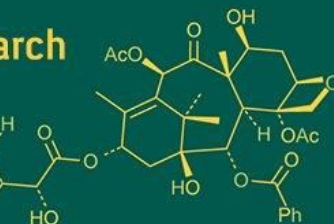


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Enhancing shelf life and quality of tamarind pulp through pre-treatment and storage management

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Abstract

Pre-treatment plays a critical role in determining the post-harvest quality and storage stability of tamarind pulp. In this study, deseeded tamarind pulp was subjected to salt (10%), ascorbic acid (5%) and untreated control treatments to evaluate their effects on storage stability. Key quality parameters, including moisture content, pH, TSS, TA and TS, were analyzed at monthly intervals. Among the evaluated treatments, ascorbic acid showed superior effectiveness in maintaining moisture content and TSS. Refrigerated storage at $4 \pm 2^\circ\text{C}$ further contributed to the preservation of biochemical and sensory quality by minimizing browning reactions and maintaining desirable acidity levels. In contrast, salt-treated and untreated control samples exhibited higher moisture uptake and pronounced acidity changes, suggesting limited suitability for extended storage. The observed effects confirm that ascorbic acid suppresses both enzymatic and non-enzymatic browning through pH reduction and enhanced antioxidant protection, whereas salt treatment was associated with increased colour changes. The refrigerator storage method together with ascorbic acid pre-treatment produced the highest physicochemical results after four months which proved to be an effective method for extending shelf life while enhancing product marketability. The research results offer operational recommendations to tamarind processors based on their discovery that ascorbic acid functions as a suitable food-grade additive which preserves pulp freshness while maintaining customer satisfaction during extended storage periods.

Keywords: Tamarind pulp, pre-treatment, ascorbic acid, refrigerated storage, physicochemical stability and shelf-life extension

1. Introduction

Tamarind (*Tamarindus indica* L.) is a versatile tropical fruit tree native to Central Africa [21], now widely cultivated across many tropical and subtropical regions, including India, Thailand and several countries in Africa and the Americas [24]. This species belongs to the Leguminosae family and is prized primarily for its edible pulp which functions as an essential component and flavoring element in multiple cooking traditions especially South Asian cuisine [23]. Commonly referred to as an Indian date due to its sweet-sour taste and appearance resembling that of dates [21], tamarind provides significant nutritional value and health benefits and economic benefits. The fruit pulp contains high levels of carbohydrates and organic acids which include tartaric acid and dietary fiber and protein and B-complex vitamins and vitamin C and essential minerals such as calcium and phosphorus and potassium [19]. These attributes provide the product with essential nutritional value and therapeutic benefits and commercial value which extends to food and pharmaceutical and traditional medicinal systems used throughout India and Africa [21]. Tamarind seeds and other plant parts also hold industrial and nutritional significance [23]. India leads global tamarind production and export, with key growing states being Tamil Nadu, Karnataka, Kerala and Andhra Pradesh [17], underscoring its economic relevance.

Despite its importance, tamarind pulp is highly perishable and presents considerable storage challenges. The hygroscopic nature of the pulp leads to moisture absorption from the surrounding environment, resulting in undesirable softening and pectolytic degradation during storage [26]. Further, the pulp is subjected to biochemical changes, including the browning reactions of both enzymatic and non-enzymatic types, such as the Maillard reaction [19], which darken the natural golden-brown colour into an unattractive blackish

shade, hence, negatively impacting its market quality [23]. The effects of these quality-deteriorating reaction phases are controlled by storage factors such as temperature, relative humidity and the presence of oxygen [15]. Also, the moisture content that is inherent in tamarind pulp renders the tamarind pulp more susceptible to microbial spoilage, thereby reducing shelf life mainly [8]. The preservation of tamarind pulp during storage requires effective preservation methods which protect its biochemical composition and its colour and taste and its sensory attributes.

Tamarind pulp continues to be a highly perishable product because existing research mainly studies single methods of storage and preservation. There is a lack of research that investigates how pre-treatment and storage conditions together affect quality retention. The complete assessment of essential quality indicators including moisture content, pH, total soluble solids, titratable acidity, sugar profile and colour stability across various tamarind genotypes and storage conditions remains unfinished [23, 25]. Moreover, there is limited clarity regarding the interaction between commonly used food-grade pre-treatments, such as salt and ascorbic acid and storage conditions including refrigeration and sub-baric storage, leading to inconsistencies in recommended storage protocols [11]. The knowledge gap prevents optimal preservation strategy development which results in shorter product lifespan and reduced market potential of tamarind pulp for small processors and farmers.

The present study aims to assess how pre-treatment methods and storage conditions work together to affect the biochemical and colour and sensory characteristics of tamarind pulp. The researchers treated deseeded pulp with three conditions which included salt at 10% and ascorbic acid at 5% and an untreated control condition and they refrigerated the samples at 4 ± 2 °C range and they used controlled pressure storage at 650 mm Hg. The researchers used factorial experimental design to monitor key quality parameters which included moisture content and pH and total soluble solids and titratable acidity and total sugars and colour attributes and sensory acceptability during a four-month storage period. The study results will provide the best tamarind pulp preservation methods which will help solve the problem of high perishability while offering processors and producers scientifically supported methods to decrease postharvest losses and extend product shelf life and improve tamarind availability throughout the year in the tamarind value chain.

2. Materials and Methods

2.1 Experimental Design

The study used a factorial Completely Randomized Design (CRD) to assess how different storage conditions and pre-treatment methods and tamarind pulp varieties combined to affect the quality and shelf life of tamarind pulp.

Independent Variables	Levels
Storage conditions	C1: Refrigerated condition (4 ± 2 °C) and C2: Sub-baric condition
Preservative treatments	T ₁ : Salt at 10%, T ₂ : Ascorbic acid at 5% and T ₃ : Untreated (control)
Product varieties	Local NFN-6 NFN-7 Red-T
Storage intervals (days)	0, 30, 60, 90, 120
Replications	3
Total experiments	$2 \times 3 \times 4 \times 3 = 72$ total observations over five storage intervals

2.2 Raw Material Procurement and Preparation

Fully matured, ripe and dried tamarind fruits of four genotypes (NFN-6, NFN-7, red tamarind and a local variety) were procured from ICAR-AICRP (Agro-Forestry), UAS Bangalore. Fruits were selected for uniform maturity and absence of physical injuries. The pods were sun-dried for three days until brittle and manually shelled by beating. The deseeded pulp was further sun-dried for one day and used for treatments.

2.3 Pre-treatment, Packaging and Storage

The pulp was divided into three pre-treatments: 10% (w/w) salt, 5% (w/w) ascorbic acid and an untreated control. Each 50 g sample was mixed uniformly and packed in sealed pouches to prevent moisture entry. The packets were stored for 120 days under two conditions: refrigerated storage (4 ± 2 °C) and sub-baric storage (650 mm Hg), with temperature and pressure continuously monitored. The experimental setup, showing the factorial arrangement of pre-treatments and storage conditions, is illustrated in Figure 1. The study used a Completely Randomised Design (CRD) with factorial treatment design which included two factors (storage condition and pre-treatment) and three replications [16, 25].

