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Effect of Different Packaging Methods on the Postharvest Shelf Life and Quality of Dragon Fruit (*Hylocereus spp.*)

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Abstract: Packaging plays a vital role in extending the postharvest shelf life and maintaining the quality of fresh produce, especially fruits like dragon fruit (*Hylocereus spp.*), which are highly sensitive to environmental factors. This study investigated the effects of three packaging methods—stretch wrap, polyethylene plastic (PE), and ziplock packaging—on the physical and chemical quality attributes of dragon fruit stored at 7 ± 2°C for 7 days. Parameters such as weight loss, skin color, firmness, pH, soluble solids content (SSC), titratable acidity (TA), and vitamin C content were evaluated. Results revealed that ziplock packaging was the most effective in reducing weight loss (0.40%), maintaining vivid skin color, and preserving fruit firmness (1.8 N). Polyethylene packaging exhibited the highest pH (6.08) and vitamin C content (8.0 mg/100g), while all treatments showed similar TA levels (0.3%). These findings indicate that packaging type significantly influences the shelf life and quality of dragon fruit, with ziplock packaging being optimal for maintaining physical attributes and polyethylene packaging for chemical stability.

Keywords: Dragon fruit, packaging method, shelf life, postharvest quality, physical parameters, chemical analysis

1. Introduction

Dragon fruit (*Hylocereus spp.*) is a tropical fruit gaining popularity in both domestic and international markets due to its unique appearance, high nutritional value, and refreshing taste. However, like many other climacteric fruits, dragon fruit is highly perishable and susceptible to postharvest losses during transportation and storage. These losses are primarily attributed to physical damage, moisture loss, microbial infection, and physiological changes, all of which compromise the quality and marketability of the fruit.

Proper packaging is essential in postharvest handling to mitigate these challenges. Effective packaging plays a critical role in preserving the postharvest quality of fresh produce by managing internal humidity and gas exchange, thereby reducing water loss, slowing respiration, and limiting microbial activity (Mahajan et al., 2015; Reddy & Singh, 2020). Jalgaonkar et al., 2020 emphasized that dragon fruit harvested at optimal maturity, typically between 27 and 33 days after flowering, should be thoroughly graded, cleaned, and packaged to minimize physical damage and extend postharvest shelf life. The standard postharvest storage conditions for dragon fruit include temperatures between 7–10°C and 85–90% relative humidity, which can extend shelf life to several weeks.

However, despite adhering to general handling guidelines, quality degradation remains a concern due to inadequate packaging practices. Conventional methods often fail to prevent physical damage such as bruising and skin tears, especially during transit. Improper packaging may also result in suboptimal ventilation, which elevates internal humidity and accelerates microbial spoilage. Therefore, the selection of appropriate packaging material and method is crucial to minimize postharvest losses.

Various studies have demonstrated the role of innovative packaging techniques in preserving fruit quality. For instance, modified atmosphere packaging with polymer-based films such as PLA-based bio nanocomposite and low-

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density polyethylene stretch wrap has been shown to significantly reduce respiration, maintain firmness, minimize weight loss, and inhibit microbial growth in fresh produce under refrigerated storage conditions (Khodaei et al., 2023; Irianto et al., 2024). Stretch wrap forms a semi-permeable barrier around the fruit, helping to slow moisture loss and reduce mechanical injuries (Thakur et al., 2017). Ziplock bags offer reseal ability and moderate barrier properties, while polyethylene packaging is valued for its lightweight, flexibility, and semi-permeable characteristics (Singh et al., 2023).

This study aimed to evaluate the effects of three commonly used packaging methods—stretch wrap, ziplock, and polyethylene plastic—on the physical and chemical quality of dragon fruit during 7 days of cold storage. Specifically, we assessed the impact of packaging on fruit weight loss, skin colour, firmness, pH, soluble solids content (SSC), titratable acidity (TA), and vitamin C content.

