influence of various osmotic pre-treatments on the physicochemical characteristics of banana slices (Kamalapur Red and Grand Naine varieties) over a four-month storage period, focusing on moisture content, yield, drying ratio, sugar profiles, titratable acidity and total soluble solids (TSS). Osmotic Dehydration (OD) significantly impacted all parameters, with the severity of the treatment (solution concentration, contact duration and inclusion of NaCl) being the primary determinant, although a significant variety ($\times$) treatment (V $\times$ T) interaction was consistently observed. Moisture content differed significantly between varieties, with Kamalapur Red generally retaining more moisture (average 45.56%) than Grand Naine (44.42%). Moisture loss was maximized by the most severe osmotic treatment, T8 (60°Brix, 24 h), yielding the driest slices (38.94%), while the fresh control, T13, retained the highest moisture (51.14%). Osmotic treatments, by causing water loss and solid gain, consistently reduced yield (lowest in T13 control) and increased the drying ratio (highest in T13 control, lowest in T12), which is consistent with the mass transfer mechanisms of OD. Total and reducing sugars increased substantially post-OD, peaking with the most rigorous treatments, T9 (70°Brix, 24 h) and T12 (70°Brix + 1% salt, 24 h), due to solute absorption and subsequent sucrose inversion during storage; the reducing sugars continued to increase up to 4 months, while non-reducing and total sugars exhibited minor reductions, which is indicative of ongoing inversion and non-enzymatic browning (Maillard reactions) in the low-moisture matrix. Titratable acidity (TA) was lowest in the control (T13) and the most intense OD treatments (T9, T12) and highest in the milder treatment T1 (50°Brix, 4 h), suggesting that high-severity OD results in greater acid dilution/utilization. Total Soluble Solids (TSS) also tracked treatment intensity: high-intensity protocols (high °Brix, 24 h, $\pm$ salt) resulted in the highest TSS (T9, T12) at all stages, reflecting maximal solute impregnation, while the control (T13) remained the lowest. Kamalapur Red consistently exhibited superior baseline TSS and acidity, leading to higher final TSS and TA values than Grand Naine across equivalent treatments. The results affirm that while solution concentration, contact time and salt addition dictate the overall magnitude of change, the cultivar's intrinsic composition governs the ultimate physicochemical potential and stability in the osmosed product.

Keywords: Banana, Osmotic Dehydration, Physiochemical and Storage

Introduction

Banana (*Musa* spp.) ranks among the most widely consumed fruits globally, with annual production exceeding 115 million metric tons, making it a crucial commodity for both developed and developing nations (FAO, 2020) [8]. India stands as the largest producer of bananas, contributing approximately 30% of global production, with varieties such as Grand Naine and indigenous cultivars like Kamalapur Red playing significant roles in commercial cultivation (Mohapatra *et al*., 2010) [33]. Despite their nutritional richness, including high levels of potassium, dietary fiber, vitamins and antioxidants, fresh bananas are highly perishable with moisture content ranging from 70-80%, leading to substantial post-harvest losses estimated at 20-40% in tropical regions (Aurore *et al*., 2009) [4].

The challenge of preserving banana quality while extending shelf life has driven extensive research into various preservation techniques. Among these, osmotic dehydration has emerged as a promising pre-treatment method that offers advantages over conventional drying processes by better retaining nutritional components, color, flavor and texture

(Rastogi *et al*., 2002) [23]. This process involves immersing fruit pieces in hypertonic solutions, typically containing sugars or salts, which creates an osmotic pressure gradient facilitating water removal from the fruit tissue while simultaneously allowing solute uptake (Torreggiani & Bertolo, 2001) [35]. The dual mass transfer mechanism not only reduces moisture content but also improves the physico-chemical stability of the final product.

Recent studies have demonstrated that osmotic dehydration significantly influences various quality parameters of banana products, including water activity, texture, color retention and overall sensory acceptability (Fernandes *et al*., 2016) [9]. The effectiveness of this technique depends on multiple factors such as solution concentration, temperature, immersion time, fruit-to-solution ratio and intrinsic varietal characteristics (Azoubel & Murr, 2004) [5]. Different banana varieties exhibit distinct responses to osmotic treatment due to variations in cellular structure, initial sugar content and pectin composition, which directly impact mass transfer kinetics and final product quality (Kaur & Singh, 2016) [12].

Kamalapur Red and Grand Naine represent two commercially important banana varieties with contrasting characteristics. While Grand Naine is widely cultivated for export markets due to its uniform size and extended shelf life, Kamalapur Red is valued for its distinctive flavor and nutritional profile but remains underutilized due to limited processing knowledge (Kumar *et al*., 2012) [32]. Understanding how osmotic dehydration influences the physico-chemical properties and storage stability of these varieties is essential for developing variety-specific processing protocols and reducing post-harvest losses. This study aims to investigate the comparative effects of osmotic dehydration on quality attributes and storage behavior of banana slices from both varieties, thereby contributing to the optimization of preservation strategies for diverse banana cultivars.

Materials and method

The present investigation on “Development of osmotic dehydrated product from banana” was carried out in the Department of Postharvest Management, College of Horticulture, UHS, Bagalkot, Karnataka during the year 2024-2025. The samples of banana utilized in the current study were obtained from reputed suppliers in a bid to ensure consistency and quality. Two varieties of banana were chosen in the current study and they were Grand Naine (G9) and Kamalapur Red Banana. Physiologically ripe, disease-free and uniformity in colour, size, mature fruits at the edible stage were directly taken from well-maintained orchards in and around Bagalkot district, Karnataka.

Osmosis treatment

Banana slices weighing 1 kg each were immersed in sugar syrup solutions of 50, 60 and 70°Brix at a slice to syrup ratio of 1:2 and allowed to undergo osmosis for 4, 6 and 24 hours at room temperature (20-30°C). At the end of each osmotic period, the slices were removed from the syrup and quickly rinsed with water to eliminate any sugar coating sticking to their surface and then surface dried under fan. The osmosed banana slices were then weighed and recorded in grams.

Dehydration

After osmosis treatment measured amounts of osmosed banana slices were spread arranged on stainless steel trays and placed inside a cabinet tray dryer. The slices were dried thoroughly with warm air at 55-60°C until they attained the target moisture content and quality. The duration required to reach the optimal dryness was noted for each treatment.

The laboratory experiment was conducted using a Factorial Completely Randomized Design (Factorial CRD) consisting of 26 treatments, with each treatment replicated twice.