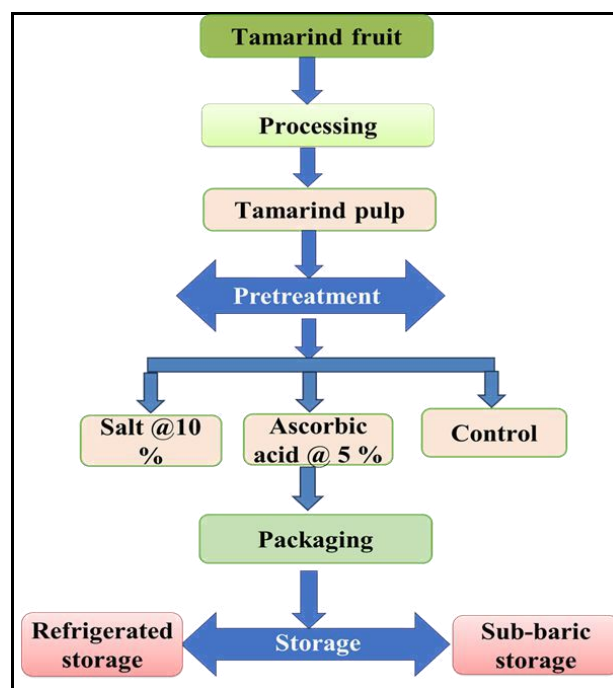


Fig 1: Process Flow Diagram for Pretreatment and Storage of Tamarind Pulp

2.4 Physicochemical Analysis

The study conducted physicochemical analyses at 30-day intervals which included measurements at 0 days, 30 days, 60 days, 90 days and 120 days to track changes in tamarind pulp quality during storage. The analytical tests required three separate tests for each sample and their results were reported based on the weight of fresh materials. The researchers measured moisture content using the ^[4] method and the moisture was expressed in a percentage by using the hot air oven method. The pH was taken with a calibrated digital pH meter. Total soluble solids (TSS) were measured with a digital refractometer and were given in °Brix ^[18]. The titratable acidity was figured by standard sodium hydroxide titration and was given as a percent of tartaric acid ^[12]. The total sugars were found following AOAC rules by converting all sugars first to reducing sugars, then titrated against 0.1 N sodium hydroxide (NaOH) using phenolphthalein as an indicator until a persistent light pink endpoint was obtained. Colour characteristics of tamarind pulp samples were measured using a Konica Minolta tristimulus colour spectrophotometer, calibrated with a standard white reference tile prior to analysis ^[19, 27]. The overall colour change during storage was quantified by calculating the total colour difference (ΔE) using the following equation:

$$\Delta E = \sqrt{[(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2]}$$

The total soluble solids or TSS of tamarind pulp were measured using a digital refractometer which had been calibrated and the results were shown in °Brix because this unit indicates the soluble solid content present in the pulp ^[6]. Titratable acidity was estimated by titrating a known quantity of pulp extract against standardized 0.1 N sodium hydroxide (NaOH) solution using phenolphthalein as an indicator and expressed as percentage of tartaric acid, the predominant organic acid in tamarind ^[22]. Total sugars were measured according to ^[4, 13] methods which first required the hydrolysis of non-reducing sugars to producing reducing sugars before the resulting extract underwent standard titrimetric testing to determine percentage value based on fresh weight. The study of tamarind pulp storage revealed the significant effects of storage conditions and pretreatments on the pulp quality and biochemical properties after 120 days.

2.7 Statistical Analysis

The experimental data were statistically analyzed using

analysis of variance (ANOVA) under a factorial Completely Randomized Design (CRD) to determine the effects of storage conditions, pre-treatment methods, varieties and their interactions on quality attributes of tamarind pulp. Statistical significance was assessed at the 5% probability level ($p \leq 0.05$). When significant differences were observed, treatment means were compared using the Critical Difference (CD) test. Statistical computations were performed using appropriate statistical software ^[28].

3. Results and Discussions

3.1 Effect of Storage on Moisture Content of Tamarind Pulp

The moisture content in tamarind steadily increased during the storage period for all four varieties (Table 1), with noticeable differences occurring after 30 days. The moisture content at the end of the 120-day period, Local, NFN-6, NFN-7 and Red-T under C₁ was 18.99%, 17.98%, 18.52% and 18.97% respectively, showing a controlled moisture increase. On the other hand, C₂ absorbed more moisture giving 19.85%, 19.08%, 19.15% and 19.85% for Local, NFN-6, NFN-7 and Red-T, respectively, at the end of 120 days, which indicated an increased humidity uptake under reduced-pressure conditions. The varietal differences were pronounced: Local and Red-T monopolized the moisture under C₂, whereas NFN-6 was the lowest under C₁ and NFN-7 was intermediate between the two conditions. Among preservatives, T₂ recorded the lowest moisture consistently at 120 days for all varieties (18.00%, 17.71%, 18.24%, 19.14%), followed by T₁, while the T₃ gave the highest values in most combinations (Figure 2).

The increase in moisture observed is in accordance with the property of tamarind pulp to absorb moisture and ^[3] have also concluded the same. The rise in C₂ treatments is possibly because of the relaxation and migration of moisture more easily under reduced pressure. T₂, along with other treatments, has contributed to keeping moisture level low and this has been referred to as its stabilising influence on pulp structure ^[15]. T₁ was able only to a certain extent to keep moisture under control, perhaps because of its own nature of being hygroscopic. The very significant interaction emphasises the truth that the effectiveness of preservatives is very much dependent on the atmosphere of the storage, with the refrigeration being able to enhance the moisture-limiting action of the preservatives ^[3]. Such findings mark the combination of cold storage along with ascorbic acid (C₁T₂) as the most successful strategy in preventing an increase in moisture ^[15].

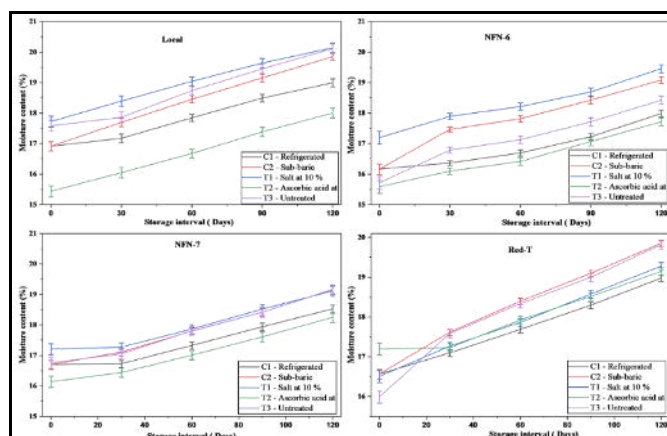


Fig 2: Changes in Moisture Content (%) of Tamarind Pulp from Four Varieties Under Different Storage Conditions Over 120 Days

Table 1: Effect of Storage Conditions, Preservative Treatments and Storage Duration on Moisture Content (%) of Tamarind Pulp