2. Materials and Methods

2.1 Sample Preparation

A total of nine dragon fruits (*Hylocereus polyrhizus*) at uniform maturity stage (maturity index 3: full skin coloration, firm texture, and optimal sweetness) were procured from Segi Mart, Tanjong Malim, Malaysia. The fruits were washed with clean tap water to remove debris and potential pesticide residues, followed by drying with clean cloths and further air-dried at ambient room temperature (25 ± 2°C) for 2–4 hours. This step ensured removal of excess surface moisture and reduced the risk of microbial growth during storage.

2.2 Packaging Treatments

Three different types of packaging materials were employed in this study to evaluate their effects on the postharvest quality of dragon fruit. The packaging methods were selected based on their common use in horticultural postharvest handling and their varying levels of permeability and sealing efficiency.

2.2.1 Ziplock Packaging (ZL)

Fruits were carefully placed into resealable plastic ziplock bags, ensuring that overpacking was avoided to minimize the risk of mechanical damage or bruising. The ziplock bags were then sealed to maintain a humid microenvironment and to restrict excessive gas exchange. Dragon fruits were cleaned and dried before being packed into durable ziplock bags. Proper arrangement was ensured to avoid excessive pressure. The sealed ziplock maintained internal humidity and minimized exposure to external factors. This method is flexible and easy to handle. Fruits were stored at 7 ± 2°C to maintain freshness and limit microbial growth.

2.2.2 Stretch Wrap (SW)

Each fruit was individually wrapped using flexible stretch film to tightly enclose the fruit surface. This method was intended to reduce moisture loss by limiting transpiration while also providing moderate mechanical protection during handling. This method involves the use of plastic film that adheres tightly to the fruit surface. It provides protection from external mechanical damage and reduces moisture loss. Dragon fruits were washed, cleaned and air-dried before wrapping. Packaged fruits were then stored at 7 ± 2°C to preserve quality and reduce microbial contamination during storage.

2.2.3 Polyethylene Packaging (PE)

Each fruit was individually packed in a low-density polyethylene (LDPE) bag with a thickness ranging between 20 and 40 microns. This material was selected due to its lightweight and flexible properties, which make it suitable for protecting fruits against physical damage during storage. After cleaning and drying, the fruits were placed into LDPE bags and sealed with plastic ties. This packaging method helped retain internal moisture and reduced gas exchange, thereby minimizing ethylene accumulation within the packaging. All packaged fruits were stored at 7 ± 2°C to maintain freshness and overall fruit quality during the storage period.

Following packaging, all samples were stored in a refrigerated chamber maintained at 7 ± 2°C for a period of seven days. Each packaging treatment consisted of three replicates (n = 3) to ensure statistical reliability of the data collected.

2.3 Physical Quality Evaluation

2.3.1 Weight Loss (%)

Fruit weights were recorded at Day 0 (before storage) and Day 7 (after storage) using a digital weighing scale with high precision to ensure accurate and consistent readings. Measurement were taken three times for each fruit under each packaging type (stretch wrap, ziplock, polyethylene packaging). This procedure was conducted to evaluate the weight changes during the storage period and to examine the relationship between packaging type and weight loss (%). Weight loss was calculated as a percentage of the initial weight using the formula:

$$PWL = \frac{(Initial\ fruit\ weight - Fruit\ weight\ on\ the\ day\ observation)}{initial\ fruit\ weight}\ x\ 100$$

2.3.2 Skin Color

Fruit skin color was measured using a chromameter or visual assessment against based on a standard color chart. Parameters recorded included L* (lightness), a* (red/green), b* (yellow/blue), chroma (C*), and hue angle (H°) which are commonly used to quantify color changes in horticultural produce. These color attributes serve as indicator of fruit ripeness and overall appearance quality. The assessment was conducted at Day 0 and Day 7 of storage to monitor the extent of color changes occurring during the storage period. This evaluation aimed to determine how different packaging types (stretch wrap, ziplock and polyethylene packaging) influenced the skin color development and ripening progression of dragon fruit under storage condition (7 ± 2°C).