Treatments

Factor -1	Factor -2
V_1: Kamalapur red banana	T_1: Dipping in 50°Brix sugar syrup for 4 hrs
V_2: Grand naine	T_2: Dipping in 60°Brix sugar syrup for 4 hrs
	T_3: Dipping in 70°Brix sugar syrup for 4 hrs
	T_4: Dipping in 50°Brix sugar syrup for 6 hrs
	T_5: Dipping in 60°Brix sugar syrup for 6 hrs
	T_6: Dipping in 70°Brix sugar syrup for 6 hrs
	T_7: Dipping in 50°Brix sugar syrup for 24 hrs
	T_8: Dipping in 60°Brix sugar syrup for 24 hrs
	T_9: Dipping in 70°Brix sugar syrup for 24 hrs
	T_{10}: Dipping in 50°Brix sugar syrup + 1% salt for 24 hrs
	T_{11}: Dipping in 60°Brix sugar syrup + 1% salt for 24 hrs
	T_{12}: Dipping in 70°Brix sugar syrup + 1% salt for 24 hrs
	T_{13}: Control (dip in 0.1% KMS for 10 min)

Note: Constant factors
Preservatives: KMS (0.1%), Citric acid: 0.2%

Weight loss (%)

Weight loss of the samples during storage was expressed as a percentage and calculated by recording the initial weight at the beginning of the storage period and comparing it with the weight at each sampling interval.

$$\text{Weight loss (\%)} = \frac{\text{Initial weight} - \text{Weight at time}}{\text{Initial weight}} \times 100$$

Moisture loss (%)

Moisture loss during storage or processing was determined as a percentage reduction from the initial moisture content. The calculation was based on the difference between the initial moisture and the moisture content recorded at a given time.

$$\text{Moisture loss (\%)} = \frac{\text{Initial moisture} - \text{Moisture at time}}{\text{Initial moisture}} \times 100$$

Solid gain (%)

Solid gain (%) was estimated to understand the net uptake of solutes during the process. It was calculated by subtracting the percentage weight loss from the percentage moisture loss at each sampling point, using the following expression:

Moisture loss (%) - Weight loss (%)

Yield (%)

Yield (%) was calculated to assess the amount of usable product obtained after processing. It was expressed as the ratio of the weight of the prepared fruit pieces to the weight of the fresh, unprocessed fruit, multiplied by 100.

Dehydration ratio
The dehydration ratio was calculated to evaluate the extent of moisture removal during the drying process. It was expressed as the ratio of the weight of fresh fruit slices to the weight of the dehydrated slices

$$\text{Dehydration ratio} = \frac{\text{Weight of fresh slices}}{\text{Weight of dehydrated slices}}$$

Total soluble solids (°Brix)
Total soluble solids (TSS) of fresh slices and osmo-dehydrated slices were recorded using hand refractometer (0-32° Brix). The TSS was expressed as °Brix after making necessary temperature corrections to the recorded readings.

Moisture content (%)
Moisture content was measured using a moisture balance. Two grams of the osmotically dehydrated sample were placed in the sample dish and dried within the electric moisture balance. The device automatically showed the moisture content as a percentage and signaled the completion of the measurement with an audible beep, providing a stable moisture value.

Titratable acidity (%)
Titratable acidity was determined by titrating a measured aliquot of the sample with standard 0.1 N NaOH using phenolphthalein as the indicator and the results were expressed as a percentage of citric acid.

Total sugars (%)
The lead acetate-free filtrate was prepared following the, Fifty milli liters of this filtrate was taken and 5 ml of concentrated 12N HCl was added, then left overnight to allow slow inversion. After cooling, the acid was neutralized initially with 40% NaOH and later near the endpoint with 0.1 N NaOH using phenolphthalein as an indicator, making the solution slightly alkaline. The volume was then adjusted to 100 ml. This prepared solution was titrated against Fehling's solution to estimate total sugars, with the results expressed as a percentage on a weight basis.

$$\text{Total sugars \%} = \frac{\text{Factor x Volume made up x Dilution x 1000}}{\text{Titre value x Sample weight}}$$

Sucrose % = (Total sugars % - Reducing sugars %) x 0.95

Total sugars % = Reducing sugars % + Sucrose %

Results and Discussion

Effect of pre-treatments on moisture content (%) of osmosed banana slices
Significant difference in moisture content among types, with Kamalapur Red (45.56%) outperforming Grand Naine (44.42%). Significant disparities existed across the treatments. T_{13} exhibited the highest mean moisture content at 51.14 per cent, whereas T_8 displayed the lowest at 38.94 per cent. Additional low-moisture regimens included T_{12} (40.06%) and T_{10} (41.69%). A notable interaction occurred between V and T. The moisture content in Kamalapur Red varied from 51.90 per cent (T_{13}) to 40.39 per cent (T_8), while in Grand Naine, it ranged from 50.38 per cent (T_{13}) to 37.49 per cent (T_8). The fresh control (T_{13}) retained the greatest moisture, while the prolonged/high-severity osmotic treatment (T_8) produced the driest slices in Table 1.

Osmotic dehydration (OD) extracts water by immersing tissue in a hypertonic solution. To increase the °Brix of the solution, incorporate sodium chloride (NaCl) and prolong the tissue's contact with the solution; this will decrease external water activity and elevate the chemical potential gradient. This accelerates the water's egress, resulting in the tissue retaining less moisture. Consequently, stringent, prolonged schedules (such as T_8) yield the minimal moisture, whilst the control (T_{13}), lacking any external osmotic driving force, remains unchanged. Established mechanisms and trends indicate that authoritative reviews and banana-specific kinetic studies consistently demonstrate that moisture loss escalates with increased solution concentration and duration. Furthermore, the presence of NaCl in sucrose exacerbates water removal by diminishing water activity and modifying transport dynamics (Torreggaini, 1993; Yavda and Singh, 2012; Rastogi *et al*., 2002) [29,34].
Studies that are analogous or corroborative. Mercali *et al*. 2010 [14] quantified the osmotic pressure and effective diffusivities in bananas. Increased sugar concentrations and the presence
of NaCl enhance water loss, resulting in a reduced ultimate moisture content. The initial rapid phase is induced by a significant osmotic gradient, which diminishes when the gradient lessens (Merciali *et al*., 2010). Mirzayi *et al*. (2018) [15} employed response-surface designs to demonstrate that water loss increases with the proportion of sucrose, salt and duration. They discovered that moderate quantities of salt can alter the absorption of solids while simultaneously promoting more water drainage, which aligns well with our low-moisture treatments.
Comprehensive OD investigations on fruits and vegetables (Torreggiani, 1993; Yadav *and Singh* 2014; Asghari *et al*., 2024) [29, 3] affirm that solution concentration and exposure duration are the primary determinants of moisture decrease, whereas tissue microstructure (variety) establishes the achievable limits. This elucidates the significant disparity in mean variety and the V×T relationship.

Effect of osmotic pre-treatments on the yield and drying ratio of osmotically dehydrated banana slices
The influence of osmotic pre-treatments on the yield and drying ratio of banana slices shown considerable discrepancies across treatments and kinds as in Table 2. The maximum yield was observed in treatment T_{13} (control), which excluded osmotic pre-treatment. The outcomes were 28.02 per cent for Kamalapur Red and 28.96 per cent for Grand Naine, resulting in a treatment mean of 21.33 per cent. Treatment T_{13} exhibited the lowest yield, with 21.77 per cent in Kamalapur Red and 20.89 per cent in Grand Naine. The diminished yield in treated samples relative to the control may be attributed to osmotic dehydration, which resulted in increased solid gain and water loss, facilitating the transfer of soluble solids from the syrup into the fruit tissues and the migration of soluble components from the fruit into the osmotic medium.
The drying ratio also altered in the contrary direction. The control samples (T_{13}) exhibited the highest drying ratios, measuring 5.26 for Kamalapur Red and 5.49 for Grand Naine, whereas T_{12} demonstrated the lowest drying ratios, recorded at 4.24 for Kamalapur Red and 3.44 for Grand Naine. The treated samples exhibited reduced yields due to an increase in solids and a greater loss of moisture, resulting

in a bigger ratio of raw to dry weight. The findings demonstrate that osmotic pre-treatments influence both mass transfer mechanisms during dehydration and the recovery of the final product's weight.

