International Journal of Advanced Biochemistry Research 2025; SP-9(12): 56-61

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(12): 56-61
www.biochemjournal.com
Received: 08-10-2025
Accepted: 13-11-2025

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Effect of postharvest coating treatments on the shelf life and quality attributes of Kachai lemon (*Citrus jambhiri* Lush.)

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DOI: https://www.doi.org/10.33545/26174693.2025.v9.i12Sa.6451

Abstract
The study investigates the impact of various postharvest coatings on the shelf life and quality of Kachai lemon (*Citrus jambhiri* Lush.), a regionally important citrus fruit known for its high acidity and vitamin C content. Seven treatments were evaluated: control (uncoated), bee wax, mustard oil with 1.5% sodium alginate, soybean oil with 1.5% sodium alginate, groundnut oil with 1.5% sodium alginate, coconut oil with 1.5% sodium alginate, and only 1.5% sodium alginate. Key parameters analyzed included physiological loss of weight (PLW), juice content, shrinkage, spoilage percentage, total soluble solids (TSS), titratable acidity, ascorbic acid content, sensory evaluation, and storability. Results revealed that mustard oil with 1.5% sodium alginate (T_2) was the most effective in preserving quality and extending the storage life to 45 days, compared to 32 days for the uncoated control. The findings suggest that edible coatings, particularly those combining natural oils with sodium alginate, offer a sustainable and cost-effective strategy for improving postharvest quality of Kachai lemon.

Keywords: Kachai lemon, postharvest coating, sodium alginate, storability, quality parameters

1. Introduction
Kachai lemon (*Citrus jambhiri* Lush.), a prominent citrus fruit, is widely cultivated in northeastern India, particularly in Manipur. Known for its distinct aroma, high acidity, and vitamin C content, it plays a significant role in regional diets and the local economy. However, like other citrus fruits, Kachai lemon is highly perishable, exhibiting rapid weight loss, spoilage, and degradation of nutritional quality during storage.

Postharvest losses in citrus are primarily due to moisture loss, microbial spoilage, and biochemical changes, which collectively shorten shelf life and reduce marketability. Edible coatings have emerged as an effective method to mitigate these challenges. By forming a thin, semi-permeable barrier on the fruit surface, coatings can reduce moisture loss, delay ripening, and maintain nutritional quality.

Sodium alginate, a natural polysaccharide derived from brown algae, has been widely used as an edible coating due to its biodegradability and safety. Combining sodium alginate with natural oils such as mustard, soybean, groundnut, or coconut oil may enhance barrier properties and antimicrobial effects.

The objective of this study was to evaluate the effects of different postharvest coatings on the shelf life and quality of Kachai lemon, with a focus on physiological weight loss, juice content, spoilage, and sensory attributes.

2. Materials and Methods
Experimental Site and Design

The experiment was carried out to evaluate the effect of different edible coatings on the post-harvest quality and shelf life of Kachai lemon. The study was conducted under ambient room temperature conditions. A Completely Randomized Design (CRD) was adopted, consisting of seven treatments with three replications each. A total of 30 fruits per treatment were selected, with 10 fruits per replication. Observations were recorded at 6-day intervals up to 24 days (Day 0, 6, 12, 18, and 24).

Treatment Details

Table 1: The treatments included various edible coatings using natural wax, plant-based oils, and sodium alginate

Treatment Code	Treatment Description
T_0	Control (Uncoated fruits)
T_1	Bee wax coating
T_2	Mustard oil + 1.5% Sodium Alginate
T_3	Soybean oil + 1.5% Sodium Alginate
T_4	Groundnut oil + 1.5% Sodium Alginate
T_5	Coconut oil + 1.5% Sodium Alginate
T_6	Sodium Alginate (1.5%) only

Parameters Recorded

1. Physiological Loss in Weight (PLW%)

Weight loss was determined by recording the initial weight of fruits followed by subsequent measurements during storage. The percentage of weight loss was calculated using the formula:

PLW (%) = (Initial weight - Final weight) / Initial weight × 100

2. Juice Content (%)

Juice was extracted manually by squeezing the fruits and the volume was measured using a graduated beaker. The percentage of juice content was calculated as:

Juice (%) = (Juice weight per fruit / Weight of individual fruit) × 100

3. Total Soluble Solids (TSS)

The TSS of fruit juice was determined using a hand refractometer (Model: Erma, Japan) and expressed in °Brix. Temperature corrections were made using a standard temperature correction chart at 20°C, following the method of AOAC (1990).

