The Effect of Storage Temperature and Packaging Method on the Shelf Life of Broccoli *(Brassica oleracea* L. *var italica)*

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ABSTRACT

This study is aimed to evaluate the most effective storage temperature conditions and packaging methods for maintaining broccoli's physical quality, including changes in weight, water content, texture, and color during storage. This study used a descriptive method with six treatments: a combination of three storage temperature (5°C, 19°C, and 27°C) and two packaging methods: plastic film wrapping (PFW) and vacuum packaging (VP), each were duplicated. The results showed that the 5°C temperature treatment with PFW provided the best results in maintaining broccoli's physical quality during 15 days of storage. This treatment showed a relatively low weight loss of 12.77%, stable moisture content ranging from 79.5% to 77%, and higher firmness retention, with a decrease in hardness from 237.68 N to 170.18 N. Color change was also slower than other treatments, with L, a*, and b* values remaining within the range indicating a fresh green color. Meanwhile, treatments with higher storage temperatures, 19°C and 27°C, showed a rapid quality decline, in terms of weight loss, decrease in moisture content and hardness, and color change, especially in VP. Overall, the combination of a storage temperature of 5°C and the PFW method was the most effective treatment in extending the shelf life and maintaining the physical quality of broccoli. These findings highlight the importance of integrating temperature management and appropriate packaging strategies to extend the shelf life of broccoli during postharvest handling and distribution.*

Keywords: *Broccoli; packaging; storage temperature.*

ABSTRAK

Penelitian ini bertujuan untuk mengevaluasi kondisi suhu penyimpanan dan metode pengemasan yang paling efektif dalam menjaga kualitas fisik brokoli, termasuk perubahan berat, kadar air, tekstur, dan warna selama penyimpanan. Penelitian ini menggunakan metode deskriptif dengan enam perlakuan: kombinasi tiga suhu penyimpanan (5°C, 19°C, dan 27°C) dan dua metode pengemasan: pembungkus film plastik (PFW) dan pengemasan vakum (VP), masing-masing diulang dua kali. Hasil penelitian menunjukkan bahwa perlakuan suhu 5°C dengan PFW memberikan hasil terbaik dalam menjaga kualitas fisik brokoli selama 15 hari penyimpanan. Perlakuan ini menunjukkan kehilangan berat yang relatif rendah sebesar 12,77%, kadar air yang stabil berkisar antara 79,5% hingga 77%, serta retensi kekencangan yang lebih tinggi, dengan penurunan kekerasan dari 237,68 N menjadi 170,18 N. Perubahan warna juga terjadi lebih lambat dibandingkan perlakuan lain, dengan nilai L*, a*, dan b* tetap berada dalam rentang yang menunjukkan warna hijau segar. Sementara itu, perlakuan dengan suhu penyimpanan yang lebih tinggi, yaitu 19°C dan 27°C, menunjukkan penurunan kualitas yang cepat, baik dalam hal kehilangan berat, penurunan kadar air dan kekerasan, maupun perubahan warna, terutama pada varietas VP. Secara keseluruhan, kombinasi antara suhu penyimpanan 5°C dan metode PFW merupakan perlakuan yang paling efektif dalam memperpanjang umur simpan dan menjaga kualitas fisik brokoli. Temuan ini menekankan pentingnya mengintegrasikan pengelolaan suhu dan strategi pengemasan yang tepat untuk memperpanjang umur simpan brokoli selama penanganan pascapanen dan distribusi.

Kata kunci : Brokoli; kemasan; suhu penyimpanan.

INTRODUCTION

Broccoli (*Brassica oleracea* L.), a member of the Brassicaceae family, is characterized by its edible portion, which consists of a compact inflorescence composed of more than 5,000 flower buds. It is widely consumed due to its high nutritional value, including vitamins C and K, dietary fiber, and bioactive compounds such as glucosinolates and phenolic antioxidants (Syed el al., 2023; Paulsen et al., 2023). These compounds contribute to the growing demand for broccoli in global vegetable markets.

However, broccoli is highly perishable due to its high respiration rate and sensitivity to environmental conditions during postharvest storage. After harvest, broccoli undergoes rapid physiological deterioration, including moisture loss, tissue softening, and chlorophyll degradation, which result in reduced shelf life and market quality. Temperature management is widely recognized as the most critical factor influencing the postharvest quality of fresh vegetables. Low-temperature storage slows respiration and metabolic activity, thereby delaying senescence and extending shelf life. In contrast, higher storage temperatures accelerate transpiration and respiration processes, resulting in faster quality deterioration (Djarkasi, et al., 2021)

Packaging technologies have also been widely investigated to improve postharvest preservation of horticultural products. Packaging can regulate gas exchange and relative humidity around the product, thereby influencing moisture retention and metabolic processes. Therefore, this study aimed to evaluate the combined effects of storage temperature and packaging method on the shelf life and physical quality of broccoli during storage.