Table 1: Effect of osmotic treatment on moisture loss (%) and moisture content (%) in osmosed slices of banana varities kamalapur red and grand naine

Treatment	Moisture loss (%)			Moisture content (%)		
	Variety		Treatment Mean	Variety		Treatment Mean
	Kamalapur red banana	Grand Naine		Kamalapur red banana	Grad Naine	
T_1: 50°B 4h	21.43^{ij}	18.29^{i}	19.86^{h}	50.05^{bc}	49.70^{c}	49.87^{b}
T_2: 60°B 4h	24.50^{fgh}	17.13^{l}	20.81^{gh}	49.71^{c}	48.33^{de}	49.02^{c}
T_3: 70°B 4h	25.26^{fgh}	20.80^{jk}	23.03^{f}	47.10^{f}	45.17^{h}	46.13^{e}
T_4: 50°B 6h	25.43^{fgh}	19.01^{kl}	22.22^{fg}	48.02^{e}	48.54^{d}	48.28^{d}
T_5: 60°B 6h	28.21^{cde}	21.69^{ij}	24.95^{e}	45.48^{h}	46.31^{g}	45.89^{e}
T_6: 70°B 6h	29.21^{bcd}	23.27^{hij}	26.24^{de}	44.33^{i}	44.11^{i}	44.22^{g}
T_7: 50°B 24h	31.05^{ab}	23.82^{ghi}	27.43^{cd}	44.17^{i}	42.05^{j}	43.08^{h}
T_8: 60°B 24h	25.81^{f}	26.72^{def}	28.76^{bc}	40.39^{l}	37.49^{n}	38.94^{k}
T_9: 70°B 24h	31.34^{ab}	28.97^{bcd}	30.15^{b}	45.07^{h}	44.29^{i}	44.68^{f}
T_{10}: 50°B 24h S	28.25^{cde}	23.70^{ghi}	25.97^{de}	42.23^{j}	41.15^{k}	41.69^{i}
T_{11}: 60°B 24h S	30.39^{abc}	26.25^{efg}	28.32^{c}	42.01^{j}	41.82^{j}	41.92^{i}
T_{12}: 70°B 24h S	32.69^{a}	31.31^{ab}	32.00^{a}	41.86^{j}	38.26^{m}	40.06^{j}
T_{13}: Control	12.24^{k}	11.64^{m}	11.53^{i}	51.90^{a}	50.38^{b}	51.14^{a}
Variety Mean	26.92^{a}	22.50^{b}		45.56^{a}	44.42^{b}	
	S.Em ±	CD @ 1%		S.Em ±	CD @ 1%	
Variety (V)	0.21	0.86		0.04	0.16	
Treatment (T)	0.55	2.19		0.10	0.41	
V × T	0.79	3.10		0.15	0.58	

S- Salt Control - 0.1% KMS 10 min
70°B 24h S - 70°Brix 24 hours + 1% salt

Table 2: Effect of osmotic treatment on yield (%) and drying ratio (%) in osmosed slices of banana varities kamalapur red and grand naine

Treatment	Yield (%)			Drying ratio		
	Variety		Treatment Mean	Variety		Treatment Mean
	Kamalapur red banana	Grand Naine		Kamalapur red banana	Grad Naine	
T_1: 50°B 4h	23.50	25.53	24.52^{f}	5.26:1	4.89;1	5.07:1^{b}
T_2: 60°B 4h	25.88	27.16	26.52^{de}	5.09:1	4.61:1	4.85:1^{b}
T_3: 70°B 4h	26.40	28.03	27.21^{cde}	4.84:1	4.49:1	4.67:1^{cd}
T_4: 50°B 6h	25.23	26.11	25.67^{ef}	4.92:1	4.72:1	4.82:1^{c}
T_5: 60°B 6h	27.54	28.46	28.00^{bcd}	4.67:1	4.53:1	4.60:1de
T_6: 70°B 6h	28.16	29.90	29.03^{bc}	4.55:1	4.32:1	4.43:1^{ef}
T_7: 50°B 24h	28.01	29.27	28.64^{bc}	4.58:1	4.45:1	4.51:1de
T_8: 60°B 24h	33.15	33.53	33.34^{a}	4.37:1	4.15:1	4.26:1^{fg}
T_9: 70°B 24h	33.64	34.25	33.94^{a}	4.13:1	3.97:1	4.05:1^{gh}
T_{10}: 50°B 24h S	27.43	28.00	27.71^{bcd}	4.63:1	4.40:1	4.51:1de
T_{11}: 60°B 24h S	28.39	31.07	29.73^{b}	4.32:1	4.18:1	4.25:1^{fg}
T_{12}: 70°B 24h S	35.15	34.27	34.71^{a}	4.24:1	3.44:1	3.84:1^{h}
T_{13}: Control	21.77	20.89	21.33^{g}	5.26:1	5.49:1	5.64:1^{a}
Variety Mean	28.02^{b}	28.96^{a}		4.72:1^{a}	4.43:1^{b}	
	S.Em ±	CD @ 1%		S.Em ±	CD @ 1%	
Variety (V)	0.25	0.99		0.02	0.11	
Treatment (T)	0.64	2.52		0.07	0.28	
V × T	0.9	NS		0.10	NS	

*NS - Non-significant S- Salt Control - 0.1% KMS 10 min
70°B 24h S - 70°Brix 24 hours + 1% salt

The present findings correspond with earlier research by Torreggiani (1993) [29], which shown that osmotic dehydration leads to significant water loss and solid absorption, thereby reducing the final yield while increasing the drying ratio. Similarly, Panagiotou *et al.* (1999) [18] and Rastogi *et al*. (2002) highlighted that the improvement of the drying ratio via osmotic treatment is attributable to the reduction in initial moisture content and the incorporation of solutes, hence increasing the dry matter content of the product before hot air drying. Sagar and Kumar (2010) [25] said that osmotic pretreatments enhance product quality; nevertheless, they invariably reduce yield due to the leaching of soluble fruit components.

Effect of pre-treatments on reducing, non-reducing and total sugars in osmotically dehydrated banana slices

The results where illustrated as in the Table 3, 4 and 5.