4. Shrinkage (%)

Fruit diameter was measured at four points using a Verniercaliper—two measurements at the polar region and two at the equatorial region. The fruit volume was calculated using the formula:

Volume = $4/3 \times \pi \times r^3$

Shrinkage (%) = (Initial volume - Successive volume) / Initial volume × 100

5. Spoilage Percentage (%)

Spoilage percentage was determined by counting the number of fruits showing visible signs of spoilage at each observation interval. It was calculated as:

Spoilage (%) = (Number of spoiled fruits / Total number of fruits) × 100

6. Titratable Acidity (%)

Titratable acidity was determined using phenolphthalein as an indicator and 0.1N sodium hydroxide (NaOH) as a titrant. Sample preparation: 2 ml of fruit juice was diluted to 10 ml with distilled water.

Calculation:

Titratable Acidity (%) = (0.0067 × V × 100) / Volume of juice taken

Where V = Volume of 0.1N NaOH used (ml) (AOAC, 2005).

7. Ascorbic Acid (Vitamin C)

Reagents Prepared:

- **3% Metaphosphoric acid (HPO_3):** 3 g HPO_3 dissolved in 100 ml distilled water.
- Ascorbic acid standard: 100 mg L-ascorbic acid dissolved in 100 ml of 3% HPO_3, further diluted so that 1 ml = 0.1 mg ascorbic acid.
- **Dye solution:** Dissolve 50 mg sodium salt of 2,6-dichlorophenolindophenol and 42 mg sodium bicarbonate in approximately 150 ml hot distilled water. Cool and dilute to 200 ml. Store in a refrigerator and standardize daily.

Procedure

1. **Standardization of dye:** Take 5 ml standard ascorbic acid + 5 ml HPO_3 and titrate against the dye solution until a pink endpoint persists for 15 seconds.
2. **Sample preparation:** Dilute 10 ml of juice sample to 100 ml with 3% HPO_3, filter or centrifuge. Titrate 10 ml aliquot against the standardized dye.

Calculation:

Ascorbic Acid (mg/100 g or ml) = (T × D × V1 × 100) / (W × V2)

Where:
T = Volume of dye used (ml)
D = Dye factor (mg of ascorbic acid per ml of dye)
V1 = Total volume of extract (ml)
V2 = Volume of extract taken for titration (ml)
W = Weight of sample taken (g) (Shankar, 1999).

8. Sensory Evaluation

Sensory quality was evaluated after 24 days of storage by a panel of six trained judges. Fruits were assessed for color, flavor, texture, and overall acceptability using a nine-point Hedonic scale, where 1 = extremely undesirable and 9 = extremely desirable.

Table 2: Nine-point Hedonic scale

Score	Description
9	Extremely desirable
8	Very much desirable
7	Moderately desirable
6	Slightly desirable
5	Neither desirable nor undesirable
4	Slightly undesirable
3	Moderately undesirable
2	Very much undesirable
1	Extremely undesirable

9. Shelf-Life Assessment

Shelf life was determined based on visual observation, physicochemical parameters, and overall fruit acceptability until fruits were no longer edible or marketable (Moneruzzaman *et al.*, 2009; Mandal *et al.*, 2018) [13, 12].

10. Statistical Analysis

Data collected from the experiment were subjected to Analysis of Variance (ANOVA) as per the CRD method. Treatment means were compared using the F-test at a 5% level of significance. Statistical calculations were carried out using standard statistical software.