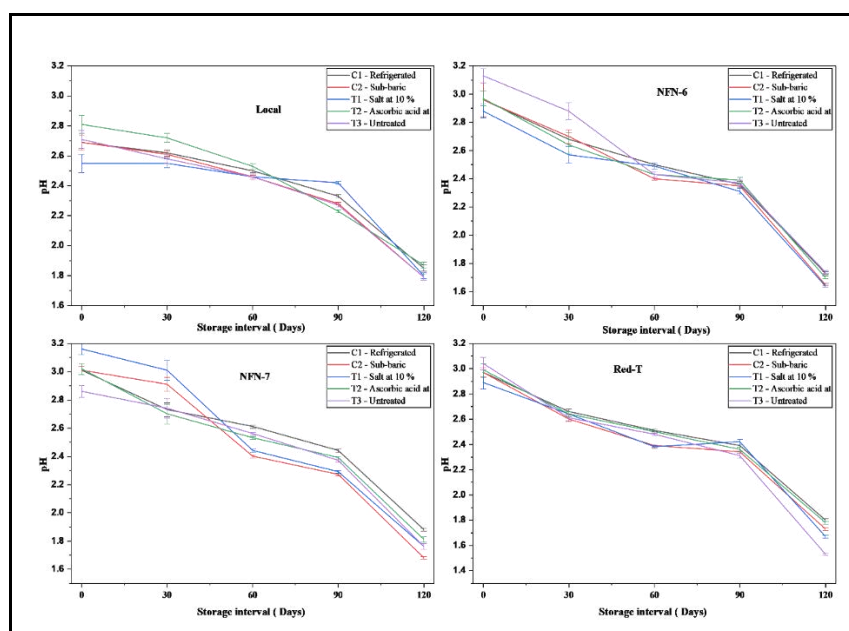
C1 Treatments	Storage interval (Days)															
	0				30				60				90			
	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T
A. Storage conditions																
C ₁ Refrigerated	16.91	16.16	16.69	16.56	17.17	16.36	16.72	17.09	17.84	16.69	17.32	17.68	18.49	17.22	17.93	18.29
C ₂ Sub-baric	16.91	16.16	16.69	16.56	17.69	17.46	17.10	17.61	18.45	17.81	17.79	18.39	19.15	18.42	18.41	19.09
F-test	NS	NS	NS	NS	*	*	*	*	*	*	*	*	*	*	*	*
S.E.m±	0.15	0.17	0.15	0.12	0.14	0.08	0.12	0.08	0.12	0.10	0.12	0.08	0.13	0.11	0.13	0.08
CD at 5%	-	-	-	-	0.40	0.24	0.36	0.23	0.36	0.29	0.34	0.25	0.37	0.31	0.37	0.23
B. Preservatives																
T ₁ Salt at 10%	17.72	17.19	17.20	16.50	18.39	17.89	17.26	17.26	19.04	18.21	17.86	17.86	19.64	18.69	18.51	18.57
T ₂ Ascorbic acid at 5%	15.43	15.58	16.13	17.19	16.04	16.09	16.43	17.22	16.67	16.41	17.00	17.92	17.38	17.06	17.60	18.51
T ₃ Untreated	17.58	15.71	16.75	15.98	17.86	16.78	17.04	17.58	18.73	17.12	17.80	18.33	19.45	17.71	18.41	18.99
F-test	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
S.E.m±	0.18	0.21	0.18	0.15	0.17	0.10	0.15	0.10	0.15	0.12	0.14	0.10	0.15	0.13	0.16	0.10
CD at 5%	0.52	0.61	0.52	0.43	0.49	0.29	0.44	0.28	0.44	0.35	0.42	0.30	0.45	0.38	0.46	0.29
Interactions (A×B)																
F-test	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	NS	NS	*	NS	NS
S.E.m±	0.26	0.30	0.26	0.21	0.24	0.15	0.22	0.14	0.22	0.17	0.21	0.15	0.23	0.19	0.23	0.14
CD at 5%	-	-	-	-	-	0.42	-	-	-	0.50	-	-	-	0.54	-	-

3.2 Effect of Storage on pH of Tamarind Pulp

The pH of tamarind underwent a gradual decrease in all four varieties during the storage period, with differences emerging significantly after 60 days, as evidenced by Figure 3 and Table 2. The pH values after 120 days of storage under C₁ were 1.85 for Local, 1.73 for NFN-6, 1.88 for NFN-7 and 1.80 for Red-T, indicating a development of moderately strong acids. On the other hand, C₂ made the pH values reach 1.79 in Local, 1.65 in NFN-6, 1.68 in NFN-7 and 1.73 in Red-T at 120 days, that was showing slightly lower pH retention at the end of the storage period, indicating marginally faster acid buildup under reduced-pressure conditions. The varietal differences were evident; NFN-6 had the lowest pH under C₁ storage, while Local had the greatest decline under C₂ and NFN-7 and Red-T behaved similarly in-between both conditions. Across preservatives, T₂ and T₁ consistently recorded higher pH at 120 days for all varieties (T₂: 1.87 Local, 1.70 NFN-6, 1.81 NFN-7, 1.78 Red-T; T₁: 1.80 Local, 1.64 NFN-6, 1.76 NFN-7, 1.67 Red-T), while the T₃ showed the lowest values in most combinations.

The determined pH drops points to the fact that tamarind pulp is acidic, which is confirmed by the ongoing acidification of tamarind pulp through the active microbial

fermentation, organic acid buildup and pectin hydrolysis during the storage under different conditions [1, 20, 25]. The slightly faster decline in C₂ treatments might be directly linked to the pressure effects on the metabolic processes operating under sub-baric conditions, making varieties such as NFN-6 more susceptible under C₁ while Local and Red-T showed varietal resilience [26]. The best treatment of T₂ and T₁ in the maintenance of high pH can be explained by their respective antioxidant and osmotic stabilising effects, which limit enzymatic degradation and the production of acids by bacteria resulting in a slower rate of titratable acidity rise [5, 8]. The T₃ was not able to perform the regulation of pH as effectively as T₁ or T₂, possibly due to unregulated changes in metabolism, though it did respond to the treatment variably. The strong interaction means the effectiveness of preservatives is largely determined by storage atmosphere, with the cold conditions providing better main effects for the preservation of pH. Hence, it can be concluded that the combination of cold storage with ascorbic acid or salt (C₁T₂ or C₁T₁) is the optimal method to reduce pH drop characteristics, which in turn increases the long-term quality and shelf stability of tamarind during storage. [20, 1] have also reported similar findings.

**Fig 3:** Changes in pH of Tamarind Pulp from Four Varieties Under Different Storage Conditions Over 120 Days

3.3 Effect of Storage on TSS of Tamarind pulp

TSS of tamarind increased progressively during storage across all four varieties, with significant differences emerging after 30 days, as shown in Figure 4 and summarised in Table 3. Under C_1 , the 120-day TSS values were 21.86 in Local, 21.52 in NFN-6, 21.68 in NFN-7 and 21.71 in Red-T, indicating moderate soluble solids development. In contrast, C_2 resulted in slightly higher TSS accumulation, reaching 23.67 in Local, 22.98 in NFN-6, 23.20 in NFN-7 and 22.91 in Red-T at 120 days, showing accelerated solids buildup under reduced-pressure

conditions. Varietal differences were clear: Local accumulated the highest TSS under C_2 , whereas NFN-6 showed relatively lower increase under C_1 and NFN-7 and Red-T exhibited intermediate behaviour across both conditions. Across preservatives, T_1 and T_2 consistently recorded higher TSS at 120 days for most varieties (T_1 : 23.23 Local, 22.41 NFN-6, 22.46 NFN-7, 22.66 Red-T; T_2 : 23.06 Local, 22.39 NFN-6, 22.44 NFN-7, 22.61 Red-T), while the T_3 showed the lowest values in several combinations.