2.3.3 Firmness (N)

Fruit firmness was measured on day 7 of storage using a handheld penetrometer. The probe was inserted into the flesh of the fruit, and the force required to penetrate the tissue was recorded in Newtons (N). This measurement was used to evaluate the texture and structural integrity of the fruit after storage. Firmness was not measured on Day 0 to avoid causing physical damage to the fruit which could affect its quality and storage performance. The assessment also aimed to determine the effect of different packaging types on firmness retention of dragon fruit during the storage period.

2.4 Chemical Quality Evaluation

2.4.1 pH

Fruit juice was extracted from the dragon fruit samples and immediately analyzed using a calibrated digital pH meter to determine the acidity or alkalinity of the fruit. The pH value serves as an important indicator of the fruit's biochemical condition, where lower pH values typically reflect higher acidity (sourness), and higher pH values suggest lower acidity, which is commonly associated with sweetness and increased ripeness. Assessing pH also provides insight into fruit freshness and postharvest quality, as pH levels can fluctuate due to metabolic activity, respiration, and microbial development during storage. To ensure measurement accuracy, all readings were taken at room temperature, and each sample was measured in triplicate. The final pH value was expressed as the average of three readings:

$$pH = \frac{(R1+R2+R3)}{3}$$

2.4.2 Soluble Solids Content (SSC) (%)

The soluble solids content (SSC) of dragon fruit was measured using a digital refractometer and expressed in degrees Brix (°Brix). Juice was extracted from the fruit flesh and filtered to remove particulate matter. A small volume of the filtered juice was then applied onto the prism surface of the refractometer for measurement. SSC is an important indicator of fruit sweetness and ripeness, representing the concentration of dissolved solids—primarily sugars—within the juice. Elevated SSC values are generally associated with advanced maturity and higher sugar accumulation, both of which contribute to improved eating quality and consumer acceptance.

To account for dilution during sample preparation, SSC values were calculated using the following formula:

% SSC = (Refractometer reading × dilution factor [5]) + 0.28

2.4.3 Titratable Acidity (TA) (%)

Titratable acidity (TA) was determined by titrating 5 mL of filtered dragon fruit juice with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as an indicator. The endpoint was identified by the appearance of a persistent pale pink colour. Results were expressed as a percentage of malic acid, which is the predominant organic acid in dragon fruit.

TA reflects the total concentration of organic acids present in the juice and is commonly associated with the sourness or tartness perceived in the fruit. Higher TA values generally correspond to more acidic and sourer flavour profiles, which can influence consumer preference and market quality.

The TA value was calculated using the following formula:

$$\% \; TA = \frac{mL\ NaOH\ \ x\ 0.1M\ NaOH\ x\ vol\ of\ product\ (100mL)\ x\ 64g\ x\ 100}{weight\ of\ sample\ (20\ g)\ x\ vol.of\ sample\ for\ titration\ (5\ mL)\ x\ 1000}$$

2.4.4 Vitamin C (mg/100g)

The vitamin C content of dragon fruit samples was analyzed using the dye titration method. Fresh juice was extracted and immediately mixed with metaphosphoric acid (HPO_3) to stabilize ascorbic acid and minimize oxidative loss. The solution was then filtered, and a 5 mL aliquot of the filtrate was titrated with a standardized dye solution until a persistent colour change was observed.

Vitamin C content was calculated based on the volume of dye used and expressed as milligrams per 100 grams of fresh sample (mg/100 g FW) using the following formula:

$$Vitamin\ C\ (mg/100g) = \frac{mL{-}dye\ used\ x\ dye\ factor\ 0.01\ vol.of\ product\ (100\ mL)\ x\ 100}{weight\ of\ sample\ (20\ g)\ x\ vol.of\ sample\ for\ titration\ (5\ mL)}$$

2.5 Experimental Design and Statistical Analysis

A Completely Randomized Design (CRD) was employed with three treatments (SW, ZL, PE) and three replicates per treatment. Data collected were analyzed using one-way Analysis of Variance (ANOVA) followed by Tukey's HSD post hoc test to determine significant differences at $p < 0.05$. Statistical analysis was performed using IBM SPSS or R software. Results were presented using means ± standard deviation in tables and graphical representations for clear comparison.