3. Results and Discussion

3.1 Physiological Loss of Weight (PLW)

The physiological loss of weight of Kachai lemon increased progressively throughout the storage period across all treatments; however, the rate of increase differed significantly ($p \leq 0.05$) among the coating treatments (Table 3 and Fig. 1). By day 24, the uncoated control fruits (T_0) recorded the highest PLW of 18.99%, indicating severe moisture loss through transpiration and respiration. In contrast, fruits coated with mustard oil + 1.5% sodium alginate (T_2) exhibited the lowest PLW of 10.80%, followed closely by T_3 (soybean oil + alginate), T_4 (groundnut oil + alginate), and T_5 (coconut oil + alginate), which recorded PLW values ranging between 11.70-12.30%.

The reduced weight loss under T_2 treatment can be attributed to the semi-permeable film formed by the edible coating, which restricted water vapor diffusion and lowered the transpiration rate, thereby preserving internal moisture content. Oil-based edible coatings form a hydrophobic layer that limits water vapor transmission and reduces respiration (Ali *et al*., 2011) [1]. Similar reductions in PLW using polysaccharide-based coatings have been documented in citrus fruits (Maftoonazad & Ramaswamy, 2005; Kumar *et al*., 2017) [11, 8]. Baldwin *et al.* (2012) [2], who observed that oil-based edible coatings effectively reduce weight loss in citrus fruits by forming a moisture barrier and creating a modified internal atmosphere.

3.2 Juice Content (%)

Juice content decreased with storage time across all treatments, primarily due to moisture loss and senescence. Control fruits showed the steepest decline, from 49.60% at day 0 to 31.60% at day 24, reflecting faster desiccation and loss of turgidity. In contrast, T_2 maintained the highest juice content (41.91%) at the end of the storage period, followed by T_3 (41.72%), T4 (40.00%), and T_5 (39.20%). The bee wax coating (T_1) retained moderate juice content (38.80%) (Table 3 and Fig. 2).

The higher juice retention in oil + alginate treatments is directly related to lower transpiration and respiration rates, which slow down dehydration of the pulp. Maftoonazad and Ramaswamy (2005) [11] also reported similar trends in coated citrus fruits, where edible coatings effectively maintained internal juice content and delayed physiological softening. Coatings effectively delayed moisture loss and slowed the metabolic breakdown of internal tissues. Previous studies also confirm that edible coatings help retain juice content by reducing transpiration and delaying senescence in citrus fruits (Maftoonazad & Ramaswamy, 2008; Dang *et al.*, 2008) [10, 4].

3.3 Shrinkage (%)

Shrinkage followed a similar trend to PLW, with control fruits showing the highest shrinkage (19.12%) and T_2 recording the lowest (10.92%) after 24 days of storage (Table 3 and Fig. 3). This is because coating treatments help preserve cell integrity and minimize surface dehydration. The maintenance of peel firmness and appearance is critical for citrus fruits, as visible shrinkage negatively affects consumer preference. Comparable observations were made by Kumar *et al.* (2017) [8] and Maftoonazad and Ramaswamy (2008) [10], who confirmed that edible coatings significantly reduce fruit shrinkage during storage by lowering moisture migration. Coatings reduce cellular dehydration and maintain firmness—an effect widely reported in coated lemons and oranges (Jhalegar *et al*., 2015; Sharma *et al*., 2014; Valencia *et al.*, 2012) [6, 21, 22].

3.4 Spoilage Percentage (%)

Visible spoilage symptoms (soft rot, fungal infection, and surface browning) were first observed in control fruits on day 18 and increased sharply to 66.67% by day 24. Bee wax coating (T_1) limited spoilage to 13.33%, whereas T_2, T_3, T_4, and T_5 treatments showed no spoilage (0%) during the entire 24-day observation period (Table 3 and Fig. 4). This indicates the antimicrobial activity and barrier properties of the oil + sodium alginate coatings. The hydrophobic oil layer prevents surface wetting and microbial penetration, while sodium alginate helps form a stable film on the peel surface. Similar antimicrobial effects of edible coatings enriched with oils or bioactive compounds have been reported in citrus and other fruits (Rojas-Graü *et al*., 2009; Raybaudi-Massilia *et al.*, 2008; Valencia-Chamorro *et al*., 2011) [19, 18, 23].