The reduction in sugar throughout treatments varied from 36.96 per cent in T_{13} (control; 0.1% KMS, 10 min) to 50.82 per cent in T_9 (70°Brix, 24 h), T_{12} (70°Brix + 1% salt, 24 h;

49.63%), T_{11} (60°Brix + 1% salt, 24 h; 48.23%), T_8 (60°Brix, 24 h; 47.53%) and T_6 (70°Brix, 6 h; 47.42%) were notable performers. T_1 (50°Brix, 4 h; 42.58%) and T_2 (60°Brix, 4 h; 43.32%) exhibited reduced results, attributable to milder and shorter conditions. Kamalapur red exhibited a range of 37.92 to 51.22 per cent (minimum T_{13}, maximum T_9), while Grand Naine displayed a range of 36.00 to 50.42 per cent (minimum T_{13}, maximum T_9).
The total amounts for each treatment were between 43.25 per cent in T_{13} (control; 0.1% KMS, 10 min) and 67.73 per cent in T_9 (70°Brix, 24 h). The highest values were T_{12} (66.43%), T_{11} (63.21%), T_8 (62.56%) and T_6 (62.23%). The intermediate values were T_5 (59.10%), T_7 (58.81%), T_{10} (58.13%), T_3 (56.99%) and T_4 (55.03%). The lowest values were T_2 (54.83%) and T_1 (51.60%), while the control (T_{13}) was the lowest. The ranges were big for each type: Kamalapur red: 44.32-68.29 per cent (T_{13} to T_9); Grand Naine: 42.19-67.17 per cent (T_{13} to T_9).
This illustrates solute absorption and moisture reduction during osmotic dehydration, succeeded by sucrose inversion and the progressive involvement of reducing sugars in non-enzymatic browning within a low-moisture matrix (Mari *et al*., 2024; Rai *et al*., 2022; Mirzayi *et al*., 2018; Cordenunsi-Lysenko *et al*., 2019; Kathuria *et al*., 2023) [13, 22, 15, 7, 11].

Table 3: Effect of osmotic treatment on reducing sugar at different storage stage in osmosed slices of banana varities kamalapur red and grand naine at different storage stages

Treatments	Reducing sugar (%) Initial			Reducing sugar (%) 2MAS			Reducing sugar (%) 4MAS		
	Variety		Treatment mean	Variety		Treatment mean	Variety		Treatment mean
	Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine	
T_1: 50°B 4h	43.04^{r}	42.12^{s}	42.58^{k}	43.96^{l}	43.41^{l}	43.68^{i}	44.19^{l}	43.75^{l}	43.97^{h}
T_2: 60°B 4h	43.71^{q}	42.92^{r}	43.32^{j}	44.91^{k}	44.14^{l}	44.53^{h}	46.13^{ijk}	45.45^{k}	45.79^{g}
T_3: 70°B 4h	45.10^{l}	44.72^{n}	44.91^{g}	46.75^{g}	46.21^{h}	46.48^{f}	47.08^{ghi}	47.65^{fgh}	47.36^{e}
T_4: 50°B 6h	44.06^{p}	43.10^{r}	43.58^{i}	45.45^{ij}	45.14^{jk}	45.30^{g}	46.05^{jk}	46.92^{hij}	46.48^{f}
T_5: 60°B 6h	46.51^{i}	45.44^{k}	45.98^{e}	48.21^{f}	47.10^{g}	47.66^{e}	49.93^{c}	48.41^{ef}	49.17^{c}
T_6: 70°B 6h	47.13^{h}	47.71^{g}	47.42^{d}	50.03^{d}	49.02^{e}	49.53^{d}	49.61^{cd}	48.02^{efg}	48.81^{cd}
T_7: 50°B 24h	45.91^{j}	44.91^{n}	45.41^{f}	47.02^{g}	46.21^{h}	46.61^{f}	48.88^{de}	47.81^{fgh}	48.34^{d}
T_8: 60°B 24h	48.01^{f}	47.05^{h}	47.53^{d}	50.63^{c}	50.05^{d}	50.34^{c}	54.10^{a}	51.08^{b}	51.42^{b}
T_9: 70°B 24h	51.22^{a}	50.42^{b}	50.82^{a}	53.42^{a}	48.01^{f}	50.71^{b}	54.10^{a}	24.00^{n}	39.05^{i}
T_{10}: 50°B 24h S	45.01^{lm}	44.52^{o}	44.76^{h}	46.71^{g}	45.90^{hi}	46.30^{f}	47.72^{fgh}	46.92^{hij}	47.32^{e}
T_{11}: 60°B 24h S	48.21^{e}	48.25^{e}	48.23^{c}	50.16^{d}	49.92^{d}	50.04^{c}	51.03^{b}	50.94^{b}	50.99^{b}
T_{12}: 70°B 24h S	50.02^{c}	49.42^{d}	49.63^{b}	53.05^{ab}	52.71^{b}	52.88^{a}	53.82^{a}	53.22^{a}	53.52^{a}
T_{13}: Control	37.92^{t}	36.00^{u}	36.96^{l}	37.80^{n}	36.01^{o}	36.91^{j}	38.92^{m}	37.41^{n}	38.16^{j}
Variety Mean	45.83^{a}	45.11^{b}		47.55^{a}	46.45^{b}		48.40^{a}	45.50^{b}	
	S.Em±	CD @ 1%		S.Em±	CD @ 1%		S.Em±	CD @ 1%	
Variety (V)	0.01	0.06		0.04	0.17		0.08	0.33	
Treatment (T)	0.04	0.16		0.11	0.44		0.21	0.86	
V × T	0.06	0.23		0.16	0.62		0.31	1.21	

S- Salt Control - 0.1% KMS 10 min
70°B 24h S - 70°Brix 24 hours + 1% salt

Table 4: Effect of osmotic treatment on non-reducing sugar (%) at different storage stages in osmosed slices of banana varities kamalapur red and grand naine at different storage stages

Treatments	Non-reducing sugar (%) Initial			Non-reducing sugar (%) 2MAS			Non-reducing sugar (%) 4MAS		
	Variety		Treatment mean	Variety		Treatment mean	Variety		Treatment mean
	Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine	
T_1: 50°B 4h	9.11^{o}	8.91^{p}	9.01^{i}	6.04^{s}	5.01^{u}	5.52^{l}	4.18^{r}	4.04^{t}	4.11^{l}
T_2: 60°B 4h	11.87^{l}	11.15^{m}	11.51^{h}	7.16^{s}	7.16^{s}	7.16^{k}	5.00^{n}	4.38^{p}	4.69^{k}
T_3: 70°B 4h	12.09^{k}	12.05^{k}	12.07^{g}	8.88^{l}	7.88^{q}	8.38^{i}	5.21^{l}	4.79^{o}	5.00^{i}
T_4: 50°B 6h	11.90^{l}	10.98^{n}	11.44^{h}	7.94^{p}	7.37^{r}	7.66^{j}	5.14^{m}	4.71^{p}	4.93^{j}
T_5: 60°B 6h	13.61^{h}	12.62^{j}	13.12^{f}	9.69^{i}	8.76^{m}	9.23^{h}	5.49^{j}	5.00^{n}	5.24^{h}
T_6: 70°B 6h	14.97^{d}	14.65^{f}	14.81^{d}	10.97^{d}	9.03^{k}	10.00^{e}	7.02^{cd}	5.38^{k}	6.20^{e}
T_7: 50°B 24h	13.74^{g}	13.05^{i}	13.40^{e}	10.57^{g}	8.63^{n}	9.60^{g}	6.86^{e}	5.22^{l}	6.04^{f}
T_8: 60°B 24h	15.15^{c}	14.91^{de}	15.03^{c}	11.13^{b}	9.77^{h}	10.45^{c}	7.00^{d}	6.05^{g}	6.52^{c}
T_9: 70°B 24h	17.07^{a}	16.75^{b}	16.91^{a}	11.96^{a}	10.97^{d}	11.47^{a}	8.03^{a}	6.05^{g}	7.04^{a}
T_{10}: 50°B 24h S	13.68^{gh}	13.05^{i}	13.37^{e}	11.07^{c}	8.37^{o}	9.72^{f}	6.67^{f}	5.12^{m}	5.90^{g}
T_{11}: 60°B 24h S	15.24^{c}	14.84^{e}	15.04^{c}	10.89^{f}	9.55^{j}	10.22^{d}	7.05^{c}	5.59^{i}	6.32^{d}
T_{12}: 70°B 24h S	16.96^{a}	16.64^{b}	16.80^{b}	11.11^{bc}	10.84^{f}	10.98^{b}	7.97^{b}	5.88^{h}	6.93^{b}
T_{13}: Control	6.39^{q}	6.18^{r}	6.29^{j}	4.97^{u}	4.47^{v}	4.72^{m}	4.10^{s}	4.00^{u}	4.05^{m}
Variety Mean	13.21^{a}	12.75^{b}		9.41^{a}	8.29^{b}		6.13^{a}	5.09^{b}	
	S.Em±	CD @ 1%		S.Em±	CD @ 1%		S.Em±	CD @ 1%	
Variety (V)	0.01	0.04		0.004	0.01		0.003	0.01	
Treatment (T)	0.02	0.10		0.01	0.04		0.01	0.03	
V × T	0.03	0.15		0.0	0.06		0.01	0.05	