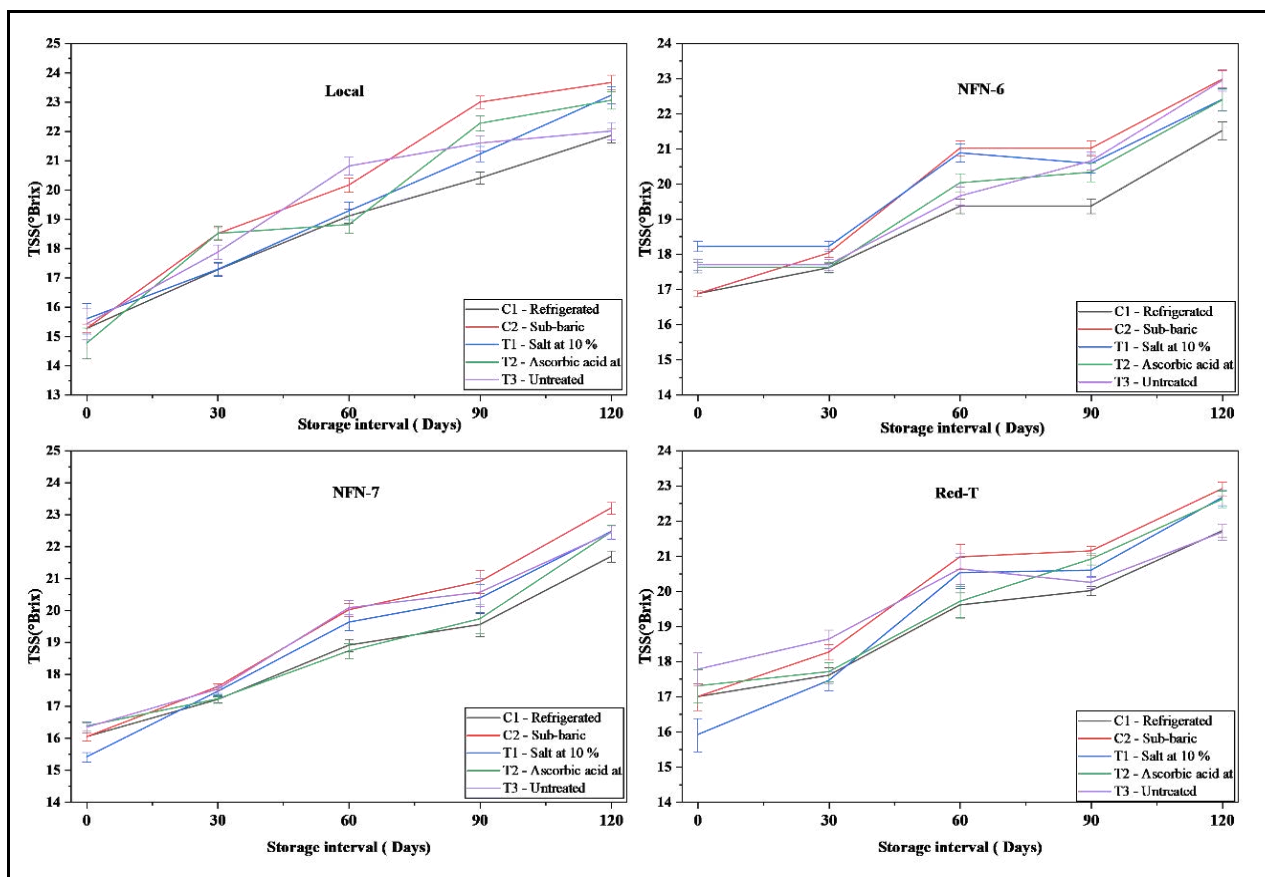


Fig 4: Changes in Total Soluble Solids (TSS, °Brix) of Tamarind Pulp from Four Varieties Under Different Storage Conditions Over 120 Days

The observed TSS increase aligns with tamarind pulp's hydrolytic nature, driven by polysaccharide conversion to soluble sugars via pectin degradation, enzymatic hydrolysis and microbial activity. Faster C_2 rise relates to enhanced breakdown under sub-baric pressure, with Local most responsive and NFN-6 moderated under C_1 . T_1 and T_2 promoted higher TSS through osmotic and antioxidant effects, facilitating controlled hydrolysis while limiting microbial overgrowth. T_3 regulated TSS less efficiently due to unbalanced metabolism. Significant interaction shows

preservative efficacy varies by atmosphere, with sub-baric enhancing TSS promotion. Thus, C_2T_1 or C_2T_2 combinations best maximise TSS, enhancing sensory quality and shelf stability. The current conclusions are similar for storage of tamarind cubes by [7, 9, 10, 15], who reported an improvement of TSS during storage of tamarind jelly cube. The increase in TSS might be due to the alteration in cell wall structure and breakdown of complex carbohydrates into simple sugars during storage.

Table 2: Effect of Storage Conditions, Preservative Treatments and Storage Duration on pH of Tamarind Pulp

Treatments	Storage interval (Days)																			
	0				30				60				90				120			
	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T
A. Storage conditions																				
C ₁ Refrigerated	2.69	2.96	3.01	2.97	2.62	2.68	2.73	2.66	2.50	2.50	2.61	2.51	2.33	2.36	2.44	2.39	1.85	1.73	1.88	1.80
C ₂ Sub-baric	2.69	2.96	3.01	2.97	2.61	2.70	2.91	2.60	2.46	2.40	2.40	2.39	2.28	2.35	2.27	2.34	1.79	1.65	1.68	1.73
F-test	NS	NS	NS	NS	NS	NS	*	*	*	*	*	*	*	NS	*	*	*	*	*	*
S.Em±	0.05	0.12	0.03	0.04	0.02	0.05	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01
CD at 5%	-	-	-	-	-	-	0.16	0.05	0.04	0.04	0.03	0.03	0.03	-	0.03	0.04	0.05	0.03	0.04	0.02
B. Preservatives																				
T ₁ Salt at 10%	2.55	2.88	3.16	2.89	2.55	2.57	3.01	2.64	2.46	2.49	2.44	2.38	2.42	2.31	2.29	2.42	1.80	1.64	1.76	1.67
T ₂ Ascorbic acid at 5%	2.81	2.97	3.02	2.99	2.72	2.64	2.70	2.64	2.53	2.43	2.53	2.50	2.23	2.39	2.39	2.36	1.87	1.70	1.81	1.78
T ₃ Untreated	2.71	3.13	2.86	3.04	2.58	2.88	2.74	2.61	2.46	2.43	2.56	2.48	2.27	2.37	2.37	2.31	1.79	1.74	1.76	1.53
F-test	*	*	*	NS	*	*	*	NS	*	*	*	*	*	*	*	*	*	*	*	*
S.Em±	0.06	0.05	0.04	0.05	0.03	0.06	0.07	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.01
CD at 5%	0.17	0.14	0.11	-	0.08	0.16	0.19	-	0.04	0.05	0.04	0.03	0.04	0.07	0.03	0.05	0.06	0.04	0.05	0.03
Interactions (A×B)																				
F-test	NS	NS	NS	NS	NS	*	*	*	NS	*	*	*	*	NS	*	*	*	*	*	*
S.Em±	0.08	0.07	0.06	0.07	0.04	0.08	0.09	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.01
CD at 5%	-	-	-	-	-	0.23	0.27	0.09	-	0.07	0.05	0.05	0.05	-	0.05	0.07	0.08	0.06	0.06	0.04

Table 3: Effect of Storage Conditions, Preservative Treatments and Storage Duration on Total Soluble Solids (°Brix) of Tamarind Pulp