Table 3: Effect of different postharvest coating on physical properties of Kachai lemon

	PWL (%)				Juice content (%)				Shrinkage (%)				Spoilage (%)			
Ttreatments	6 days	12 days	18 days	24 days	6 days	12 days	18 days	24 days	6 days	12 days	18 days	24 days	6 days	12 days	18 days	24 days
T_0	5.15	8.73	13.88	18.99	49.6	40.99	35.5	31.6	5.29	8.9	13.96	19.12	0	0	20	66.67
T_1	3.66	6.35	9.6	12.7	53.6	53.4	47.7	38.8	3.78	6.49	9.72	12.88	0	0	0	13.33
T_2	1.7	4.8	7.4	10.8	57.9	56.52	52.47	41.91	1.78	4.92	7.56	10.92	0	0	0	0
T_3	2.8	5.68	8.76	11.7	56.84	55.9	52.38	41.72	2.93	5.77	8.8	11.86	0	0	0	0
T_4	3.33	5.86	8.87	11.83	56.7	55.99	52.5	40	3.45	5.94	8.9	11.93	0	0	0	0
T_5	3.48	5.98	9.23	12.3	56.83	44.9	42.8	39.2	3.59	6.09	9.34	12.48	0	0	0	0
T_6	3.77	6.53	9.77	12.94	44.4	42	35.56	32.5	3.9	6.68	9.92	12.98	0	0	6.67	40
F-test	S	S	S	S	S	S	S	S	S	S	S	S	-	-	S	S
CD 5%	0.54	0.63	0.56	0.42	0.45	0.72	0.44	0.49	0.41	0.48	0.62	0.44	0	0	8.39	11.86

3.5 Total Soluble Solids (TSS)

TSS increased gradually during storage across all treatments due to the conversion of starches and polysaccharides into simple sugars during ripening. Control fruits exhibited the most rapid increase (from 7.8 °Brix on day 0 to 9.2 °Brix by day 24), whereas T_2 showed a slower and more controlled increase (from 7.0 °Brix to 8.4 °Brix) (Table 4 and Fig. 5). This slower TSS accumulation in coated fruits reflects delayed ripening and reduced respiration rate due to the semi-permeable barrier of the coating. Baldwin *et al*. (2012) [2] observed similar effects in coated citrus fruits, noting that reduced oxygen availability inside the coated fruits slows down sugar accumulation and senescence. Similar results was also obtain by Dhall (2013), and Perez-Gago & Krochta (2001) [17].

3.6 Titratable Acidity (%)

Titratable acidity declined significantly over time, with the control showing a sharp drop from 5.60% to 3.40%, while T_2 maintained a higher acidity of 4.90% at the end of storage (Table 4). The retention of acidity in coated fruits indicates slower utilization of organic acids during respiration and delayed metabolic breakdown. Maintaining acidity is crucial for preserving the characteristic sour taste and consumer acceptability of Kachai lemon. Similar observations have been reported by Kader (2002) [7] and Sharma *et al*. (2014) [21], who found that coating treatments delay acid loss in citrus fruits during storage.

3.7 Ascorbic Acid Content (mg/100 ml)

Ascorbic acid, a key nutritional component of citrus fruits, decreased substantially during storage. In the control, vitamin C content dropped from 31.00 mg/100 ml at day 0 to 10.00 mg/100 ml by day 24, while T_2 retained the highest content of 26.00 mg/100 ml (Table 4 and Fig. 6). The slower degradation of ascorbic acid in coated fruits may be attributed to reduced oxidative stress and lower oxygen permeability. Edible coatings can act as protective films, reduce oxygen diffusion, minimizing oxidative degradation of vitamin C. Similar trends have been documented in coated lemons and oranges (Maftoonazad & Ramaswamy, 2008; Nimmathota *et al*., 2020) [10, 14].