S- Salt Control - 0.1% KMS 10 min
70°B 24h S - 70°Brix 24 hours + 1% salt

Table 5: Effect of osmotic treatment on total sugar (%) in osmosed slices of banana varities kamalapur red and grand naine at different storage stages

Treatments	Total sugar (%) Initial			Total sugar (%) 2MAS			Total sugar (%) 4MAS		
	Variety		Treatment mean	Variety		Treatment mean	Variety		Treatment mean
	Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine	
T_1: 50°B 4h	52.16^{r}	51.04^{s}	51.60^{l}	50.01^{o}	48.42^{p}	49.21^{k}	48.38^{m}	47.79^{m}	48.08^{h}
T_2: 60°B 4h	55.59^{p}	54.08^{q}	54.83^{k}	52.08^{m}	51.31^{n}	51.69^{j}	51.13^{k}	49.83^{jk}	50.48^{g}
T_3: 70°B 4h	57.20^{m}	56.78^{n}	56.99^{i}	55.64^{i}	54.10^{k}	54.87^{h}	52.30^{ij}	52.44^{hij}	52.37^{e}
T_4: 50°B 6h	55.97^{o}	54.09^{q}	55.03^{j}	53.40^{l}	52.52^{m}	52.69^{i}	51.20^{k}	51.63^{jk}	51.41^{f}
T_5: 60°B 6h	60.13^{g}	58.07^{k}	59.10^{f}	57.91^{h}	55.87^{i}	56.89^{f}	55.43^{f}	53.41^{h}	54.42^{c}
T_6: 70°B 6h	62.11^{g}	62.36^{f}	62.23^{e}	61.01^{e}	58.06^{h}	59.53^{e}	56.64^{de}	53.40^{h}	55.02^{c}
T_7: 50°B 24h	59.66^{i}	57.96^{k}	58.81^{g}	57.60^{h}	54.84^{j}	56.22^{g}	55.74^{ef}	53.03^{hi}	54.39^{c}
T_8: 60°B 24h	63.16^{e}	61.96^{g}	62.56^{d}	61.77^{d}	59.82^{f}	60.79^{c}	58.76^{bc}	57.14^{d}	57.95^{b}
T_9: 70°B 24h	68.29^{a}	67.17^{b}	67.73^{a}	65.38^{a}	58.99^{g}	62.18^{b}	62.13^{a}	30.06^{p}	46.09^{i}
T_{10}: 50°B 24h S	58.70^{j}	57.57^{l}	58.13^{h}	57.78^{h}	54.28^{k}	56.03^{g}	54.39^{g}	52.04^{ijk}	53.22^{d}
T_{11}: 60°B 24h S	63.46^{d}	65.89^{c}	63.21^{c}	61.06^{e}	59.47^{fg}	60.26^{d}	58.09^{c}	53.53^{de}	57.31^{b}
T_{12}: 70°B 24h S	66.98^{b}	63.09^{e}	66.43^{b}	64.16^{b}	63.55^{c}	63.86^{a}	61.80^{a}	59.10^{b}	60.45^{a}
T_{13}: Control	44.32^{t}	42.19^{u}	43.25^{m}	42.78^{q}		41.63^{l}	43.03^{n}	41.41^{o}	42.22^{j}
Variety Mean	59.05^{a}	57.86^{b}		56.96^{a}	54.74^{b}		54.54^{a}	50.60^{b}	
	S.Em±	CD @ 1%		S.Em±	CD @ 1%		S.Em±	CD @ 1%	
Variety (V)	0.02	0.08		0.04	0.18		0.08	0.34	
Treatment (T)	0.05	0.21		0.11	0.46		0.22	0.87	
V × T	0.07	0.30		0.16	0.65		0.31	1.24	

S- Salt Control - 0.1% KMS 10 min
70°B 24h S - 70°Brix 24 hours + 1% salt

Effect on reducing sugars, non-reducing sugars at 2 MAS

Treatment means went up compared to the first stage. T_{12} (70°Brix + 1% salt, 24 h; 52.88%) was the highest, followed by T_9 (70°Brix, 24 h; 50.71%), T_8 (60°Brix, 24 h; 50.34%) and T_{11} (60°Brix + 1% salt, 24 h; 50.04%), T_6 (70°Brix, 6 h) also stayed high at 49.53%. Again, the control group, T_{13}, had the lowest score (36.91%). Effect on non-reducing sugars at 2 MAS Treatment signifies a diminished effect compared to the outset, aligning with the partial hydrolysis (inversion) of sucrose into reducing sugars. The mean for T_9 was 11.47 per cent, succeeded by T_{12} at 10.98 per cent, T_8 at 10.45 per cent, T_{11} at 10.22 per cent and T_6 at 10.00 per cent. T_{10} (9.72%), T_7 (9.60%) and T_5 (9.23%) occupied the intermediate tier. T_3 (8.38%), T_4 (7.66%), T_2 (7.16%) and T_1 (5.52%) had diminished values, whereas the control T_{13} recorded a value of 4.72 per cent. In comparison to the initial stage, the majority of treatments demonstrated a little reduction in total sugars. The treatment with the greatest mean was T_{12} (70°Brix + 1% salt, 24 hours; 63.86%). Subsequently, T_9 (70°Brix, 24 h; 62.18%), T_8 (60°Brix, 24 h; 60.79%) and T_{11} (60°Brix + 1% salt, 24 h; 60.26%) were observed. T_6 (59.53%), T_5 (56.89%), T_7 (56.22%) and T_{10} (56.03%) occupied the subsequent tier. T_3 (54.87%), T_4 (52.69%), T_2 (51.69%) and T_1 (49.21%) occupied the bottom tier and T_{13} (41.63%) was the lowest.

