



Research Article

Enhancing Shelf Life and Quality of Carrots as Influenced by Modified Atmosphere Packaging (MAP)

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ABSTRACT

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Purpose: This study aims to address the postharvest losses of carrots in Bangladesh by evaluating the effect of modified atmosphere packaging (MAP) on the shelf life and quality of three carrot varieties. **Research Method:** A two-factor experiment was conducted using three carrot varieties (Shidur, Improved Kuroda, and Orange King) and three packaging treatments (control, perforated, and non-perforated polyethylene bag) under ambient condition. The experiment was conducted in a completely randomized design (CRD), and data were analyzed using ANOVA. **Findings:** Perforated MAP significantly enhanced postharvest performance. Shidur in perforated bags (T₁V₁) retained deep orange color, excellent freshness, and the highest firmness (11.55 kg/cm²). It showed minimal weight loss (3.98%) superior dry matter content (19.13%), and optimal sugar composition with high reducing sugar (3.43%). Disease incidence and severity were lowest at 19 DAS (67.78% and 55%, respectively), and shelf life extended up to 17.4 days. Non-perforated packaging conserved moisture but was less effective in maintaining quality. Control treatments showed rapid deterioration, with high weight loss (up to 58.66%), increased TSS (13.87%), and 100% disease incidence by day 14. These results demonstrate the combined effect of packaging and varietal physiology in preserving carrot quality. **Research Limitations:** The study was limited to ambient storage conditions and three carrot varieties. The study did not measure physiological parameters, including respiration and ethylene production under MAP, and excluded biodegradable packaging, so little was known about the storage mechanisms and sustainability, although this could be explored in future work to make it more applicable. **Originality/Value:** This research provides authentic evidence that perforated MAP, especially with the Shidur variety, is a practical and effective strategy for reducing postharvest losses, enhancing shelf life, and supporting food security and export potential.

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Introduction

Carrot (*Daucus carota*) is an edible root, rich in nutrients, and is cultivated annually around the world. It is one of the top ten vegetables in terms of worldwide production and market value, making it a highly significant crop in the global horticulture industry (Sun *et al.*, 2020). Carrot is a very healthy vegetable that originates from Asia and is commonly eaten as a salad. It is a rich source of carotene (a vitamin A precursor), proteins, carbohydrates, dietary fiber, potassium, sodium, thiamine, riboflavin, and natural sugars. Carrots are also high in antioxidants (Cefola *et al.*, 2012). Regular consumption is associated with better resistance to blood-related and eye conditions, further increasing its global demand and acceptance. Bangladesh produced approximately 46192 tons of

carrots on 4140 hectares of land, with an average yield of 11.16 tons per hectare in 2023 (FAO, 2023). However, about 32% of the produced carrots in Bangladesh is wasted due to mishandling and postharvest losses (Hassan, 2010). The main contributors to these losses are the perishable nature of carrots, sprouting, water loss during storage, microbiological contamination, pathogenic organism infestation, and improper handling. The perishable nature of carrots leads to various physiological and physicochemical changes, such as weight loss, respiration, transpiration, pulp softening, and a decrease in sugar and acid content (Firmin, 1997). Currently, the primary postharvest challenge for carrots is their short storage life.

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Modified atmosphere packaging (MAP) is an established method that modify the gas composition surrounding vegetables during storage, thereby enabling a significantly longer shelf life. MAP involves altering the atmosphere inside the produce packaging by regulating the levels of natural gases, such as oxygen, nitrogen, and carbon dioxide. These changes either remove or adjust gas levels in the package, impeding the growth of microorganisms in stored food or controlling the respiration rate of fresh produce, thereby extending shelf life (Priyadarshi et al., 2020).

Perforated bags enable moderate gas exchange, creating a balanced gaseous environment that discourages anaerobic conditions and prevents drying. This reduces respiration and ethylene production, slows ripening, senescence, and pathogen growth, and thus prolongs storage life (Haile et al., 2018; Adhikari et al., 2020). However, the perforation of packaging can also create an internal environment around fresh produce that may have either positive or negative effects on quality and shelf life (Kumara et al., 2020).

Although modified atmosphere packaging (MAP) is a widely accepted postharvest practice, the best packaging scheme for different carrot variety has not been clearly defined. The present study was to assess the effect of MAP (both perforated and non-perforated packaging) on the physical, chemical, and microbial quality of three carrot varieties during storage. The objective was to identify the most effective MAP method for enhancing shelf life, maintaining quality, and reducing microbial spoilage through sustainable storage and reduced postharvest losses.

Materials & Methods

Experimental location and material

The experiment was conducted at the Postharvest Laboratory of the Department of Horticulture and Laboratory of Biochemistry and Molecular Biology, Bangladesh Agricultural University, Mymensingh during the period from March to May 2025. Healthy, similar-sized, and fully developed three carrot varieties were collected from the Horticulture Farm of the Department of Horticulture, Bangladesh Agricultural University, Mymensingh, and brought to the Postgraduate Laboratory for the experiment. For the experiment, healthy carrots of uniform maturity were selected and stored at ambient condition ($25 \pm 1^\circ\text{C}$).

Treatments of the investigation and experimental design

The experiment was conducted in a completely randomized design (CRD) with three replications

included three carrot varieties viz. V₁: Shidur, V₂: Improved Kuroda, and V₃: Orange King, and three postharvest treatments, Control (T₀), Low density perforated polyethylene bag (8" x 12"), LDPPE (T₁), Low density non-perforated polyethylene bag (8" x 12"), LDNPPE (T₂). Ten carrot roots, those that were similar and uniform in shape and size were included in each bag. Ten carrot roots were also taken as destructive samples, and the others were checked for color, freshness, percentage of weight loss, firmness, disease infection and severity, and shelf life. A total of 540 carrot roots were investigated for this experiment in 9 treatment combinations.

Modified atmosphere packaging (MAP) materials

In the perforated treatment (T₁), approximately twenty (20) circular holes (50 micrometer) of equal dimensions were punched on each polyethylene bag to achieve a balanced alteration of the internal environment. The non-perforated polyethylene treatment (T₂) involved enclosing carrot roots in a non-perforated polyethylene bag, creating a sealed environment that minimized gas exchange with the outside. The polyethylene bags were sealed at the top edge with a zipper lock.