Table 4: Effect of different postharvest coating on quality attributes of Kachai lemon

	Total Soluble Solids (ºbrix)				acidity (%)				ascorbic acid (mg/100ml)			
Treatments	**6 days**	**12 days**	**18 days**	**24 days**	**6 days**	**12 days**	**18 days**	**24 days**	**6 days**	**12 days**	**18 days**	**24 days**
T_0	7.8	8.2	8.7	9.2	5.60	4.90	4.10	3.40	31.00	25.50	18.30	10.00
T_1	7.8	7.9	8.6	8.9	5.70	5.10	4.50	3.90	34.00	27.50	20.70	15.30
T_2	7.0	7.5	8.0	8.4	6.00	5.60	5.20	4.90	39.30	35.00	30.40	26.00
T_3	7.2	7.5	8.0	8.5	6.00	5.50	5.10	4.80	39.00	34.50	29.50	24.00
T_4	7.2	7.6	8.2	8.7	5.90	5.30	4.70	4.30	36.00	30.00	25.00	22.50
T_5	7.6	7.8	8.3	8.8	5.90	5.40	4.60	4.10	35.00	28.00	23.50	18.00
T_6	7.8	8.1	8.6	9.0	5.70	5.00	4.30	3.60	30.00	25.20	19.50	12.00
F-test	S	S	S	S	S	S	S	S	S	S	S	S
CD (5%)	0.25	0.39	0.36	0.20	0.18	0.51	0.37	0.99	0.74	3.09	0.22	2.39

3.8 Sensory Evaluation and Shelf Life

Sensory scores for color, flavor, texture, and overall acceptability were significantly higher for T_2 than for other treatments (Table 5). After 24 days of storage, T_2 recorded scores of 6.7 (color), 7.5 (flavor), 7.3 (texture), and 7.1 (overall acceptability), indicating superior fruit quality. Control fruits, on the other hand, received the lowest scores (5.1 for overall acceptability) due to visible shrinkage, loss of juice content, and spoilage. Studies across citrus confirm that edible coatings significantly improve appearance, texture, flavor retention, and storability (Baldwin *et al*., 2012; Lin & Zhao, 2007; Olivas & Barbosa-Cánovas, 2005) [2, 9, 15].

In terms of storability, T_2 extended the shelf life of Kachai lemon up to 45 days, compared to 32 days for control fruits. Other treatments (T_3-T_5) also prolonged shelf life to 40-43 days, and bee wax (T_1) to 38 days. These results are consistent with the findings of Sharma *et al*. (2014) [21], who demonstrated that edible coatings can extend the marketable life of citrus fruits by 30-50%.

Table 5: Effect of different postharvest coating on sensory evaluation and shelf life of Kachai lemon

Treatments	Color	Flavor	Texture	Overall acceptability	Storability (days)
T_0	5.9	6.0	5.8	5.1	32
T_1	6.4	6.8	6.6	6.0	38
T_2	6.7	7.5	7.3	7.1	45
T_3	6.6	7.3	7.4	6.9	43
T_4	6.5	7.1	7.0	6.4	41
T_5	6.4	7.0	7.0	6.2	40
T_6	5.9	6.2	6.0	5.8	35

4. Conclusion

The present study clearly demonstrates that postharvest edible coatings significantly enhance the shelf life and quality retention of Kachai lemon (Citrus jambhiri Lush.) under ambient storage conditions. Among all treatments evaluated, mustard oil combined with 1.5% sodium alginate (T_2) proved to be the most effective, as evidenced by the lowest physiological weight loss, minimal shrinkage, zero spoilage, superior retention of juice content, titratable acidity, and ascorbic acid, along with the highest sensory acceptability. The T_2 treatment successfully extended the shelf life of Kachai lemon up to 45 days, compared to 32 days for uncoated fruits. These findings confirm that oil-based edible coatings, particularly when integrated with sodium alginate, serve as a cost-effective, eco-friendly, and practical postharvest strategy for citrus growers and traders, especially in regions with limited cold-storage infrastructure. The technology holds strong potential for commercialization and for minimizing postharvest losses in Kachai lemon and similar citrus crops.