Two months subsequent to confinement (2 MAS). The sequence remained unchanged. The quantity of reducing sugars increased further, whereas the level of non-reducing sugars decreased. This occurs when sucrose decomposes during storage. In the rigors programmes, the total quantity of sugars remained elevated compared to the milder schedules and the control group. The significance of variety, treatment and their interaction suggests that, although the intensity-based ranking remains applicable, the extent of change within a treatment is contingent upon the cultivar (Cordenunsi-Lysenko *et al*., 2019)[7].

Effect on reducing sugars at 4 MAS

The V, T and V×T effects remained significant after 4 months (CD at 1%: V = 0.08/0.33; T=0.21/0.86; V×T =0.31/1.21). The Kamalapur variety exhibits a percentage of 48.40 per cent, compared to Grand Naine's 45.50 per cent indicating that the varietal advantage persists even after prolonged storage. The optimal treatment mean was T_{12} (70°Brix + 1% salt, 24 h; 53.52%), followed by T_8 (60°Brix, 24 h; 51.42%) and lastly T_{11} (60°Brix + 1% salt, 24 h; 50.99%). The subsequent tier consisted of T_5 (60°Brix, 6 hours; 49.17%) and T_6 (70°Brix, 6 hours; 48.81%). The lowest values were seen in T_{13} (control; 38.16%) and an exceptionally low mean in T_9 (70°Brix, 24 h; 39.05%). In the non reducing sugars The stage-wise treatment means were the lowest across the three time points, indicating that the inversion is ongoing. At 4 MAS, T_9 (7.04%) exhibited the highest mean, closely succeeded by T_{12} (6.93%), T_{11} (6.32%) and T_8 (6.52%). Additional upper-mid results were T_6 at 6.20 per cent and T_7 at 6.04 per cent. The middle band comprised T_5 (5.24%), T_4 (4.93%), T_3 (5.00%) and T_2 (4.69%). T_1 (4.11%) and the control T_{13} (4.05%) constituted the lowest category.

Treatment means revealed a bigger drop overall compared to 2 MAS. T_{12} (70°Brix + 1% salt, 24 h; 60.45%) was the best, followed by T_8 (57.95%) and T_{11} (57.31%). T_6 (55.02%), T_5 (54.42%), T_7 (54.39%) and T_{10} (53.22%) were the other upper-mid values. T_1 (48.08%), T_3 (52.37%), T_4 (51.41%) and T_2 (50.48%) were the lowest tier treatments. The control T_{13} was the lowest at 42.22%. For T_9 at 4 MAS, there was a strange event: Kamalapur red stayed high (62.13%), while Grand Naine fell abruptly to 30.06%, bringing the treatment mean down to 46.09%. This crossover fits with the big V×T phrase at this point. This occurred because of a significantly low Grand Naine value (24.00%) at 4 MAS, despite the high Kamalapur value (54.10%). This outlier aligns with the substantial V×T term. A notable crossover in a rigors schedule highlighted the strong variety × treatment interaction Kamalapur Red stayed increased while Grand Naine decreased demonstrating that different cultivars respond variably to the same treatments. The observed sequential alterations result from the concurrent processes of sucrose inversion and non-enzymatic browning. These mechanisms involve the decomposition of reducing sugars and the formation of brown polymers (Cordenunsi-Lysenko *et al.*, 2019 [7]; Kathuria *et al*., 2023) [11].

Effect of pre-treatments on titrable acidity in osmotically dehydrated banana slices

The acidity levels ranged from 0.73 per cent in T_{13} (control; 0.1% KMS, 10 min) to 1.31 per cent in T_1 (50°Brix, 4 h) across the treatment procedures. T_2 (1.25%), T_4 (1.23%), T_5 (1.22%), T_7 (1.23%) and T_{10} (1.21%) yielded the highest outcomes. The values in $T_3/T_8/T_{11}$ (about 1.16-1.17%) and T_6 (1.16%) were moderate. The treated samples exhibited the lowest values in T_9 (1.11%) and T_{12} (1.12%), while the control T_{13} recorded the lowest value overall. A diverse array of variants exists: Kamalapur red ranges from approximately 0.81 to 1.48 per cent (minimum T_{13}, maximum T_1), whereas Grand Naine ranges from about 0.66 to 1.14 per cent (minimum T_{13}, maximum T_1), as showed in table 6. In comparison to the outset, the majority of treatments demonstrated a slight reduction in acidity after 2 months. T_1 (1.20%) had the highest treatment mean, followed closely by T_2 (1.17%), T_4 (1.13%), T_7 (1.11%), T_5 (1.10%) and T_{10} (1.12%). T_{11} (1.07%), T_8 (1.05%) and T_6/T_9 (about 1.02-1.04%) exhibited intermediate outcomes. T_{12} reached 1.00 per cent, whereas T_{13}, the control, had the lowest value at 0.67 per cent.

Treatment indicates an improvement from 2 MAS. The highest tier included T_1 (1.11%) and T_2 (1.07%), succeeded by T_{10} (1.05%), T_4/T_7 (about 1.03%) and T_5 (1.04%). T_8/T_{11} (about 0.97-0.98%), T_3/T_{12} (around 0.96%) and T_6 (0.93%)/T_9 (0.94%) were situated within a mid-lower range. The control, T_{13}, remained constant at 0.58 per cent. The ranges for several types were: Kamalapur red: 0.71-1.28 per cent (minimum T_{13}, maximum T_1); Grand Naine: 0.46-0.95 per cent (minimum T_{13}, maximum T_1). After four months, the milder pre-treatments (T_1-T_2) exhibit the highest acidity, while the control demonstrates the lowest acidity. More intense osmotic circumstances (elevated °Brix, extended time, ±salt) result in reduced final acidity; hence, Kamalapur red has a distinct acidity advantage over Grand Naine.

Initially, at 2 months and 4 months, statistically significant changes in titratable acidity were observed attributable to variety, osmotic pre-treatments and their combination (Table 4). Kamalapur Red consistently exhibited greater acidity than Grand Naine at all stages, attributable to its bigger organic acid reservoir and lower sugar-to-acid ratio at baseline. Consequently, following analogous dehydration histories, the acid percentage remained elevated in Kamalapur Red compared to Grand Naine (varietal impact). The most acidity was observed in the moderate, short exposure (T_1) at each step, whereas the least acidity was recorded in the control (T_{13}). Intense schedules (high °Brix ± salt, extended contact) exhibited reduced acidity compared to T_1.