Treatments	Storage interval (Days)																			
	0				30				60				90				120			
	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T
A. Storage conditions																				
C ₁ Refrigerated	15.27	16.88	16.04	16.99	17.28	17.62	17.20	17.60	19.11	19.37	18.90	19.60	20.41	19.37	19.55	20.01	21.86	21.52	21.68	21.71
C ₂ Sub-baric	15.27	16.88	16.04	16.99	18.51	18.04	17.60	18.26	20.17	21.02	20.01	20.97	23.00	21.02	20.90	21.14	23.67	22.98	23.20	22.91
F-test	NS	NS	NS	NS	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
S.Em±	0.15	0.09	0.12	0.38	0.20	0.12	0.10	0.22	0.24	0.21	0.20	0.36	0.21	0.21	0.36	0.13	0.25	0.25	0.18	0.19
CD at 5%	-	-	-	-	0.57	0.35	0.30	0.63	0.70	0.61	0.56	1.02	0.62	0.61	1.03	0.36	0.71	0.73	0.52	0.55
B. Preservatives																				
T ₁ Salt at 10%	15.60	18.23	15.41	15.91	17.29	18.23	17.46	17.45	19.29	20.89	19.62	20.52	21.23	20.59	20.38	20.59	23.23	22.41	22.46	22.66
T ₂ Ascorbic acid at 5%	14.77	17.63	16.37	17.30	18.52	17.63	17.22	17.70	18.82	20.04	18.72	19.70	22.28	20.34	19.73	20.91	23.06	22.39	22.44	22.61
T ₃ Untreated	15.43	17.71	16.33	17.77	17.88	17.71	17.53	18.63	20.82	19.66	20.07	20.63	21.60	20.66	20.56	20.24	22.01	22.95	22.43	21.67
F-test	*	*	*	*	*	*	NS	*	*	*	*	NS	NA	*	NS	*	*	NS	NS	*
S.Em±	0.52	0.15	0.15	0.47	0.24	0.15	0.13	0.27	0.30	0.26	0.24	0.44	0.26	0.26	0.44	0.16	0.30	0.31	0.22	0.23
CD at 5%	4.55	0.43	0.42	1.34	0.69	0.43	-	0.78	0.86	0.75	0.69	1.25	-	0.75	-	0.45	0.86	-	-	0.67
Interactions (A×B)																				
F-test	NS	NS	NS	NS	*	NS	*	NS	NS	NS	*	NS	NS	*	NS	NS	NS	NS	*	NS
S.Em±	0.26	0.15	0.21	0.66	0.34	0.21	0.18	0.38	0.42	0.37	0.35	0.62	0.40	0.40	0.62	0.22	0.43	0.44	0.32	0.33
CD at 5%	-	-	-	-	0.98	-	0.52	-	-	-	0.99	-	-	1.14	-	-	-	-	0.19	-

3.4 Effect of Storage on Titratable Acidity of Tamarind pulp

Tamarind pulp titratable acidity (TA) rose consistently in all varieties during the 120-day storage period (Figure 5 & Table 4). Among different storage conditions, the C₁ gave the lowest acidity values (16.92-15.84) while the one under reduced pressure, C₂ resulted in much higher acidity levels (18.13-18.88), the latter indicating more rapid acid formation under lower pressure. The response of the varieties differed, with NFN-6 and NFN-7 exhibiting the

highest increases under C₂, whereas Local had lower acidity levels even under the C₁. The use of preservatives had a direct impact on the acidity; T₁ and T₂ have always limited the TA increase more effectively than the T₃, which is a direct implication of their osmotic and antioxidant activity in the process of acid formation. The significant interaction further supported that combinations like C₁T₁ and C₁T₂ were the most efficient in reducing acid build-up and consequently flavour stability.

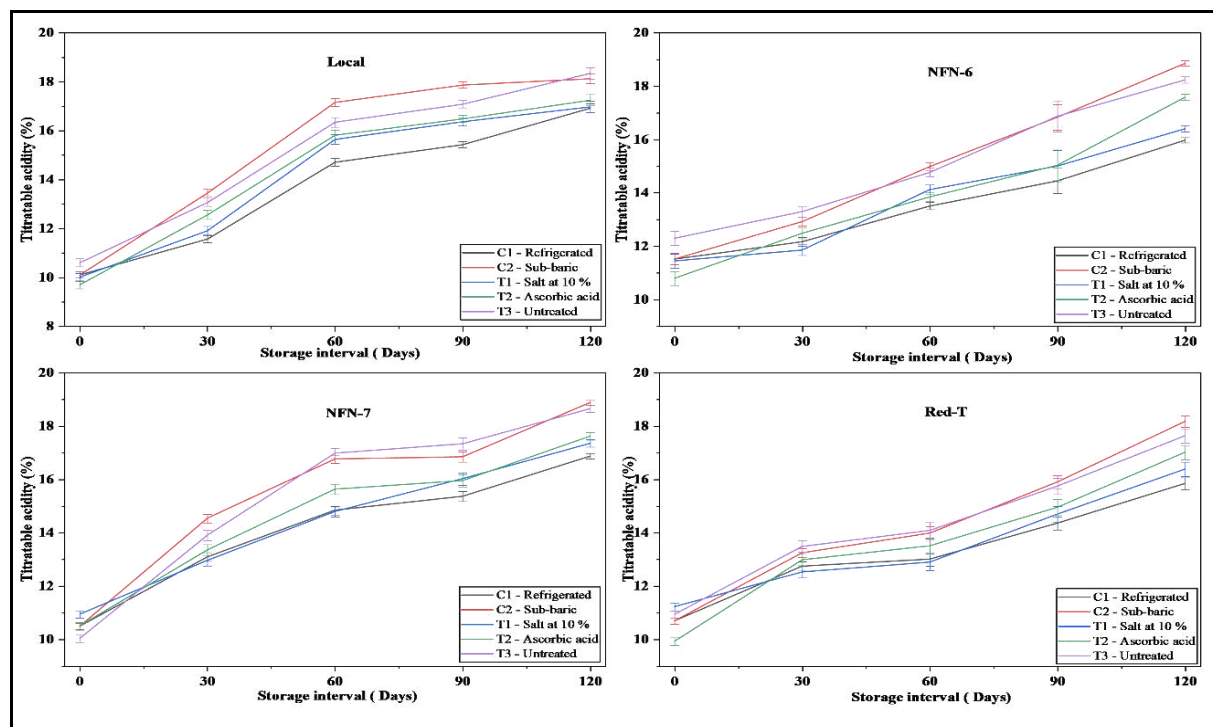


Fig 5: Changes in Titratable Acidity (%) of Tamarind Pulp from Four Varieties under Different Storage Conditions Over 120 Days

The storage-induced increase in tamarind acidity has been reported in previous investigations, citing its causes as pectin degradation, microbial growth and sugar conversion to acid [14, 26]. Refrigerated or moisture-free storage conditions were shown in this study not only to slow down the development of acidity in the case of tamarind but also in several studies dealing with tamarind pulp packed in moisture-resistant materials [3, 15]. In a similar study, [7] reported practising several processing treatments that led to gradual acidification of powdered tamarind and processed tamarind products over time, thus confirming that the application of a controlled environment and appropriate preservatives would significantly prolong the shelf life of

tamarind pulp.

3.5 Effect of Storage on Total Sugar of Tamarind Pulp

Total sugars (TS) decreased progressively during storage across all four varieties (Figure 6 & Table 5), with significant differences after 30 days. C₁ showed better TS retention at 120 days (12.18-14.48) compared to C₂, which recorded lower values (9.74-13.05). Red-T consistently retained the highest TS under both conditions, while Local showed the greatest decline. Among preservatives, T₁ and T₂ maintained higher TS throughout storage than the T₃, confirming their protective osmotic and antioxidant effects.