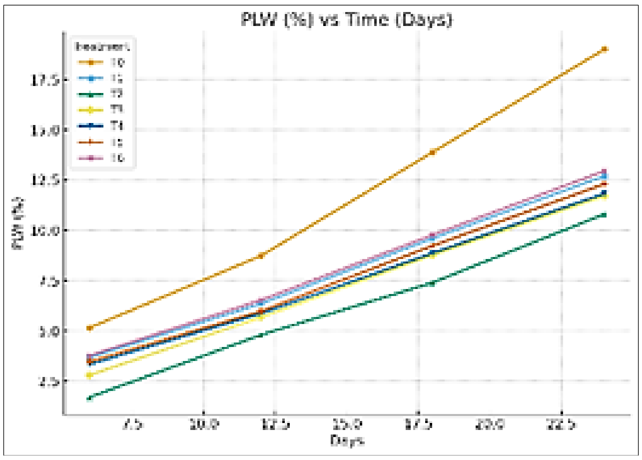

Fig 1: Effect on PWL during storage

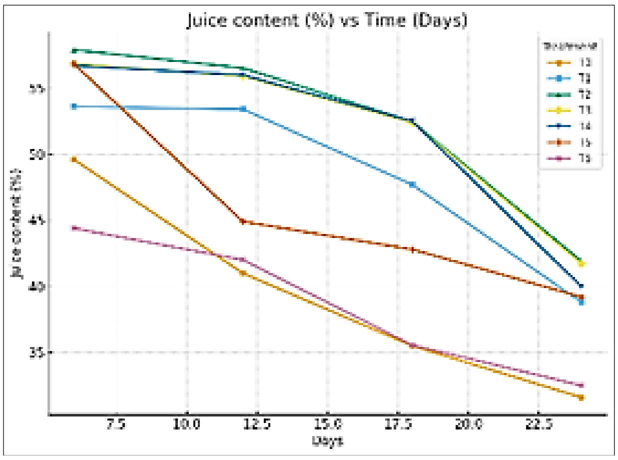

Fig 2: Effect on juice content during storage

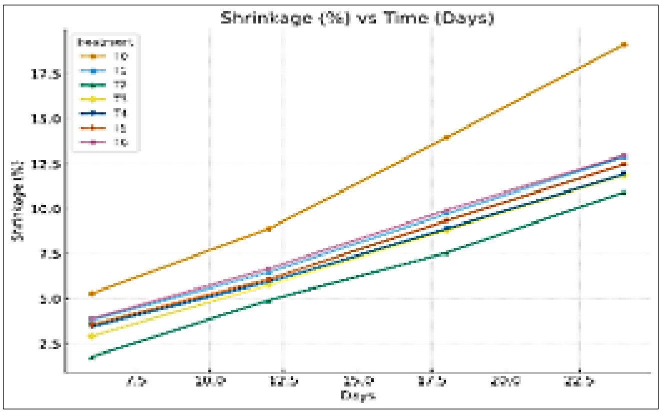

Fig 3: Effect on Shrinkage% during storage

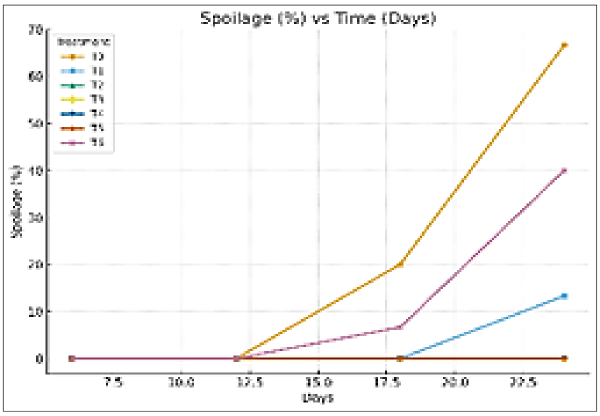

Fig 4: Effect on Spoilage% during storage