3. Results and Discussion

3.1 Weight Loss (%)

Weight loss is a critical parameter in evaluating postharvest deterioration, as it reflects moisture loss primarily caused by transpiration and respiration. The extent of weight reduction observed in this study differed significantly across the three packaging treatments, as illustrated in Figure 1.

Fruits stored in ziplock packaging (ZL) exhibited the lowest weight loss at 0.40%, indicating the effectiveness of this packaging in reducing moisture escape. The semi-airtight nature of ziplock bags limits water vapor loss, thereby maintaining fruit freshness. This finding is consistent with the results reported by Nguyen and Hall (2003), who observed a minimal weight loss of 0.93% in apples stored in ziplock packaging for 46 days under cold storage conditions.

Stretch wrap (SW) resulted in a slightly higher weight loss of 0.49%. The moderate gas and moisture permeability of the stretch film allowed limited moisture exchange while also facilitating the formation of a modified internal atmosphere. This condition helped slow down respiration and reduced the rate of water loss. Similar observations were noted by Hasbullah et al. (2024), who reported comparable outcomes in papaya stored using stretch film packaging.

In contrast, polyethylene packaging (PE) recorded the highest weight loss at 0.53%. Although low-density polyethylene (LDPE) is commonly used for its moisture retention properties, its higher gas permeability may contribute to condensation build-up and inconsistent internal humidity. These factors could lead to increased transpiration and accelerated deterioration. The present findings are consistent with Buthelezi and Mafeo (2024), who documented moderate weight loss and preserved firmness in 'Fuerte' avocados stored in perforated LDPE packaging under ambient conditions.

Overall, the results indicate that packaging type plays a significant role in mitigating postharvest weight loss. Ziplock packaging proved to be the most effective in preserving fruit weight, likely due to its balance between sealing efficiency and gas exchange.

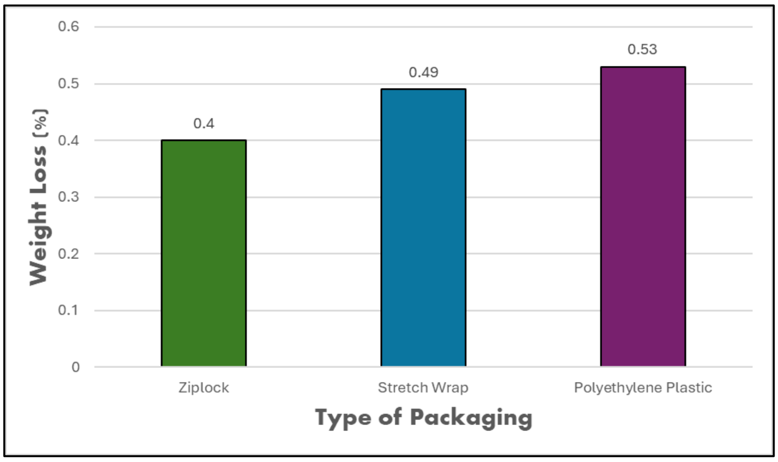

Fig. 1: Weight loss in dragon fruit after 7 days of cold storage under different packaging types.

3.2 Skin Colour

Skin colour is a vital postharvest attribute that directly influences consumer acceptance and marketability. In this study, colour changes were evaluated using L* (lightness), a* (red-green component), b* (yellow-blue component), chroma (colour intensity), and hue angle (colour tone), as summarised in Table 1.

Fruits stored in ziplock packaging (ZL) maintained a vivid red-purple skin colour across all replicates. This was reflected in consistently high chroma values and low hue angles, indicating stable anthocyanin retention. The minimal pigment degradation observed suggests that the semi-airtight environment within ziplock packaging effectively slowed oxidative processes. These findings are consistent with Gonzalez-Aguilar et al. (2008), who reported improved pigment preservation under modified atmosphere conditions.