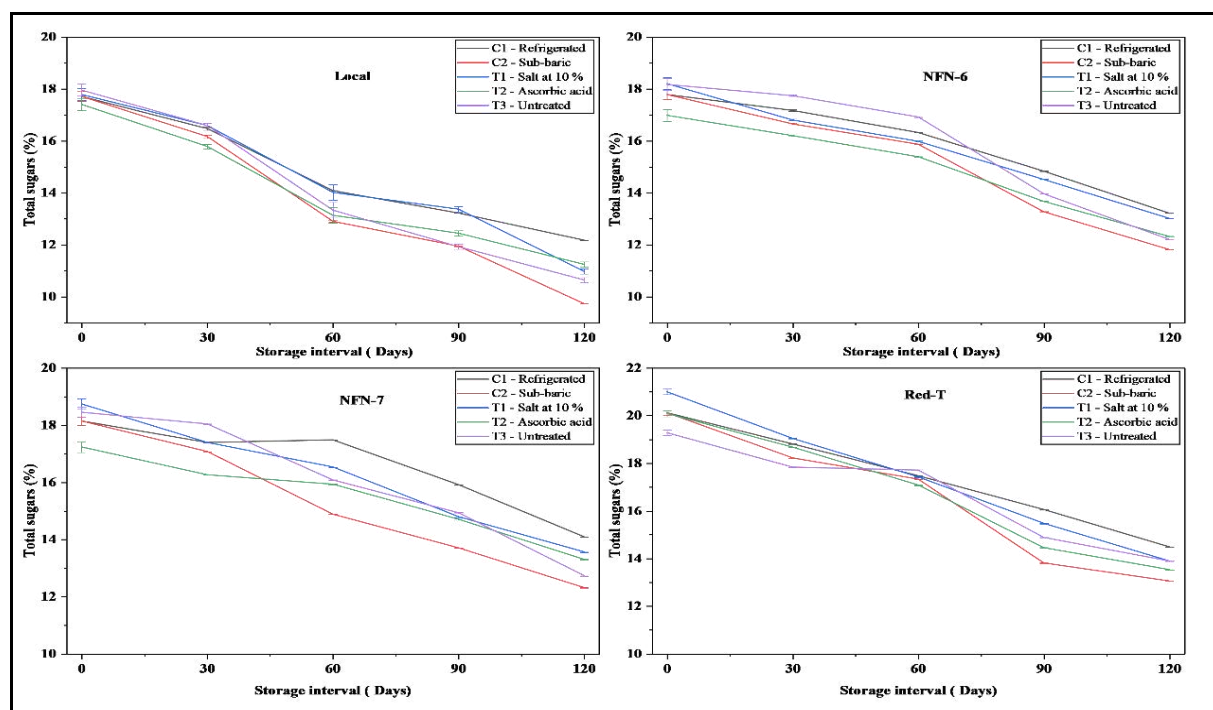


Fig 6: Changes in Total Sugar (%) of Tamarind Pulp from Four Varieties Under Different Storage Conditions Over 120 Days

TS reduction occurs because sugars transform into organic acids through respiration and enzymatic hydrolysis and microbial sugar consumption. The earlier studies show that total and reducing sugar amounts decrease during tamarind storage for both tamarind cubes and pulp products [7, 25]. The

most effective method to reduce sugar loss while preserving sweetness for extended storage periods involves using refrigerated conditions with T₁ or T₂ (C₁T₁/C₁T₂) combination.

Table 4: Effect of Storage Conditions, Preservative Treatments and Storage Duration on Titratable Acidity (%) of Tamarind Pulp

Treatments	Storage interval (Days)															
	0				30				60				90			
	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T
A. Storage conditions																
C ₁ Refrigerated	10.10	11.52	10.49	10.69	11.57	12.17	13.09	12.74	14.71	13.51	14.84	13.00	15.43	14.45	15.36	14.35
C ₂ Sub-baric	10.10	11.52	10.49	10.69	13.45	12.93	14.54	13.24	17.16	14.99	16.76	13.98	17.87	16.84	16.84	15.90
F-test	NS	NS	NS	NS	*	*	*	*	*	*	*	*	*	*	*	*
S.E.m±	0.13	0.21	0.11	0.12	0.15	0.17	0.16	0.17	0.16	0.14	0.16	0.26	0.13	0.48	0.19	0.24
CD at 5%	-	-	-	-	0.42	0.48	0.46	0.48	0.46	0.4	0.44	0.74	0.36	1.36	0.54	0.70
B. Preservatives																
T ₁ Salt at 10%	10.01	11.45	10.94	11.22	11.91	11.86	12.96	12.52	15.65	14.13	14.79	12.89	16.37	15.01	16.02	14.69
T ₂ Ascorbic acid at 5%	9.70	10.80	10.50	9.92	12.56	12.49	13.35	12.98	15.82	13.85	15.63	13.50	16.49	15.04	15.95	14.95
T ₃ Untreated	10.60	12.30	10.03	10.93	13.06	13.30	13.90	13.48	16.35	14.77	16.98	14.08	17.09	16.88	16.33	15.74
F-test	*	*	*	*	*	*	*	*	*	*	*	*	NS	*	NS	*
S.E.m±	0.16	0.26	0.14	0.14	0.18	0.20	0.20	0.21	0.20	0.17	0.19	0.31	0.15	0.58	0.23	0.30
CD at 5%	0.45	0.73	0.39	0.41	0.51	0.58	0.57	0.59	0.57	0.49	0.54	0.90	-	1.67	-	0.86
Interactions (A×B)																
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	*	NS	NS	NS
S.E.m±	0.22	0.36	0.19	0.20	0.25	0.29	0.28	0.29	0.28	0.24	0.27	0.44	0.22	0.82	0.32	0.42
CD at 5%	-	-	-	-	-	-	-	-	-	-	0.77	-	-	-	-	0.95

Table 5: Effect of Storage Conditions, Preservative Treatments and Storage Duration on Total Sugar Content (%) of Tamarind Pulp

Treatments	Storage interval (Days)															
	0				30				60				90			
	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T	Local	NFN-6	NFN-7	Red-T
A. Storage conditions																
C ₁ Refrigerated	17.72	17.79	18.14	20.12	16.48	17.18	17.39	18.81	14.09	16.33	17.48	17.47	13.23	14.84	15.91	16.05
C ₂ Sub-baric	17.72	17.79	18.14	20.12	16.17	16.66	17.07	18.22	12.91	15.88	14.88	17.33	11.95	13.28	13.70	13.81
F-test	NS	NS	NS	NS	*	*	*	*	*	*	*	*	*	*	*	*
S.E.m±	0.19	0.19	0.15	0.1	0.06	0.03	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD at 5%	-	-	-	-	0.18	0.07	0.02	0.03	0.09	0.04	0.03	0.04	0.03	0.03	0.04	0.03
B. Preservatives																
T ₁ Salt at 10%	17.79	18.21	18.74	21	16.6	16.81	17.39	19.04	14.02	15.99	16.53	17.42	13.38	14.52	14.79	15.47
T ₂ Ascorbic acid at 5%	17.41	16.99	17.23	20.08	15.79	16.21	16.26	18.67	13.14	15.40	15.93	17.08	12.45	13.68	14.70	14.45
T ₃ Untreated	17.96	18.18	18.45	19.28	16.6	17.75	18.04	17.83	13.34	16.93	16.08	17.71	11.93	13.97	14.93	14.88
F-test	NS	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
S.E.m±	0.23	0.23	0.18	0.12	0.08	0.03	0.01	0.01	0.3	0.02	0.01	0.02	0.1	0.01	0.02	0.01
CD at 5%	-	0.66	0.52	0.35	0.22	0.09	0.03	0.03	0.1	0.04	0.03	0.05	0.3	0.04	0.05	0.04
Interactions (A×B)																
F-test	NS	NS	NS	NS	*	*	*	*	*	*	*	*	*	*	*	*
S.E.m±	0.33	0.32	0.26	0.17	0.11	0.04	0.01	0.02	0.05	0.02	0.02	0.03	0.02	0.02	0.02	0.02
CD at 5%	-	-	-	-	0.31	0.13	0.04	0.04	0.15	0.06	0.05	0.07	0.05	0.05	0.07	0.06