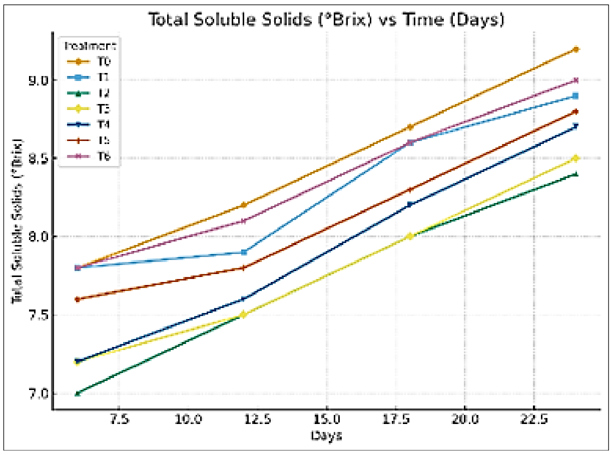

Fig 5: Effect on TSS% during storage

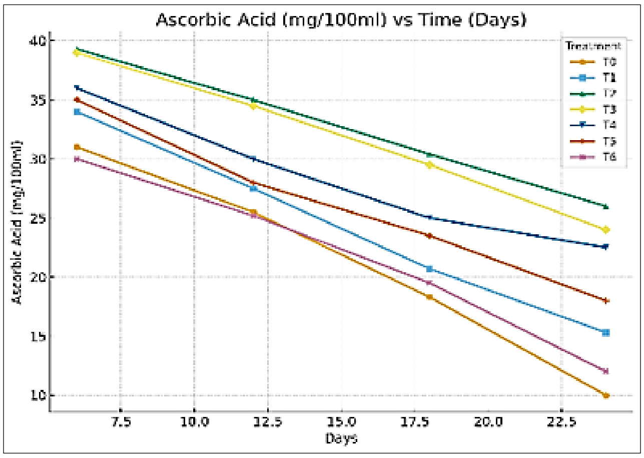

Fig 6: Effect on Ascorbic Acid during storage

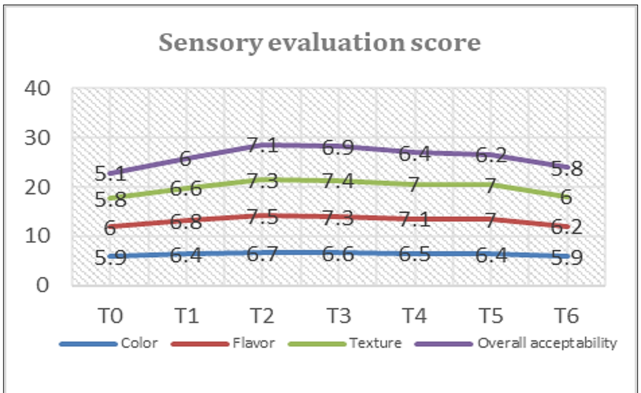

Fig 7: Effect on Sensory evaluation score

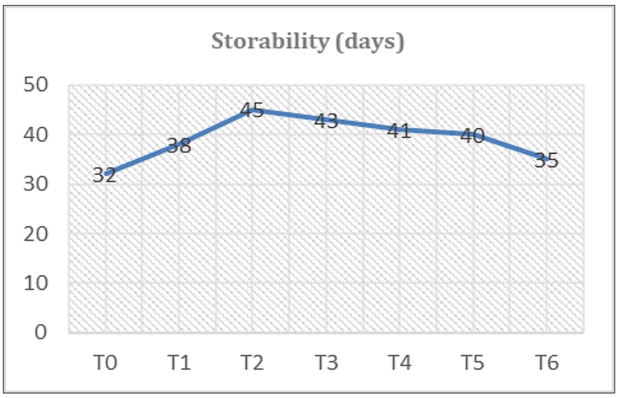

Fig 8: Effect on Storability

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