Application of the postharvest treatments

Carrot roots were set on brown paper in the laboratory under ambient conditions ($25 \pm 1^\circ\text{C}$). The carrot roots in the control treatment (T₀) were randomly chosen and placed directly on brown paper without packaging. For treatment, ten carrot roots were kept in low-density perforated polyethylene (LDPPE) bags. The bags were sealed and kept on brown paper for observation. Likewise, treatment T₂ also involved 10 carrot roots that were covered with a low-density non-perforated polyethylene (LDNPPE) bag on brown paper during the observation. Following the treatments, all carrot roots were subjected to ambient temperature storage for assessment.

Data recorded

External color

The carrot roots were observed at two-day intervals (2nd to 16th DAS). External color of carrot roots was evaluated employing a standardized color chart and classified into four types for analysis: 1 = deep orange, 2 = orange, 3 = light orange, and 4 = ashy orange.

Freshness

Carrot root freshness was scored on a 4-point numerical rating scale where 1= excellent, 2= good, 3= fair, and 4= poor. It was used to track the development of roots at various stages of freshness during storage.

Firmness (kg/cm²)

Firmness was evaluated using a fruit penetrometer (Model Cat. No. 166 (Model:GY-3). Each carrot root was pierced at two diametrically opposite points on the radial axis with the plunger, and the puncture force was recorded and presented in kg/cm².

Weight Loss (%)

Ten carrot roots were analyzed as an observation of the average. The weight loss was measured at 2-day intervals. Weight loss during the exposure was determined as a percent reduction in weight compared with the starting weight; to allow comparison between treatments, the percentage weight loss was calculated relative to the initial weight.

% weight loss = [(Initial weight of carrot (g) – Final weight of carrot (g)) / Initial weight of carrot (g)] × 100

Total soluble solids (% Brix)

TSS of carrot roots was measured at harvest and then every 2 days until 12 days after harvest using samples from different genotypes. Measurements were made with a portable refractometer (Model N-1 α, Atago Co., Japan). The device was calibrated with distilled water before use to ensure a zero reading. One to two drops of clarified juice extract were placed on the prism surface to obtain a percentage reading of TSS for each observation. The concentration was calculated based on the dilution relative to the actual TSS percentage in the pulp tissue. Since temperature variations can influence TSS readings, corrections were also applied following the method described in Ranganna (1986).

Dry matter (%) and moisture (%) contents of carrot roots

On trimming, the roots were washed well by air-drying. Roots were excised in the lab and cut into small pieces before being weighed. The fresh slices were cut into pieces of 50 g, which were initially dried at room temperature for 1 day and subsequently in an oven at 75 °C for 3 days. The dry weight was reported in grams, and the mean was determined. The dry matter content was calculated using the standard formula.

(%) Dry matter of root = {Constant dry Weight of roots (g)/Fresh Weight of roots (g)} × 100

After determining the percentage of dry matter (%) for each treatment, the Percentage moisture content was obtained by the formula:

Moisture content (%) = 100 – Dry matter content (%).

Estimation of Total Sugar

The anthrone method (Jayaraman & Jayaraman, 1981) was used to estimate total sugar content. A standard curve was prepared with glucose solutions: 0.05–0.3mg glucose was made up in 1 ml of distilled water and mixed with 4 ml anthrone reagent (0.2 g anthrone in 100 ml concentrated H₂SO₄), heated for 5 min in a

boiling water bath, and read at 680 nm against a reagent blank. A 1 g sample of the carrot pulp was homogenized in 10 ml of 70% ethanol, boiled for 10 min, cooled, and then filtered through Whatman No. 1 paper. The filtrate was diluted to 100 ml with distilled water, and 1 ml was taken, then mixed with 4 ml anthrone reagent, heated, and cooled, and its absorbance at 680 nm was determined using a UV- Vis spectrophotometer.

Calculation

Total sugar (%) = Weight of pulps (mg)/Weight of sugar (mg) × 100.

Reducing and Non-reducing Sugar Estimated

Reducing sugars were estimated by the DNS method (Miller, 1972). For sample preparation, 1 g of carrot pulp was homogenized with 10 ml of 70% ethanol in a blender, boiled for 10 min, cooled, filtered, and the volume was made up to 100 ml with distilled water. Based on it, 1 ml of extract was taken, diluted to 10 ml, and analyzed. Three milliliters of diluted extract were combined with 3 ml of DNS reagent (1 g DNS [29], 200 mg crystalline phenol, and 50 mg Na₂SO₃ dissolved in 100 ml of 1% NaOH) once again, vortexed for 5 s, and boiled in a water bath for 5 min. 1 ml of 40% Rochelle salt (sodium potassium tartrate) was added while still warm, and the mixture was cooled under running tap water. Absorbance of the pink complex formed was read at 510 nm against reagent blank (3 ml distilled water + 3 ml DNS) with UV–Vis spectrophotometer (T80, PG Instruments Ltd, UK).

Calculation

Reducing sugar (%) = Weight of pulp (mg)/ Weight of sugar (mg) × 100

Formula 2: Non-reducing sugar (%) = Total Sugar (%) - Reducing sugar (%)

Estimation of Titratable Acidity

Titrate acidity was determined according to AOAC (2000). In sample preparation, 10 g of carrot was homogenized in 200 ml of distilled water, poured into a beaker (500 ml), boiled for 40 min, cooled for 20 min, and made up to 250 ml with distilled water. A 5 ml aliquot of the extract was titrated against 0.1 N NaOH using phenolphthalein as an indicator, with the endpoint marked by a pale pink coloration. Titratable acidity was calculated using the formula:

Titrate acidity = (Titrate × Normality of alkali × Equivalent weight of acid × 1000) / Weight of sample

Disease Incidence (%)

Disease incidence was defined as the percentage of carrot samples having visual symptoms of infection. It was calculated for each replication as a proportion of

diseased roots from the total of 10 roots chosen. Disease was confirmed by symptomatic recognition. Incidence was calculated as follows:

(%) Disease Incidence = (No of infected carrots / Total number of carrots taken up for observation) × 100

Disease Severity (%)

Disease severity represents the percentage of the infected sample that is diseased. The percentage of carrot diseases was recorded from 2 days after storage. All the infected carrots were selected to determine the percentage of infected area of the carrot. The proportion of diseased area was estimated visually by eye assessment.