3.6 Effect of Colour Parameters (L*, a*, b*, ΔE) During Storage of Tamarind pulp

The colour attributes of tamarind pulp (L*, a*, b*, ΔE) changed remarkably, showing deterioration after the 120-day storage period. The storage conditions, preservatives and varietal characteristics were the main factors influencing the changes, as seen in Table 6. The loss of lightness (L*) was uniform for all samples, the darkening being very gradual and thus, the typical response to such a situation was the popping up of both enzymatic and non-enzymatic browning. For the Local variety, L* changed from 37.50 at 0 days to 33.43 at the end of the refrigerated salt treatment (C₁T₁) and then, it dropped more sharply to 29.93 during the sub-baric salt treatment (C₂T₁), which implies that the sub-baric storage promoted browning. The same was true for NFN-6, NFN-7 and Red-T, but for the lightness loss, the period of the sampling under sub-baric untreated conditions (C₂T₃) was the longest and, often by day 120, L* values fell below 28. The redness (a*) values behaved differently for the different genotypes. NFN-7, which was naturally higher in a*, showed a reduction of

moderate extent or even slight stabilization under refrigeration (e.g., C₁T₂: 12.45-12.10), while under sub-baric conditions, the decline was very significant (e.g., C₂T₃: 12.45-8.41), which is interpreted as pigment degradation by oxidation. The yellowness (b*) values for all treatments dropped quickly, indicating the breakdown of carotenoid-linked pigments, with Red-T being the most affected, thus implying that chromatic fading was accelerated due to the reduced pressure.

The total colour difference (ΔE) shows that all treatments led to complete colour degradation which reached its highest level during for untreated samples whereas the ascorbic acid-treated refrigerated samples showed their lowest ΔE results. The research shows that ascorbic acid functions as the strongest anti-browning substance because it completely stops polyphenol oxidase activity while it also highly restricts non-enzymatic Maillard reactions. Refrigeration has been found to be the next best thing in colour retention since it slows down the oxidation and the activity of enzymes. [2, 19, 20] have reported similar results.

Table 6: Effect of Storage Conditions, Preservative Treatments and Storage Duration on Colour Values of Tamarind Pulp

Tamarind varieties	Treatments	Storage interval (Days)																		
		0			30				60				90				120			
		L _o *	a _o *	b _o *	L _t *	a _t *	b _t *	ΔE*	L _t *	a _t *	b _t *	ΔE*	L _t *	a _t *	b _t *	ΔE*	L _t *	a _t *	b _t *	ΔE*
Local	C ₁ T ₁	37.50	12.53	14.61	36.79	12.62	13.68	1.18	34.68	12.70	12.78	3.37	33.67	12.85	10.78	5.43	33.43	12.92	8.30	7.52
	C ₁ T ₂	37.37	12.22	14.52	36.89	12.36	12.78	1.81	34.78	12.48	12.67	3.20	32.67	12.56	9.67	6.77	31.85	12.62	8.78	7.98
	C ₁ T ₃	36.88	12.73	14.85	36.13	12.81	12.66	2.32	32.99	12.99	12.37	4.62	32.78	13.15	11.89	5.07	30.06	13.22	11.68	7.54
	C ₂ T ₁	37.50	12.53	14.61	36.11	11.98	11.78	3.20	32.78	10.56	9.65	7.13	30.78	8.09	7.78	10.56	29.93	4.08	6.78	13.79
	C ₂ T ₂	37.37	12.22	14.52	32.97	11.89	9.27	6.86	29.98	8.89	8.78	9.94	28.78	7.88	7.78	11.75	23.01	6.90	6.90	17.11
	C ₂ T ₃	36.88	12.73	14.85	35.67	11.99	10.89	4.21	31.67	6.78	7.89	10.54	26.67	7.78	6.89	13.86	25.18	3.09	4.57	18.32
NFN-6	C ₁ T ₁	38.07	12.89	15.30	37.07	12.92	14.56	1.25	34.95	12.94	13.89	3.43	33.67	13.15	13.47	4.78	33.01	13.45	13.38	5.44
	C ₁ T ₂	37.73	12.60	13.71	37.89	12.69	12.75	0.98	34.89	12.77	13.28	2.88	32.88	12.96	12.89	4.94	32.70	13.24	12.59	5.20
	C ₁ T ₃	37.87	13.62	13.34	36.56	13.74	13.20	1.32	34.67	13.79	12.92	3.23	31.86	13.86	12.11	6.14	31.26	13.95	12.02	6.75
	C ₂ T ₁	38.07	12.89	15.30	35.34	12.24	10.62	5.46	33.78	11.13	8.77	8.01	32.56	10.45	7.21	10.09	31.10	9.85	7.12	11.17
	C ₂ T ₂	37.73	12.60	13.71	34.78	12.54	10.78	4.16	32.99	11.34	9.18	6.68	28.33	10.64	8.34	11.01	26.28	9.95	8.25	12.96
	C ₂ T ₃	37.87	13.62	13.34	33.78	13.34	9.76	5.44	32.78	12.23	8.78	6.97	27.73	11.86	7.33	11.92	27.98	8.52	6.19	13.23
NFN-7	C ₁ T ₁	38.18	12.45	15.49	37.67	12.67	14.54	1.10	36.90	12.86	13.89	2.09	34.67	12.92	13.78	3.93	34.29	13.15	13.32	4.51
	C ₁ T ₂	38.22	12.76	15.07	36.67	12.99	13.88	1.97	36.46	13.12	12.83	2.87	33.45	13.35	12.78	5.32	33.22	13.53	11.61	6.13
	C ₁ T ₃	38.57	13.05	15.00	37.12	13.25	14.05	1.74	36.78	13.27	12.87	2.79	34.78	13.68	12.79	4.43	33.60	13.81	12.60	5.57
	C ₂ T ₁	38.18	12.45	15.49	35.78	11.32	11.78	4.56	32.83	10.67	8.12	9.28	32.67	9.64	8.34	9.45	28.60	8.41	6.40	13.81
	C ₂ T ₂	38.22	12.76	15.07	35.67	11.36	10.67	5.27	32.78	11.64	9.40	7.93	31.79	10.75	8.78	9.21	29.69	8.53	7.39	12.23
	C ₂ T ₃	38.57	13.05	15.00	36.78	11.97	8.68	6.65	32.78	11.44	8.32	8.98	30.76	10.75	7.68	10.94	29.80	7.54	5.59	13.99
Red-T	C ₁ T ₁	38.29	13.15	15.06	37.78	13.18	14.89	0.53	34.89	13.36	13.68	3.67	33.89	13.62	9.95	6.75	32.09	13.69	9.50	8.34
	C ₁ T ₂	37.93	13.55	14.94	35.79	13.67	14.89	2.15	34.67	13.71	14.79	3.27	32.67	13.78	13.44	5.48	32.46	13.89	12.72	5.92
	C ₁ T ₃	39.08	14.62	14.78	37.78	14.69	13.78	1.64	36.89	14.72	13.68	2.45	34.78	14.92	12.89	4.70	32.77	14.98	11.85	6.96
	C ₂ T ₁	38.29	13.15	15.06	36.52	12.52	11.13	4.35	35.88	10.78	10.89	5.36	27.89	8.34	5.67	14.81	23.61	2.26	3.84	21.44
	C ₂ T ₂	37.93	13.55	14.94	35.86	12.77	12.91	3.01	32.78	8.98	9.78	8.61	28.89	6.47	6.67	14.16	25.84	4.91	6.12	17.28
	C ₂ T ₃	39.08	14.62	14.78	35.89	13.28	10.90	5.20	31.78	8.67	6.89	12.28	26.43	4.78	4.89	18.83	25.92	3.05	4.93	20.10