Table 6: Effect of osmotic treatment on titratable acidity (%) in osmosed slices of banana varities kamalapur red and grand naine at different storage stages

Treatments	Titratable acidity (%) Initial			Titratable acidity (%) 2MAS			Titratable acidity (%) 4MAS		
	Variety		Treatment mean	Variety		Treatment mean	Variety		Treatment mean
	Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine	
T_1: 50°B 4h	1.48^{a}	1.14^{h}	1.31^{a}	1.38^{a}	1.03^{g}	1.20^{a}	1.28^{a}	0.95^{e}	1.11^{a}
T_2: 60°B 4h	1.40^{bc}	1.09^{ij}	1.25^{b}	1.34^{b}	0.10^{g}	1.17^{b}	1.25^{ab}	0.90^{f}	1.07^{b}
T_3: 70°B 4h	1.32^{f}	1.03^{kl}	1.17^{d}	1.19^{de}	0.86^{j}	1.02^{ef}	1.13^{c}	0.78^{j}	0.96^{de}
T_4: 50°B 6h	1.35^{def}	1.10^{hi}	1.23^{bc}	1.26^{c}	1.00^{g}	1.13^{c}	1.16^{c}	0.91^{f}	1.03^{c}
T_5: 60°B 6h	1.37^{cde}	1.08^{ij}	1.22^{bc}	1.25^{c}	0.95^{h}	1.10^{c}	1.21^{b}	0.87^{fg}	1.04^{c}
T_6: 70°B 6h	1.31^{f}	1.01^{lm}	1.16^{d}	1.16^{ef}	0.91^{hi}	1.04^{e}	1.06^{e}	0.81^{hij}	0.93^{e}
T_7: 50°B 24h	1.42^{b}	1.05^{jk}	1.23^{bc}	1.31^{b}	0.91^{hi}	1.11^{c}	1.23^{b}	0.84^{ghi}	1.03^{c}
T_8: 60°B 24h	1.32^{f}	1.00^{lmn}	1.16^{d}	1.21^{d}	0.90^{ij}	1.05^{de}	1.15^{c}	0.79^{j}	0.97^{d}
T_9: 70°B 24h	1.26^{g}	0.97^{mn}	1.11^{e}	1.15^{ef}	0.90^{ij}	1.02^{ef}	1.08^{d}	0.80^{ij}	0.94^{e}
T_{10}: 50°B 24h S	1.39^{bcd}	1.03^{kl}	1.21^{c}	1.31^{b}	0.94^{h}	1.12^{c}	1.24^{b}	0.85^{gh}	1.05^{bc}
T_{11}: 60°B 24h S	1.34^{ef}	1.00^{lmn}	1.17^{d}	1.22^{cd}	0.92^{hi}	1.07^{d}	1.13^{c}	0.82^{hij}	0.98^{d}
T_{12}: 70°B 24h S	1.27^{g}	0.96^{n}	1.12^{e}	1.13^{f}	0.86^{j}	1.00^{f}	1.07^{d}	0.84^{ghi}	0.96^{de}
T_{13}: Control	0.81^{o}	0.66^{p}	0.73^{f}	0.76^{k}	0.59^{l}	0.67^{g}	0.71^{k}	0.46^{l}	0.58^{f}
Variety Mean	1.31^{a}	1.01^{b}		1.20^{a}	0.90^{b}		1.13^{a}	0.81^{b}	
	S.Em±	CD @ 1%		S.Em±	CD @ 1%		S.Em±	CD @ 1%	
Variety (V)	0.003	0.01		0.003	0.01		0.003	0.01	
Treatment (T)	0.009	0.03		0.009	0.03		0.009	0.03	
V × T	0.01	0.05		0.01	0.05		0.01	0.05	

S- Salt Control - 0.1% KMS 10 min

70°B 24h S - 70°Brix 24 hours + 1% salt

Numerous research provides substantial evidence supporting the preceding argument. In bananas and other tropical fruits, elevated syrup concentration and prolonged immersion time diminish titratable acidity in the dehydrated product through solute uptake-driven dilution and subsequent acid utilisation during storage: banana (Bongirwar & Sreenivasan, 1977; Pokharkar & Prasad, 1998b; Pokharkar *et al*., 1997) [6, 19, 21], mango (Nanjundaswamy *et al*., 1978 [17]; Sagar & Khurdiya, 1999 [25]; Amitabh *et al*., 2000 [2]; Varany Anond *et al*., 2000 [30]; Tiwari & Jalali, 2004a) [27], papaya (Ahmed & Choudhary, 1995) [1], apricot (Sharma *et al*., 2004) [26] and pineapple (Pokharkar & Prasad, 1998a [20]; Tiwari & Jalali, 2004b [28]). The reduction of acidity during storage has been associated with the transformation of acids, the inversion of sucrose and reactions akin to the Maillard reaction (Sharma *et al.*, 2004) [26]. Recent studies on osmotic dehydration (2018-2024) demonstrate that solution concentration, salt addition and contact duration are primary factors affecting mass transfer and the sugar/acid equilibrium in osmosed fruits. This explains why moderate T_1 displayed the maximum acidity, whereas control (T_{13}) and severe OD regimens demonstrated the lowest acidity levels.

Effect of pre-treatments on TSS of osmotically dehydrated banana slices

Throughout all stages (Initial, 2 MAS, 4 MAS), both variety (V) and treatment (T) significantly influenced TSS, consistent with osmotic dehydration (OD) theory: conditions exhibiting a more robust osmotic driving force (elevated °Brix, extended contact, ±1% NaCl) resulted in higher TSS, whereas milder or shorter conditions yielded lower TSS. The analysis indicates that Kamalapur Red consistently shown a significant varietal superiority over Grand Naine at all stages (Δ > CD at 1%), implying that intrinsic composition (baseline solids, sugars, acidity) affected TSS responses to osmotic dehydration. This varietal differentiation aligns with evidence indicating that genotype-induced compositional changes lead to distinct processing and metabolic effects (Rai *et al.*, 2022[22]; Haque *et al.*, 2020) [10]. As presented in table 7.

TSS exhibited significant variability among treatment means. The highest tier included T_{12} (67.16%), T_8 (64.39%), T_{11} (63.68%) and T_6 (61.13%). The middle tier comprised T_5 (60.46%), T_7 (60.43%), T_{10} (59.13%), T_3 (58.19%) and T_4 (57.13%). The lowest tier comprised T_2 (56.09%) and T_1 (53.43%), but the control, T_{13}, recorded the lowest percentage at 46.91 per cent. The ranges for each type were extensive: Kamalapur red exhibited 47.81-69.03 per cent (minimum T_{13}, maximum T_9), whereas Grand Naine displayed 46.01-65.67 per cent (minimum T_{13}, maximum T_{12}). Following OD, high-intensity protocols (such as elevated syrup °Brix, 24-hour contact and salt-assisted methods) yielded the optimal TSS tier. Osmotic diffusion occurs via counter-diffusion, wherein water departs from cells and sucrose and other soluble molecules enter, resulting in increased tissue concentration. Numerous studies indicate that increasing sucrose concentration and exposure duration enhances solid gain and total soluble solids (TSS) (Mirzayi *et al.*, 2018 [15]; Haque *et al.*, 2020) [10]. The control group (no osmotic dehydration, preservative dip only) had the lowest total soluble solids, indicating the absence of solute impregnation.