Shelf Life

The storage period of carrot storage roots was determined based on the general (external) quality of roots and the onset of spoilage. A product was determined to be expired when approximately 50% of the roots exhibited visible symptoms of freshness, pathogen-based decay, and injury. Evaluation of shelf life was also performed through visual quality scoring (good and marketable ≥ 3) as well as measurements for other parameters such as mold formation, tissue decay, shriveling, surface smoothness, brightness, and overall fruit uniformity (Rashid and Rahman, 2020; Rashid et al., 2015).

Statistical Analysis

The data for different characters were analyzed statistically using the software MSTAT package. Treatments were mean back-calculated per population and analyzed by analysis of variance (ANOVA) with an F-test. Means were converted by LSD at 1 and 5% level of significance as described by Gomez and Gomez (1984).

Table 1. Combined effects of modified atmosphere packaging and variety on external color at different days after storage (DAS) of carrot.

Treatment combination	External Color at different DAS							
	2	4	6	8	10	12	14	16
T ₀ V ₁	1.00	1.00	2.33	2.67	3.00	3.67	4.00	4.00
T ₀ V ₂	1.00	1.00	2.33	2.67	3.33	3.67	4.00	4.00
T ₀ V ₃	2.00	2.00	3.00	3.33	3.67	4.00	4.00	4.00
T ₁ V ₁	1.00	1.00	1.33	1.67	2.33	2.67	3.00	3.33
T ₁ V ₂	1.00	1.00	1.67	2.00	2.33	2.33	3.33	3.67
T ₁ V ₃	1.67	1.67	2.00	2.33	3.33	3.67	4.00	4.00
T ₂ V ₁	1.00	1.00	1.67	2.33	2.67	3.00	3.67	3.67
T ₂ V ₂	1.00	1.00	1.33	2.00	2.67	3.33	3.67	3.67
T ₂ V ₃	2.00	2.00	2.33	3.00	3.33	3.67	4.00	4.00
LSD _{0.05}	0.03	0.03	0.87	0.81	0.23	0.87	0.08	0.079
LSD _{0.01}	0.05	0.05	1.20	1.11	0.32	1.20	0.11	0.108
Level of significance	**	**	**	**	**	**	**	**

** = Significant at 1% level of probability, NS = Not significant, T₀ = Control, T₁ = Perforated bag, T₂ = Non-perforated bag, V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange king.

Results and Discussions

External Color Changes

The effect of MAP and carrot variety on the external color retention during storage was significantly influenced ($p < 0.01$) (Table 1). At 2 and 4 DAS, all treatments showed an acceptable color score (1.0–2.0), confirming their fresh quality. However, after 6 DAS, divergence became evident. The combination T₁V₁ (perforated bag × Shidur) recorded the least means of 1.33, 1.67, and 3.33 of color scores at 6, 8, and 16 DAS, respectively, reflecting better maintenance of orange pigments. On the other hand, the highest scores of 3.00 at 6 DAS, 3.33 at 8 DAS, and 4.00 at 12 DAS that occurred were observed with T₀V₃ (control × Orange King), indicating accelerated discoloration (Table 1). These findings indicate that with the aid of perforated packaging, maximum gas exchange delays senescence and maintains visual quality. No such drastic differences were observed in the orange-fleshed cultivar Shidur, which kept better than Kuroda Improved and Orange King, especially under MAP. T₁V₁ was the most effective treatment, and T₀V₃ was the least effective treatment. The better external color retention of T₁V₁ (perforated bag × Shidur) during storage could be due to the fact that perforated packaging improves gas exchange and thus prolongs senescence, which was consistent with the results of Chen et al. (2021). Controlled O₂ and CO₂ in micro-perforated environments minimize chlorophyll degradation, enzymatic browning, and hence visual quality (Mahajan et al., 2014). That T₀V₃ (control × Orange King) has also undergone rapid discoloration further highlights the significance of packaging permeability in carotenoid stability.

Freshness

The interaction of variety and packaging had a significant effect on freshness scores ($p < 0.01$). All treatments had a quality score of 1.00 at 2 DAS (excellent). At 6 DAS, scores for T_1V_1 , T_1V_2 , and T_1V_3 remained at the lowest level (1.00), with T_0V_2 peaking at 2.33, signifying severe deterioration at an early date. At 16 DAS, Perforated polyethylene bag treated also remained marketable fresh (2.00), while control conditions had reached 4.00, showing complete spoilage, and Nonperforated bags rated in the middle with scores around 3.33 at T_2V_2 (Table 2). Overall

retention was best for Shidur, especially with perforated packaging. In line with the observation of Caleb et al. (2013) pointed out that internal gas composition is controlled by modified atmosphere packaging (MAP) that would reduce metabolic degradation. In the off-odor and decay present in the nonperforated and control treatments, fermentation seems to be responsible for the development of these defects under conditions of anaerobiosis, a phenomenon that has already been reported by Chen et al. (2021).

Table 2. Combined effects of modified atmosphere packaging and variety on freshness at different days after storage (DAS) of carrot

Treatment combination	Freshness at different DAS							
	2	4	6	8	10	12	14	16
T_0V_1	1.00	1.33	2.00	2.33	2.67	3.33	4.00	4.00
T_0V_2	1.00	1.33	2.33	2.33	2.33	2.67	3.67	4.00
T_0V_3	1.00	1.67	2.00	2.67	3.00	3.67	3.67	4.00
T_1V_1	1.00	1.00	1.00	1.00	1.33	1.33	1.33	2.00
T_1V_2	1.00	1.00	1.00	1.00	1.33	1.67	2.00	2.00
T_1V_3	1.00	1.00	1.00	1.00	1.00	1.33	1.67	2.00
T_2V_1	1.00	1.00	1.33	1.33	1.33	2.00	2.00	2.33
T_2V_2	1.00	1.00	1.33	1.33	1.67	2.00	2.33	3.33
T_2V_3	1.00	1.00	1.33	1.33	1.33	2.00	2.33	2.33
LSD _{0.05}	-	0.041	0.044	0.06	0.07	0.06	0.07	0.029
LSD _{0.01}	-	0.056	0.060	0.09	0.09	0.08	0.10	0.039
Level of significance	-	**	**	**	**	**	**	**