The stretch wrap (SW) treatment also demonstrated the ability to preserve the bright red-purple appearance of the fruit. However, a slight decrease in b* values was noted, indicating a reduction in the yellow component. This may have resulted in a subtle shift towards deeper purple hues. Although the overall chromatic integrity was retained, the moderate permeability of stretch film could have allowed limited oxidative activity over time.

In contrast, polyethylene (PE) packaging produced inconsistent colour outcomes. The skin colour ranged from dull red-purple to bright red tones across replicates. This variation is likely attributable to uneven internal humidity and gas exchange within the LDPE bags, which may have disrupted the stability of anthocyanins and accelerated pigment breakdown.

Overall, the results suggest that packaging type plays a significant role in preserving the visual quality of dragon fruit. Ziplock packaging emerged as the most effective in maintaining skin colour consistency, most likely due to its controlled internal atmosphere that reduces oxidative stress and moisture fluctuation.

Table 1: Average skin color parameters (L*, a*, b*, chroma, hue) of dragon fruit under different packaging.

Packaging	Color Category	Notable Trends
Ziplock (ZL)	Red-purple vivid	High chroma; stable hue angle; consistent pigmentation
Stretch Wrap (SW)	Red-purple vivid	Declining b* values; slight shift to deeper purple tones
Polyethylene (PE)	Red dull to vivid	Inconsistent pigmentation; variable internal conditions

3.3 Firmness

In postharvest research, fruit firmness is a critical metric that represents textural quality, structural integrity, and consumer acceptance. It is strongly affected by physiological processes that may be controlled by packing conditions, including microbial activity, water loss, and enzymatic cell wall disintegration.

Dragon fruits in ziplock (ZL) packing had the maximum firmness value of 1.8 N after seven days of refrigeration (Figure 2). This implies that the ziplock system's semi-airtight environment successfully decreased oxygen intrusion while preserving the proper levels of internal humidity. These circumstances probably inhibited enzymatic activity and postponed cell wall polymer breakdown. These findings agree with Cheng and Huang (2023), who demonstrated that modified-atmosphere systems employing controlled permeability or perforations significantly enhanced fruit firmness retention under refrigerated storage.

The stretch wrap (SW) treatment resulted in a moderate firmness of 1.0 N. Although the stretch film offers a degree of moisture retention, its permeability to gases may have allowed partial oxygen exposure, leading to moderate softening. The film likely created a modified atmosphere that was only partially effective in slowing down texture deterioration.

In contrast, fruits packed in polyethylene (PE) bags recorded the lowest firmness value of 0.8 N. This accelerated softening may be attributed to excessive humidity and inadequate ventilation in packaging, conditions that foster ethylene accumulation and microbial growth—both of which are known to exacerbate fruit tissue breakdown (Naveed et al., 2024). The high internal moisture content could also increase enzymatic activity, further contributing to the loss of firmness.

These results reinforce the significance of selecting packaging types that can regulate gas composition and humidity to preserve fruit texture during storage. Among the treatments tested, ziplock packaging proved most effective in maintaining firmness and postharvest structural quality of dragon fruit under short-term refrigerated conditions.