Table 7: Effect of osmotic treatment on TSS (%) in osmosed slices of banana varities kamalapur red and grand naine at different storage stages

Treatments	TSS (%) Initial			TSS (%) 2MAS			TSS (%) 4MAS		
	Variety		Treatment mean	Variety		Treatment mean	Variety		Treatment mean
	Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine		Kamalapur red Banana	Grand naine	
T_1: 50°B 4h	53.75^{m}	53.10^{m}	53.43^{h}	55.56^{o}	53.80^{p}	54.68^{k}	57.95^{r}	56.71^{s}	57.33^{l}
T_2: 60°B 4h	56.81^{k}	55.37^{l}	56.09^{g}	57.86^{m}	57.01^{n}	57.43^{j}	74.42^{b}	60.08^{q}	60.92^{k}
T_3: 70°B 4h	58.11^{ij}	58.27^{hij}	58.19^{e}	61.82^{i}	60.11^{k}	60.96^{h}	63.55^{m}	63.08^{n}	63.32^{i}
T_4: 50°B 6h	56.88^{k}	57.37^{jk}	57.13^{f}	59.33^{l}	58.35^{m}	58.84^{i}	62.18^{o}	60.10^{q}	61.14^{j}
T_5: 60°B 6h	61.58^{f}	59.34^{h}	60.46^{c}	64.34^{h}	62.07^{i}	63.21^{f}	66.81^{h}	64.52^{j}	65.66^{f}
T_6: 70°B 6h	62.93^{de}	59.33^{h}	61.13^{c}	67.78^{e}	64.51^{h}	66.15^{e}	69.01^{g}	69.29^{f}	69.15^{e}
T_7: 50°B 24h	61.93^{ef}	58.92^{hi}	60.43^{c}	64.00^{h}	60.93^{j}	62.46^{g}	66.28^{i}	64.40^{k}	65.34^{g}
T_8: 60°B 24h	65.29^{bc}	33.40^{p}	64.39^{b}	68.63^{d}	66.47^{f}	67.55^{c}	70.18^{e}	68.85^{g}	69.51^{d}
T_9: 70°B 24h	69.03^{a}	46.01^{o}	51.21^{i}	72.65^{a}	65.54^{g}	69.09^{b}	75.88^{a}	74.63^{b}	75.26^{a}
T_{10}: 50°B 24h S	60.43^{g}	57.82^{ijk}	59.13^{d}	64.20^{h}	60.3	62.25^{g}	65.22^{j}	63.97^{l}	64.59^{h}
T_{11}: 60°B 24h S	64.54^{c}	62.81^{de}	63.68^{b}	67.84^{e}	66.08^{fg}	66.96^{d}	70.51^{d}	70.10^{e}	70.30^{c}
T_{12}: 70°B 24h S	68.66^{a}	65.67^{b}	67.16^{a}	71.29^{b}	70.61^{c}	70.95^{a}	74.42^{b}	73.21^{c}	73.81^{b}
T_{13}: Control	47.81^{n}	46.01^{o}	46.91^{j}	47.53^{q}	44.98^{r}	46.26^{l}	49.24^{t}	46.87^{u}	75.26^{a}
Variety Mean	60.60^{a}	56.22^{b}		63.29^{a}	60.83^{b}		65.61^{a}	64.29^{b}	
	S.Em±	CD @ 1%		S.Em±	CD @ 1%		S.Em±	CD @ 1%	
Variety (V)	0.09	0.38		0.05	0.20		0.02	0.09	
Treatment (T)	0.24	0.97		0.13	0.51		0.06	0.28	
V × T	0.35	1.37		0.18	0.73		0.08	0.33	

S- Salt Control - 0.1% KMS 10 min

70°B 24h S - 70°Brix 24 hours + 1% salt

Most therapy demonstrated an elevation in TSS relative to the initial stage. T_{12} (70.95%) exhibited the highest treatment mean, after by T_9 (69.09%), T_8 (67.55%), T_{11} (66.96%) and T_6 (66.15%). The second tier comprised T_5 (63.21%), T_7 (62.46%) and T_{10} (62.25%). T_3 (60.96%), T_4 (58.84%), T_2 (57.43%) and T_1 (54.68%) constituted the inferior tier. T_{13}, the control, remained unchanged at 46.26 per cent. At 2 MAS, TSS increased further in the majority of osmosed samples and the intensity-based ranking remained consistent: the regimens that exhibited the highest strength at day-0 continued to rank among the top at 2 MAS. This pattern corresponds with the ongoing physicochemical re-equilibration in low-moisture slices and the limited starch hydrolysis where sucrose conversion may persist in preserved banana matrices (Aurore *et al.*, 2009 [4]; Kaur, 2024) [12]. Nevertheless, as osmosed tissues inherently possess elevated solute concentrations from the outset, the subsequent increases during storage are minimal and contingent upon the therapy, thereby preserving the advantages of robust osmotic pressure. The control remained unchanged, indicating that natural ripening in untreated tissues does not compensate for the deficiency of osmotic solute absorptions in these conditions.

T_9 (75.26%) exhibited the highest treatment mean at this juncture, succeeded by T_{12} (73.81%), T_{11} (70.30%) and T_8 (69.51%). Additional upper-mid results included T_6

(69.15%), T_5 (65.66%), T_7 (65.34%) and T_{10} (64.59%). The lower means were T_3 (63.32%), T_4 (61.14%), T_2 (60.92%) and T_1 (57 .33%). The control, T_{13}, exhibited the lowest value at 42.22 per cent. At 4 MAS, total soluble solids (TSS) were maximised in the most demanding regimens, especially the high-°Brix, 24-hour, ±salt configuration. Less intensive and abbreviated treatments resulted in a reduced cluster, whereas the control remained the lowest. The stage-wise profile Initial < 2 MAS ≤ 4 MAS for robust OD aligns with sustained solids retention in a low-aw, sugar-rich matrix. In instances where TSS stabilised or decreased somewhat, non-enzymatic browning is likely responsible. Over time, reducing sugars engage in Maillard-type reactions, gradually diminishing the quantity of extractable soluble sugars or converting them into brown polymers (Sagar & Khurdiya, 1999; Ahmed & Choudhary, 1995) [24, 1].

The results demonstrate that OD regimens with high sucrose concentrations (about 60-70 °Brix), a 24-hour contact duration and a slight NaCl addition confer a TSS benefit on day zero that endures throughout storage (Mirzayi *et al*., 2018; Haque *et al*., 2020) [15, 10]. The persistent varietal superiority of Kamalapur Red indicates that both internal matrix composition (solids, sugars, acidity) and the intensity of external osmotic dehydration jointly affect the soluble-solids trajectories in osmotically dehydrated banana slices (Rai *et al*., 2022) [22].

Conclusion

The comprehensive analysis of osmotic dehydration (OD) pre-treatments on banana slices, comparing Kamalapur Red and Grand Naine cultivars, revealed that both osmotic severity and varietal differences significantly influence the final product quality. Severe OD treatments, such as T8 (60°Brix, 24 h) and T12 (70°Brix + 1% salt, 24 h), effectively lowered moisture content (down to 38.94%) and increased Total Soluble Solids (TSS) and total sugars due to a maximized osmotic driving force and solute uptake, though this resulted in a reduced product yield. Crucially, the increase in reducing sugars and the subsequent decrease in non-reducing sugars over four months of storage confirm progressive sucrose inversion in the low-moisture matrix. Kamalapur Red consistently demonstrated a superior ability to retain Titratable Acidity (TA) and maintain higher TSS compared to Grand Naine, especially under rigorous treatments, indicating a distinct varietal response to mass transfer and product stabilization that is critical for selecting optimal processing parameters.

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