** = Significant at 1% level of probability, T_0 = Control, T_1 = Perforated bag, T_2 = Non perforated bag, V_1 = Shidur, V_2 = Kuroda improved, V_3 = Orange king

Firmness

Firmness values decreased with time and were significantly maintained under MAP ($p < 0.01$). At harvest, T_1V_1 presented the highest firmness (11.55 kg/cm²) and T_0V_3 the lowest firmness (8.83 kg/cm²). At 6 DAS, T_1V_2 and T_1V_1 remained firm, demonstrating firmness above 9.00 kg/cm², whereas T_0V_3 presented firmness of 6.45 kg/cm². T_1V_2 showed the highest firmness (4.99 kg/cm²) at 12 DAS, followed by T_1V_3 (4.95 kg/cm²). The least was once more T_0V_3 (2.85 kg/cm²) (Table 3). The results obtained confirmed that perforated packaging efficiently retards the softening, where T_1V_2 was the best treatment to maintain the firmness. These results on firmness retention in T_1V_1 and T_1V_2 treatments support the contribution of perforated MAP to reduce textural deterioration. Kumar et al. (2022) found that perforated packaging preserves pericarp firmness in bell peppers by controlling humidity and minimizing water loss. The reduction in firmness in control treatments is attributed to higher enzymatic activity and cell wall degradation in the absence of modified atmospheric conditions.

Weight Loss

The packaging and variety ($p < 0.01$) significantly affected weight loss. The lowest weight loss was observed in T_2V_3 (nonperforated bag × Orange King) with values of 0.18% (2 DAS) and 3.98% (16 DAS). Meanwhile, T_0V_2 (control × Kuroda Improved) was the most vulnerable (loss of 58.66% at 16 DAS). Moisture content was best maintained under nonperforated bag treatments, while T_2V_1 and T_2V_2 lost 2.31% and 4.07% during the same time period (Table 4). All these data are indicative of the moisture-conservation benefit of nonperforated packaging, more especially for Orange King. This is in agreement with the result of Jiang & Li (2002), who observed that there is very low water loss in loquat kept under MAP. However, it appears that there is less retention of moisture, which could be related to the higher moisture and also contributes to the reduction of microbial population to a certain level, and in which higher disease severity could be observed in nonperforated treatments. An equilibrium between

the water vapor transmission rate and the permeability of the packaging is quite important (Sandhya, 2010).

Table 3. Combined effects of modified atmosphere packaging and variety on firmness at different days after storage (DAS) of carrot

Treatment combination	Firmness at different DAS						
	0	2	4	6	8	10	12
T ₀ V ₁	9.95	9.60	9.10	8.35	7.57	6.13	3.69
T ₀ V ₂	9.85	9.00	8.31	7.69	6.85	5.63	3.37
T ₀ V ₃	8.83	8.12	7.11	6.45	5.66	4.76	2.85
T ₁ V ₁	11.55	10.85	9.83	9.40	8.82	7.67	4.74
T ₁ V ₂	10.00	9.79	9.54	9.21	8.86	7.93	4.99
T ₁ V ₃	9.63	9.41	9.06	8.84	8.71	7.89	4.95
T ₂ V ₁	11.19	10.56	9.87	9.10	8.51	7.36	4.49
T ₂ V ₂	10.30	9.91	9.56	9.25	8.83	7.56	4.66
T ₂ V ₃	9.66	9.35	8.91	8.19	7.66	6.77	4.15
LSD _{0.05}	0.39	0.44	0.29	0.52	0.37	0.69	0.25
LSD _{0.01}	0.54	0.60	0.40	0.71	0.51	0.95	0.34
Level of significance	**	**	**	**	**	**	**

** = Significant at 1% level of probability, T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange king

Table 4. Combined effects of modified atmosphere packaging and variety on percent weight loss at different days after storage (DAS) of carrot

Treatment combination	Weight loss (%) at different DAS							
	2	4	6	8	10	12	14	16
T ₀ V ₁	7.66	14.32	20.16	27.52	40.62	43.86	48.69	52.28
T ₀ V ₂	9.20	16.11	24.91	28.00	40.92	45.82	51.54	58.66
T ₀ V ₃	8.15	16.00	26.04	30.78	41.83	46.11	50.19	53.24
T ₁ V ₁	1.59	2.66	5.15	6.17	9.26	11.21	13.17	17.20
T ₁ V ₂	1.97	3.18	4.50	5.76	9.85	14.58	18.08	23.55
T ₁ V ₃	1.96	3.25	5.38	6.85	10.45	12.13	14.52	20.03
T ₂ V ₁	0.37	0.52	0.65	0.81	1.08	1.36	1.60	2.31
T ₂ V ₂	0.40	0.50	0.73	1.12	1.28	1.70	2.92	4.07
T ₂ V ₃	0.18	0.18	0.34	0.55	0.74	0.92	2.80	3.98
LSD _{0.05}	0.57	1.25	1.50	1.51	1.39	1.54	2.16	2.94
LSD _{0.01}	0.79	1.71	2.05	2.06	1.91	2.11	2.95	4.03
Level of significance	**	**	**	**	**	**	**	**

** = Significant at 1% level of probability, T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange king

Total Soluble Solids (TSS)

There were significant differences in TSS value among treatments ($p < 0.01$) (Figure 1a & 1b and Table 5). The highest TSS was recorded in T₀V₂ (control × Kuroda Improved) at 13.87% Brix (12 DAS), followed by T₀V₁ (Shidur) at 13.13%. The lowest was T₂V₃ (nonperforated × Orange King, 9.80%) (Table 5). Control developed a higher accumulation of TSS, whereas MAP (in particular, nonperforated) hampered the development of TSS. These results indicate that packaging affects sugar metabolism during storage, among which control is conducive to maintaining sweetness. Control, and especially T₀V₂, treatments also showed increased TSS content, consequently increased sugar metabolism.

Zhao *et al.* (2020) also observed that the inhibitory effects of MAP treatments in response to respiration activity inhibited sugar consumption. Low TSS in nonperforated treatments would be expected due to the limited oxygen, which restricts aerobic respiration and sugar accumulation (Knee, 2002).