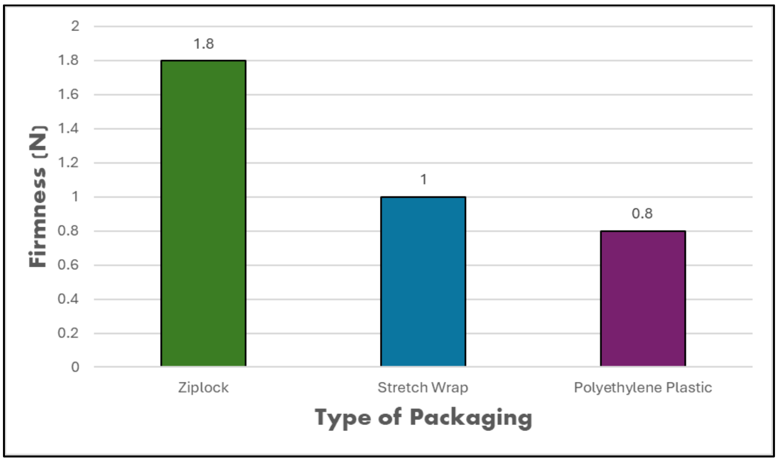

Fig. 2: Firmness (N) of dragon fruit after 7 days of storage.

3.4 pH

pH is a fundamental indicator of fruit acidity, freshness, and overall biochemical stability during storage. It reflects changes in metabolic activity such as respiration, fermentation, and microbial growth, which directly impact flavour, postharvest life, and consumer acceptability. Packaging conditions play a pivotal role in modulating internal gas composition and humidity, both of which influence pH dynamics throughout storage.

In this study, dragon fruits stored in polyethylene (PE) packaging exhibited the highest mean pH value of 6.08, suggesting better maintenance of fruit freshness and lower overall metabolic activity (Figure 3). The sealed microenvironment created by the low-density polyethylene may have stabilised internal conditions, reducing acid production during the storage period.

Fruits stored in ziplock (ZL) packaging showed a moderate pH of 5.85, likely due to limited oxygen exchange, which allows controlled respiration but may still promote slight organic acid formation.

Meanwhile, stretch wrap (SW) treatment resulted in the lowest pH value of 5.77. This reduction may be attributed to higher internal humidity and increased microbial activity, both of which are known to accelerate the breakdown of carbohydrates into organic acids. This observation supports the findings of Sivakumar and Korsten (2006), who reported that excessive humidity in packaging systems may enhance microbial-induced acidification.

These results highlight the influence of packaging environment on biochemical changes in stored fruit. Among the treatments, PE packaging was the most effective in preserving a higher and more stable pH, which may indicate improved freshness and slower physiological degradation during short-term cold storage.

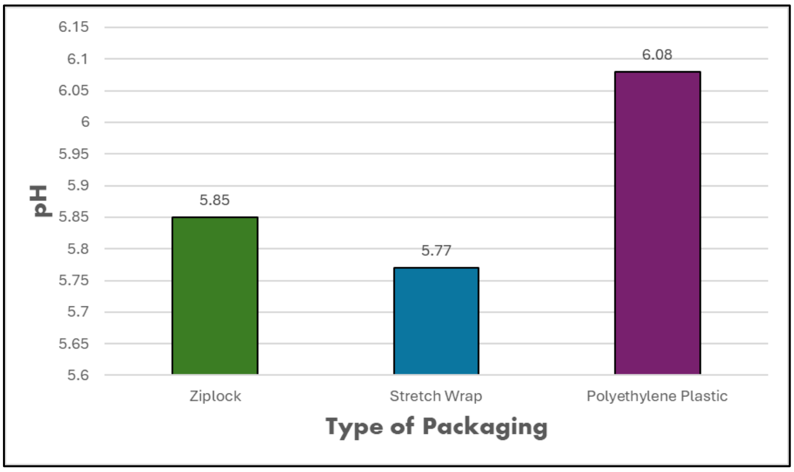

Fig. 3: pH levels of dragon fruit under different packaging treatments.

3.5 Soluble Solid Contents (SSC)

There is a significant difference in the soluble solids content (SSC) of fruits or food samples packaged using three different types of packaging materials (Figure 4). Ziplock plastic recorded the highest SSC at 11.78%, followed by Stretch Wrap plastic with 11.11%, while Polyethylene (PE) plastic showed the lowest SSC at 10.28%.