4. Summary and Conclusion

The study examined how different storage methods and pre-processing methods affect the physicochemical properties and moisture content and pH level and total dissolved solids and titratable acidity and total sugar content of tamarind pulp from four different tamarind varieties. The general trend showed that refrigerated storage methods effectively delayed quality deterioration compared to storage at room temperature while maintaining lower moisture absorption rates and better control of acidity and pH stability. NFN-6 and NFN-7 emerged as the top varieties for maintaining freshness while Local and Red-T showed greater quality changes throughout their extended storage period. The results demonstrate that any product requires both proper treatment and cold storage to achieve market suitability regardless of its variety. The study provides essential information to processors and small-scale industries and researchers who seek to develop effective tamarind storage methods that maintain product quality during extended storage periods.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

References

1. Adeola AA, Aworh OC. Effects of sodium benzoate on storage stability of previously improved beverage from tamarind (*Tamarindus indica* L.). Food Sci Nutr. 2014;2(1):17-27. doi:10.1002/fsn3.78.
2. Aderoju A, Ogugua A, Aworh C. Comparative evaluation of the chemical properties of wild tamarind (*Tamarindus indica* L.) fruits in Nigeria. 2012.
3. Agrawal AK, Khare A, Sinha G. Storage of tamarind in commonly available packaging materials. 2015.
4. AOAC. Official methods of analysis. 21st ed. Washington (DC): AOAC International; 2019.
5. Akter F, Aunsary L, Sayed K, Islam M, Islam MA. Efficacy of tamarind pulp on quality assessment and storage stability of brinjal pickle. J Bangladesh Agric Univ. 2022;20:1-???. doi:10.5455/JBAU.100282.
6. Banti M, Teka TA, Agza B, Hailu D. Proximate, physical and sensory properties of bread from taro-wheat composite flour. J Food Process Preserv. 2024;2024(1). doi:10.1155/jfpp/3575144.
7. Deokar V. Evaluation of chemical parameters of tamarind (*Tamarindus indica* Linn). Int J Food Sci Nutr. 2019;4(6):117-119.
8. Gupta C, Prakash D, Gupta S. Studies on antimicrobial activity of tamarind (*Tamarindus indica*) and its potential as food biopreservative. Int Food Res J. 2014;21(6):2437-2441.
9. Bahtiti HN. Preservative effects of Jordanian sage oil on storage stability of tamarind beverage. Food Sci Technol. 2014;2(4):47-51. doi:10.13189/fst.2014.020401.
10. Joshi AA, Kshirsagar RB, Sawate AR. Standardization of enzyme concentration and process for extraction of tamarind pulp (var. Ajanta). 2012;3(2):141.
11. Khan I. Development and quality evaluation of tamarind plum blended squash during storage. J Food Process Technol. 2017;8(3). doi:10.4172/2157-7110.1000662.
12. Kumar B, Patel S, Khokhar D, Mishra N. Effect of different flexible packaging materials on storage stability of tamarind (*Tamarindus indica* L.) pulp briquettes. 2018.
13. Moneim A, Sulieman E, Abdelmageed E, Alawad SM, Osman MA. Physicochemical characteristics of local varieties of tamarind (*Tamarindus indica* L.), Sudan. Int J Plant Res. 2015;5(1):13-18.

- doi:10.5923/j.plant.20150501.03.
14. Morsy M, Hafez EA, El-Gharabli H, El-Desouky M. Influence of different extraction conditions on tamarind (*Tamarindus indica* L.) beverage quality. 2011.
 15. Sreedevi MS, Rajkumar P, Palanimuthu V, Geethalakshmi I. Influence of storage condition and packaging on biochemical traits of tamarind pulp. 2021;10(12):3087-3094.
 16. Muzaffar K, Kumar P. Tamarind—a mini review. MOJ Food Process Technol. 2017;5(3):296-297. doi:10.15406/mojfpt.2017.05.00126.
 17. Nagalakshmi S, Chezhiyan N. Influence of packaging and storage conditions on tamarind (*Tamarindus indica*) pulp quality. J Food Sci Technol. 2004;41(5):586-590.
 18. Naik J, Nagalakshmi S, Balasubrahmanyam N, Shankaracharya NB. Packaging and storage studies on tamarind (*Tamarindus indica* L.) pulp. J Food Sci Technol. 2004;41:348-351.
 19. Ngani PP, Manditsera FA, Macheke L. Isolation and characterization of pectin from tamarind (*Tamarindus indica*) fruit pulp as a natural source. Cogent Food Agric. 2025;11(1). doi:10.1080/23311932.2025.2578335.
 20. Obulesu M, Bhattacharya S. Color changes of tamarind (*Tamarindus indica* L.) pulp during development, ripening and storage. J Food Sci. 2011. doi:10.1080/10942910903262129.
 21. Om P, Amarjeet K, Kudachikar VB. Influence of pretreatments on postharvest quality characteristics and shelf life of green tamarind fruits. 2016;8(58):3199-3204.
 22. Ravindran PN, Johny AK, Nirmal Babu K. Tamarind—the brown gold: a tree of untapped potential. 2002.
 23. Sadler G, Murphy P. pH and titratable acidity. In: Nielsen SS, editor. Food analysis. New York: Springer; 2010. p. 219-238. doi:10.1007/978-1-4419-1478-1_13.
 24. Shankaracharya NB. Tamarind—chemistry, technology and uses: a critical appraisal. J Food Sci Technol. 1998;35(3):193-208.
 25. Siddig K, Gunasena HPM, Prasad BA, Pushpakumara DKN, Ramana KVRR, Vijayanand P, *et al.* Tamarind. 2006.
 26. Singh D, Wangchu L, Moond SK. Processed products of tamarind. 2007;6(4):315-321.
 27. Sreedevi MS, Rajkumar P, Palanimuthu V, Hanumanthappa DC, Surendrakumar A, Ganapathy S, *et al.* Investigation of physical, engineering and biochemical traits of tamarind genotypes. 2022;14(3):253-260.
 28. Sreedevi MS, Rajkumar P, Palanimuthu V, Narasaiah KP, *et al.* Tamarind preservation: impact of packaging and storage conditions on quality. J Stored Prod Res. 2026;115:102832. doi:10.1016/j.jspr.2025.102832.
 29. Narina SS, Davis C, Corley M, Hamama A, Kim C, *et al.* Factors influencing postharvest quality of tamarind fruit pulp. Acta Sci Microbiol. 2019;2(12):10-19. doi:10.31080/asmi.2019.02.0422.
 30. Takhellambam RD, Bharati P. Effect of storage on quality of tamarind (*Tamarindus indica* L.) clones. 2020;9(8):2409-2416.
 31. Vanithasri J, Kanchana S, Pushpavalli K. Storage stability of tamarind RTS beverages. Int J Curr Microbiol Appl Sci. 2019;8.