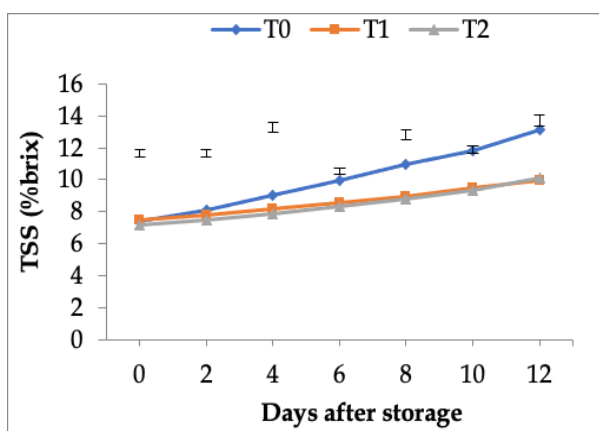


Fig. 1a: Main effects of Treatment on Total Soluble Solid at different days after storage (DAS). Vertical bars represent LSD at 1% level of significance. T0 = Control, T1 = Perforated bag, T2 = Non perforated bag

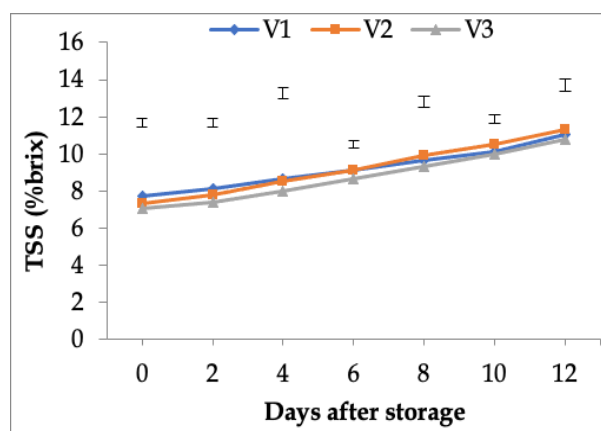


Fig. 1b: Main effects of variety on Total Soluble Solid at different days after storage (DAS). Vertical bars represent LSD at 1% level of significance. V1 = Shidur, V2 = Kuroda improved, V3 = Orange king

Table 5. Combined effects of modified atmosphere packaging and variety on TSS (%Brix) at different days after storage (DAS) of carrot

Treatment combination	TSS (%Brix) at different DAS						
	0	2	4	6	8	10	12
T ₀ V ₁	7.97	8.57	9.50	10.30	11.10	11.83	13.13
T ₀ V ₂	7.33	8.27	9.47	10.20	11.60	12.27	13.87
T ₀ V ₃	6.93	7.43	8.20	9.37	10.30	11.27	12.47
T ₁ V ₁	7.90	8.17	8.47	8.67	8.93	9.33	9.83
T ₁ V ₂	7.45	7.73	8.17	8.60	9.03	9.63	9.93
T ₁ V ₃	7.13	7.43	7.97	8.47	9.00	9.50	10.07
T ₂ V ₁	7.37	7.63	8.03	8.40	8.87	9.23	10.23
T ₂ V ₂	7.07	7.43	7.83	8.43	9.00	9.53	10.20
T ₂ V ₃	7.03	7.37	7.73	8.10	8.63	9.17	9.80
LSD _{0.05}	0.27	0.26	0.36	0.20	0.33	0.27	0.38
LSD _{0.01}	0.37	0.36	0.49	0.28	0.45	0.37	0.52
Level of significance	**	**	**	**	**	**	**

** = Significant at 1% level of probability, T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange King

Dry Matter and Moisture Content

Both dry matter content (DMC) and moisture content (MC) showed a negative relationship, which was highly influenced by the treatment ($p < 0.01$). The maximum DMC of 19.13% was obtained from T₁V₁ (perforated × Shidur), and the minimum DMC of 14.60% was attained from T₂V₃ (nonperforated × Orange King). Similarly, MC was between 80.87% (T₁V₁) and 85.40% (T₂V₃) (Table 6). The high T₁V₁ in dry matter, with a low moisture level, depicted successful water regulation under perforated MAP. Kader & Saltveit (2003) noted that in a controlled

atmosphere, cell integrity is maintained and nutrient dilution is prevented. Conversely, nonperforated treatments held excess moisture and could lead to early onset of spoilage (Robertson, 2013).

Table 6. Combined effects of modified atmosphere packaging and variety on percent dry matter content and moisture content, % Total sugar, % Reducing sugar, % Non-reducing sugar, % Titratable acidity of carrot

Treatment combination	Dry matter content %	Moisture content %	% Total sugar	% Reducing sugar	% Non-reducing sugar	% Titratable acidity
T ₀ V ₁	16.04	83.96	5.96	3.09	2.87	0.004
T ₀ V ₂	15.58	84.42	5.46	3.11	2.35	0.006
T ₀ V ₃	15.56	84.44	4.19	2.44	1.75	0.007
T ₁ V ₁	19.13	80.87	5.20	3.43	1.77	0.004
T ₁ V ₂	18.02	81.98	5.26	2.83	2.43	0.006
T ₁ V ₃	15.58	84.42	4.17	2.63	1.53	0.006
T ₂ V ₁	15.21	84.79	5.81	3.31	2.50	0.008
T ₂ V ₂	16.54	83.46	5.39	3.24	2.14	0.008
T ₂ V ₃	14.60	85.40	4.24	2.88	1.37	0.008
LSD _{0.05}	0.95	0.95	0.031	0.017	0.017	0.037
LSD _{0.01}	1.30	1.30	0.043	0.023	0.023	0.051
Level of significance	**	**	**	**	**	**

** = Significant at 1% level of probability, T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange King.

Sugar Composition and Titratable Acidity

Total sugar, reducing sugar, and non-reducing sugar content were significantly affected by packaging and variety ($p < 0.01$) (Figure 2a & 2b). Maximum total sugar recording was observed from T₀V₁ (Shidur in control) with 5.96%, and minimum was T₁V₃ (Orange King in perforated bag), 4.17%. Soluble sugar was the highest in T₁V₁, with the value of 3.43% of reducing sugar, and T₀V₁ as 2.87% of non-reducing sugar. The titratable acidity was greater in nonperforated (0.008%) and lower in the control and in perforated packages (0.004%) (Table 6). These findings reveal that the

packaging may influence sugar accumulation and acid distribution, with Shidur having a more applicable edge than other cultivars. Such findings imply the varietal variations of sugar metabolism in various package atmospheres. Rojas-Graü *et al.* (2009) reported that MAP retards the enzymatic conversion of sucrose to reducing sugars, thus keeping the original sugar profile. The high Titratable Acidity level found in the nonperforated treatments could indicate that stress-induced metabolic changes had elevated that parameter.