These differences indicate that the type of packaging material plays a crucial role in maintaining the soluble solids content during storage. SSC is commonly associated with the sweetness level and sensory quality of fruits, as well as being an indicator of ripeness and storage stability (Wills et al., 2007). In this regard, ziplock packaging may provide a more enclosed environment with lower permeability to air and moisture, thereby reducing the rate of respiration and water loss. This contributes to the retention of soluble sugars in packaged samples (Kader, 2002).

On the other hand, PE plastic, which is more permeable to gases and water vapor, may increase the rate of respiration and moisture loss, ultimately leading to a reduction in SSC in fruit (Thompson, 2014). While Stretch Wrap performs better than PE, it still allows moderate gas exchange, resulting in SSC levels that are not as high as those stored using ziplock plastic.

Overall, the use of ziplock plastic appears to be more effective in preserving the quality of fruits in terms of soluble solids content, compared to the other two types of packaging. Therefore, selecting the appropriate packaging material is crucial to ensure the quality and nutritional value of the product remains at an optimum level throughout the storage period.

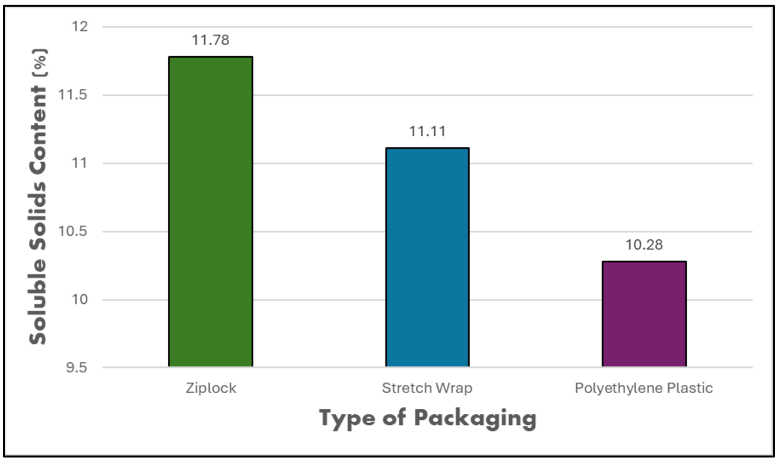

Fig. 4: Soluble solids content (%) across packaging methods.

3.6 Titratable Acidity (TA)

Titratable acidity (TA) is an important parameter that reflects the total concentration of organic acids in fruit, contributing to its flavour profile and postharvest freshness. In this study, all packaging treatments Ziplock (ZL), Stretch Wrap (SW), and Polyethylene (PE) demonstrated similar TA values of approximately 0.3%, with no statistically significant differences observed among the groups (Figure 5).

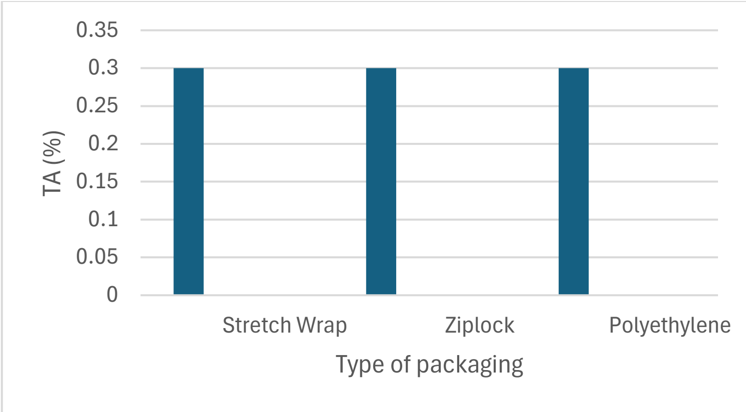

Fig. 5: TA (%) across packaging methods.

The consistent TA levels across treatments indicate that none of the packaging methods led to substantial acid degradation during the seven-day refrigerated storage period. This suggests that the relatively short storage duration and controlled temperature conditions (7 ± 2°C) were effective in preserving the organic acid content, regardless of the packaging material used.

These findings imply that, within the time frame studied, all three packaging types were equally capable of retaining the acidity of dragon fruit, thus maintaining its tartness and overall flavour quality. Future studies involving longer storage durations may reveal more pronounced differences in acid metabolism among packaging types

3.7 Vitamin C Content

Vitamin C (ascorbic acid) is a vital antioxidant and a key quality indicator in postharvest fruit studies. Due to its high sensitivity to oxygen, temperature, and moisture, its retention is significantly influenced by packaging conditions.

In this study, the highest vitamin C content was observed in fruits stored in polyethylene (PE) packaging, recording an average of 8.0 mg/100 g (Figure 6). The relatively stable internal microclimate provided by the low-density polyethylene may have contributed to reduced oxidative degradation, thus enhancing vitamin C preservation. These findings suggest that PE packaging offers superior protection against external oxygen and light exposure during short-term storage.

Fruits stored in ziplock packaging (ZL) retained a moderate vitamin C content of 7.6 mg/100 g, which indicates effective but not optimal moisture retention and air-tightness. The resealable nature of ziplock bags likely limited gas exchange and helped preserve vitamin C, though to a slightly lesser extent than PE.

In contrast, stretch wrap (SW) treatment resulted in the lowest vitamin C content, at 6.3 mg/100 g. The reduced efficiency in maintaining an ideal storage environment particularly the possibility of internal condensation and greater oxygen permeability may have accelerated ascorbic acid oxidation. This supports the notion that loosely sealed or highly permeable packaging may compromise the retention of sensitive nutrients such as vitamin C.

Overall, the results underscore the role of packaging in modulating oxidative stress and nutrient degradation during storage. Among the packaging types tested, polyethylene showed the highest efficacy in preserving vitamin C in dragon fruit under chilled conditions.

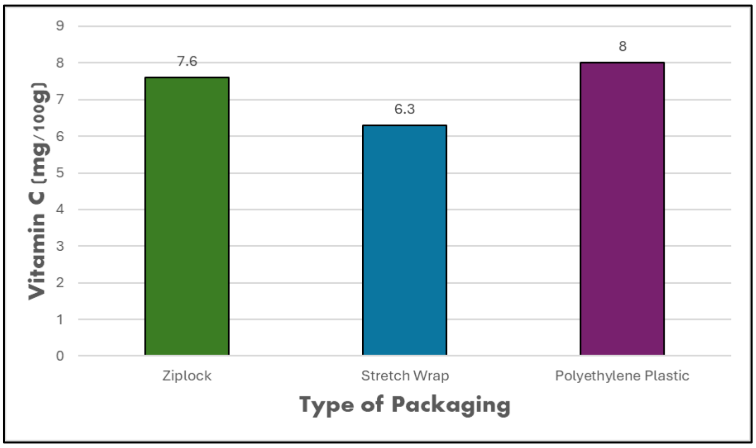

Fig. 6: Vitamin C content (mg/100g) in dragon fruit under various packaging.

4. Conclusion

This study demonstrates that the type of packaging significantly affects the postharvest quality and shelf life of dragon fruit (*Hylocereus spp.*) stored at 7 ± 2°C. Among the three packaging methods tested stretch wrap, polyethylene (PE), and ziplock. The ziplock packaging emerged as the most effective in maintaining physical quality, including minimal weight loss (0.40%), superior skin color retention, and highest firmness (1.8 N). This suggests its potential in preserving visual and textural attributes that are critical for consumer acceptance. On the other hand, polyethylene packaging provided the best protection for chemical quality, yielding the highest pH (6.08) and vitamin C content (8.0 mg/100g). This indicates that PE packaging better stabilizes the internal microclimate, thereby minimizing oxidative degradation and metabolic activity. However, PE showed higher weight loss and inconsistent color performance compared to ziplock bags. Stretch wrap offered moderate performance across all parameters but was less effective in preserving vitamin C and pH stability. Despite its common use, it may not provide optimal protection for highly perishable fruits like dragon fruit during extended storage.

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Conflict of Interest

The authors declare no conflicts of interest.

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