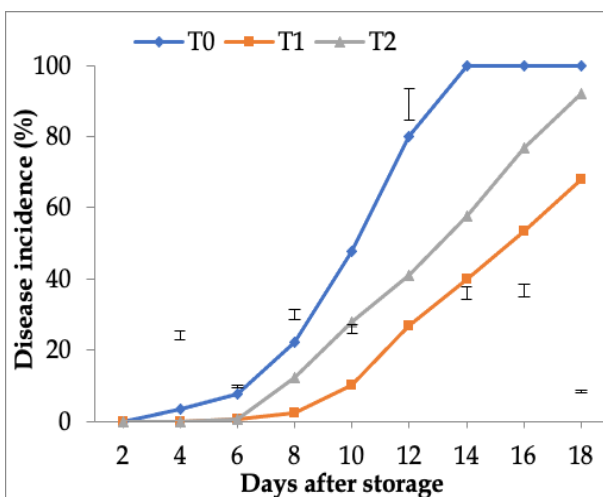


Fig. 2a: Main effects of Treatment on % Total Sugar, % Reducing sugar, % Nonreducing sugar at different days after storage (DAS). Vertical bars represent LSD at 1% level of significance. T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag.

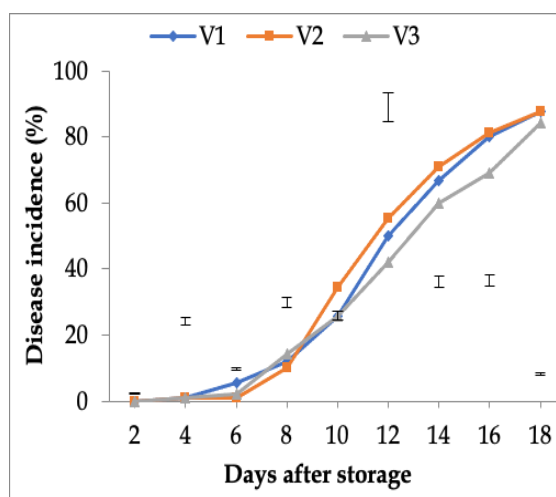


Fig. 2b: Main effects of variety on % Total Sugar, % Reducing sugar, % Nonreducing sugar at different days after storage (DAS). Vertical bars represent LSD at 1% level of significance. V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange king

Table 7. Combined effects of modified atmosphere packaging and variety on percent (%) disease incidence at different days after storage (DAS) of carrot

Treatment combination	Disease incidence (%) at different DAS							
	2	4	6	8	10	12	14	16
T ₀ V ₁	0.00	3.33	13.33	23.33	43.33	83.33	100.00	100.00
T ₀ V ₂	0.00	3.33	3.33	23.33	56.67	80.00	100.00	100.00
T ₀ V ₃	0.00	3.33	6.67	20.00	43.33	76.67	100.00	100.00
T ₁ V ₁	0.00	0.00	1.67	3.33	10.00	26.67	40.00	56.67
T ₁ V ₂	0.00	0.00	0.00	3.33	16.67	40.00	50.00	60.00
T ₁ V ₃	0.00	0.00	0.00	0.00	3.33	13.33	30.00	43.33
T ₂ V ₁	0.00	0.00	1.67	10.00	23.33	40.00	60.00	83.33
T ₂ V ₂	0.00	0.00	0.00	3.33	30.00	46.67	63.33	83.33
T ₂ V ₃	0.00	0.00	0.00	23.33	30.00	36.67	50.00	63.33
LSD _{0.05}	-	5.72	2.11	7.21	6.19	22.15	8.74	8.89
LSD _{0.01}	-	7.83	2.90	9.88	8.47	30.34	11.97	12.18
Level of significance	-	NS	**	**	**	**	**	**

** = Significant at 1% level of probability, NS = Not significant, T₀ = Control, T₁ = Perforated bag,

T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange King.

Disease Incidence and Severity

Disease incidence and severity were significantly decreased by MAP ($p < 0.01$) (Figure 3a, 3b, 4a & 4b). Disease in control treatments progressed quickly, and 100% disease was reached on day 14. Perforated bags retarded the onset of infection (67.78% by day 18 vs 92.22% for nonperforated bags) (Table 7). The severity was least in the T₁V₁ group (0.00% to 55.00%) and highest in the T₀V₃ group (15.00% to 100.00%) (Table 8). These results validate the efficacy of perforated

packaging, especially with Shidur, in the suppression of disease development during storage. The disease was the most suppressed in T₁V₁, which agreed with Romanazzi *et al.* (2016), who observed a reduction in pathogen activity with perforated MAP, by which oxygen was maintained at appropriate levels while surface moisture was decreased. The fast disease development behaviours in the control treatments emphasize the susceptibility of unpackaged fresh produce to microbial infestation.

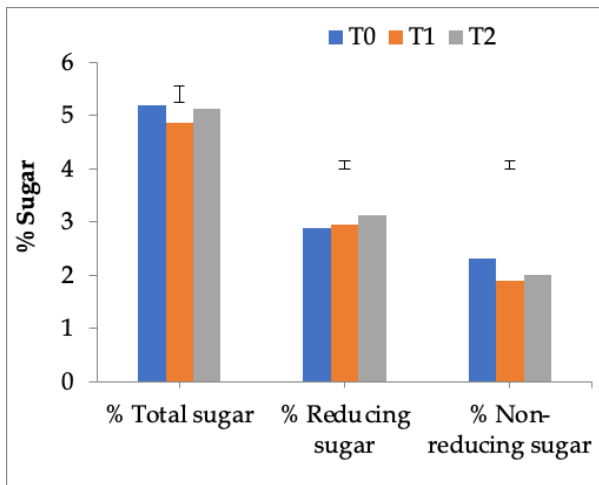


Fig. 3a: Main effects of Treatment on (%) disease incidence at different days after storage (DAS). Vertical bars represent LSD at 1% level of significance. T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag.

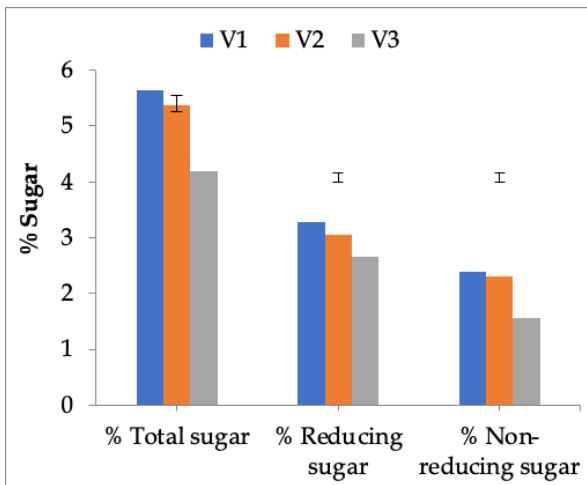


Fig. 3b: Main effects of variety on (%) disease incidence at different days after storage (DAS). Vertical bars represent LSD at 1% level of significance. V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange king.

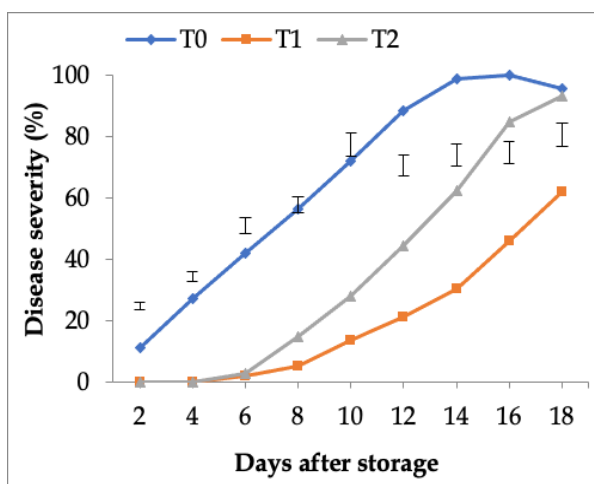


Fig. 4a: Main effects of Treatment on (%) Disease severity at different days after storage (DAS). Vertical bars represent LSD at 1% level of significance. T0 = Control, T1 = Perforated bag, T2 = Non perforated bag

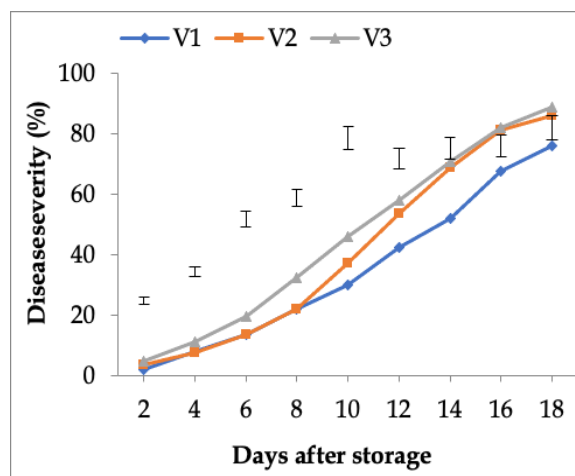


Fig. 4b: Main effects of variety on (%) Disease severity at different days after storage (DAS). Vertical bars represent LSD at 1% level of significance. V1 = Shidur, V2 = Kuroda improved, V3 = Orange king

Table 8. Combined effects of modified atmosphere packaging and variety on percent (%) disease severity at different days after storage (DAS) of carrot

Treatment combination	Disease severity (%) at different DAS							
	2	4	6	8	10	12	14	16
T ₀ V ₁	6.67	24.67	39.33	59.33	77.00	94.67	100.00	100.00
T ₀ V ₂	11.67	23.33	37.67	50.67	67.00	87.67	100.00	100.00
T ₀ V ₃	15.00	34.33	49.33	59.00	71.67	83.33	96.67	100.00
T ₁ V ₁	0.00	0.00	0.00	2.33	7.67	12.00	21.67	35.33
T ₁ V ₂	0.00	0.00	0.00	1.67	12.67	20.00	30.00	46.67
T ₁ V ₃	0.00	0.00	6.67	11.67	21.00	31.33	39.33	56.33
T ₂ V ₁	0.00	0.00	1.67	4.67	6.00	21.00	34.33	67.67
T ₂ V ₂	0.00	0.00	3.33	13.33	32.67	53.33	76.67	96.67
T ₂ V ₃	0.00	0.00	3.33	26.33	46.00	59.00	76.33	90.00
LSD _{0.05}	4.67	6.62	10.11	11.50	15.56	14.17	14.86	15.01
LSD _{0.01}	6.40	9.07	13.84	15.76	21.31	19.41	20.35	20.56
Level of significance	**	**	**	**	**	**	**	**

** = Significant at 1% level of probability, T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda improved, V₃ = Orange King

Shelf Life

The effect of MAP on shelf life was substantial ($p < 0.01$) (Figure 5a & 5b). Maximum shelf life was found in T₁V₁ (Shidur in perforated bag) up to 17.40 days, and the minimum in T₀V₂ (Kuroda Improved- Control) up to 7.67 days (Fig 5c). The longest supportability in T₁V₁ (17.40 days) substantiates the effectiveness of perforated MAP in extending postharvest longevity. Sanz *et al.* (2000) revealed that the perforation degree affects internal gas composition directly, and shelf life is affected by internal gas composition. The interaction between

varietal choice and packing design is critical for the desired storage result (Day, 2001). These findings emphasize the role of packaging and variety in postharvest life.

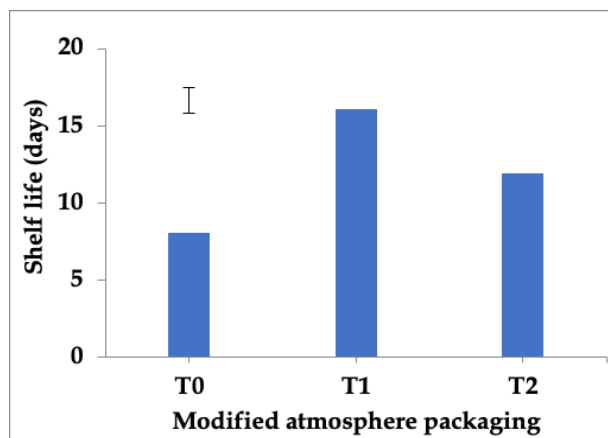


Fig. 5a: Main effects of Treatment on Shelf life (days) at different days after storage (DAS). Vertical bar represents LSD at 1% level of significance. T0 = Control, T1 = Perforated bag, T2 = Non perforated bag

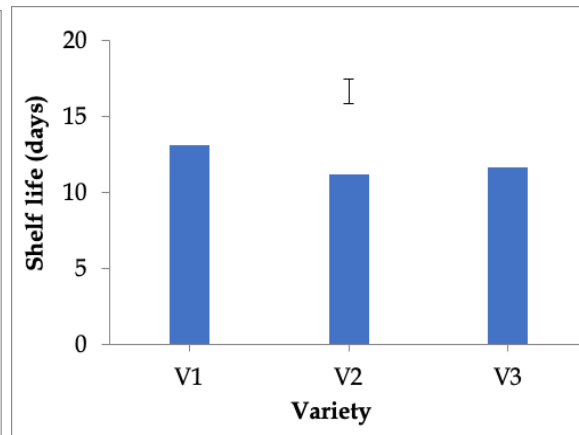


Fig. 5b: Main effects of variety on Shelf life (days) at different days after storage (DAS). Vertical bar represents LSD at 1% level of significance. V1 = Shidur, V2 = Kuroda improved, V3 = Orange king

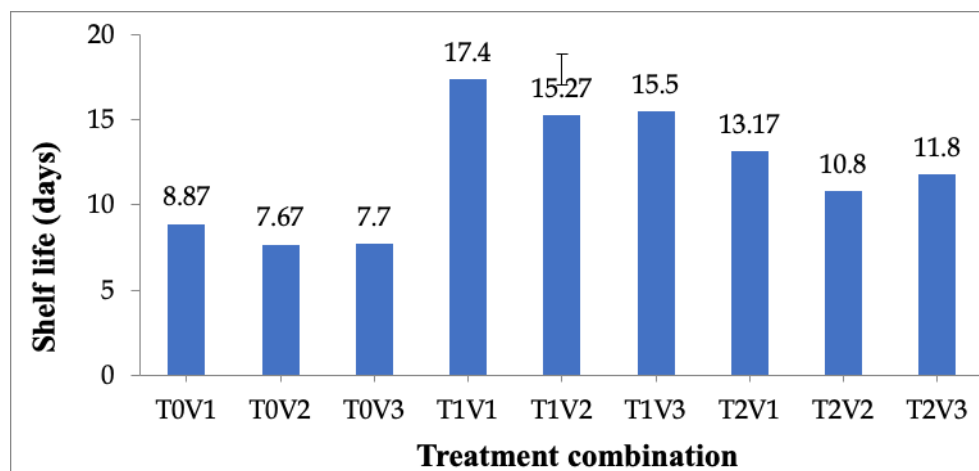


Fig. 5c: Combined effects of modified atmosphere packaging and Shelf life at different days after storage (DAS) of carrot. The vertical bar indicates LSD at 1% level of significance. T0 = Control, T1 = Perforated bag, T2 = Non perforated bag, V1 = Shidur, V2 = Kuroda improved, V3 = Orange king.

Conclusion

This study demonstrated the combined effect of modified atmosphere packaging (MAP) and varietal selection on maintaining postharvest quality and extending the shelf life of carrots. Perforated polyethylene packaging with the cultivar Shidur (T1V1) was the most effective treatment, allowing better retention of external color, firmness, and dry matter, along with the lowest disease incidence, and extended the shelf life to 17.40 days. Biochemical parameters were also consistent with the physical traits, as T1V1 showed superior retention of total, reducing, and non-

reducing sugars, indicating greater metabolic stability and preservation of sweetness. Titratable acidity was

also well maintained, which was beneficial for flavor and microbial stability. In contrast, control samples, particularly Kuroda Improved and Orange King, displayed early decay, higher weight loss, and greater disease severity. Non-perforated packaging maintained some moisture but failed to preserve overall quality. The results highlight the importance of aligning packaging type with varietal physiology to achieve optimal postharvest performance. In conclusion, perforated MAP appears to be a practical approach, and

Shidur has strong potential for long-term storage and export.

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Author's Contribution

A.K.S.: Performing the field and lab experiments, collection and analysis of data. M.H.A.R.: Design, formulation and supervision of experiment. M.J.H.B.: Co-supervision of experiment and review of manuscript, M.G.R.: Co-PI of the research project and review of manuscript, M.M.: Analysis of data and review of manuscript.

Conflict of interest

The authors conducted this research and wrote the article, and there is no conflict of interest with any other individuals.

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Supplementary figure:



Plate 1. Pictorial view of the carrot in the storage at 2 days. T_0 = Control, T_1 = Perforated bag, T_2 = Non perforated bag, V_1 = Shidur, V_2 = Kuroda Improved, V_3 = Orange King.



Plate 2. Pictorial view of the carrot in the storage at 4 days. T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda Improved, V₃ = Orange King.



Plate 3. Pictorial view of the carrot in the storage at 6 days. T_0 = Control, T_1 = Perforated bag, T_2 = Non perforated bag, V_1 = Shidur, V_2 = Kuroda Improved, V_3 = Orange King.



Plate 4. Pictorial view of the carrot in the storage at 8 days. T_0 = Control, T_1 = Perforated bag, T_2 = Non perforated bag, V_1 = Shidur, V_2 = Kuroda Improved, V_3 = Orange King.



Plate 5. Pictorial view of the carrot in the storage at 10 days. T_0 = Control, T_1 = Perforated bag, T_2 = Non perforated bag, V_1 = Shidur, V_2 = Kuroda Improved, V_3 = Orange King.



Plate 6. Pictorial view of the carrot in the storage at 12 days. T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda Improved, V₃ = Orange King.



Plate 7. Pictorial view of the carrot in the storage at 14 days. T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda Improved, V₃ = Orange King.





Plate 8. Pictorial view of the carrot in the storage at 16 days. T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda Improved, V₃ = Orange King.





Plate 9. Pictorial view of the carrot in the storage at 18 days. T₀ = Control, T₁ = Perforated bag, T₂ = Non perforated bag, V₁ = Shidur, V₂ = Kuroda Improved, V₃ = Orange King.