RESEARCH METHOD

Materials

Green broccoli, harvested at 60–70 days of maturity from a local farm in Rurukan, Tomohon, was transported to the Processing and Sensory Testing Laboratory at Sam Ratulangi University using Styrofoam boxes filled with ice.

Research Design

This study employed a descriptive method with six treatments, consisting of a combination of three storage temperatures (5 °C, 19 °C, and 27 °C) and two packaging methods, namely plastic film wrapping (PFW) and vacuum packaging (VP). The treatments were designated as follows: A1B1 = 5 °C with plastic film wrapping (PFW), A1B2 = 5 °C with vacuum packaging (VP), A2B1

= 19 °C with PFW, A2B2 = 19 °C with VP, A3B1 = 27 °C with PFW, and A3B2 = 27 °C with VP. Each treatment was duplicated.

Weight loss was monitored daily over a 15-day period, whereas moisture content was determined only on the initial and final days. Additionally, color and texture attributes were evaluated every 3 days throughout the 15-day storage period or until or until the sample spoiled.

Method of analysis

Weight Loss

The weight loss of the broccoli was determined using an SF-400 digital scale. Samples were weighed daily from the initial day until the final day of storage. The weight loss percentage was subsequently calculated using the following formula:
Berikut adalah format penulisan rumus susut bobot dalam bahasa Inggris yang lazim digunakan dalam jurnal ilmiah:

$$\mathrm{W}\ (\%) = \frac{W0-Wt}{W0} X\ 100\% \tag{1}$$

Where:

- W0 = Initial weight of the sample (g)
- Wt = Weight of the sample at time t(g)

Moisture content

A 2 g sample of broccoli was weighed, chopped, and placed into a container. The sample was then dried in an oven at 100–105°C for 3 hours, cooled in a desiccator for 15 minutes, and reweighed. The weight reduction represents the moisture content within the sample. The moisture content was calculated using the following formula:

$$\text{Moisture content}\ (\%) = \frac{\mathrm{Wi-Wd}}{\mathrm{Wi}} X\ 100\% \tag{2}$$

Where:

- Wi = Initial weight of the sample before drying (g)
- Wd = Dry weight of the sample after oven drying (g)

Texture analysis (hardness)

The hardness of the broccoli was evaluated using an A&D MCT-2150 texture analyzer. The sample was initially cleaned, cut into 2 cm pieces, and placed on the stage plate. Compression was then applied to the sample using a 21.4 mm diameter cylindrical probe at a test speed of 60.0 mm/s. The texture measurement results were recorded and displayed on a desktop computer monitor

Colour measurement (app. Color grab)

Color analysis was performed using the Colour Grab application on an Android smarphone. The broccoli sample was placed inside a mini studio arranged with ambient room lighting and camera was focused onto the sample. The color analysis measured as the L*, a*, and b values, followed by converting to the specific sample color name.

Results and Discussion

Weight Loss during Storage

Weight loss is one of the most important indicators of postharvest deterioration in fresh vegetables because it reflects moisture loss through transpiration and respiration. The percentage of weight loss of broccoli under different storage temperatures and packaging methods during the storage period is presented in **Figure 1**.

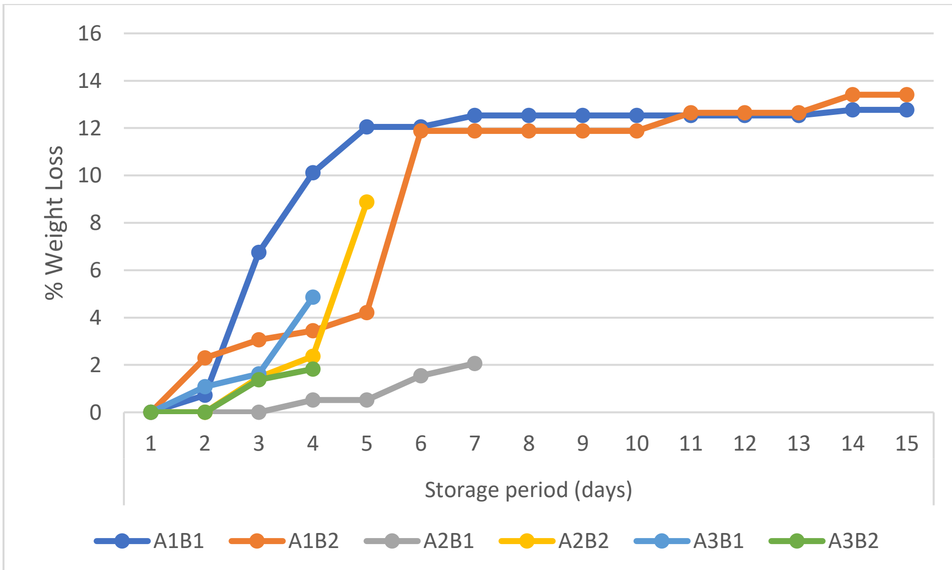


Figure 1. Weight loss (%) during storage of broccoli. A1B1 = 5 °C with plastic film wrapping (PFW), A1B2 = 5 °C with vacuum packaging (VP), A2B1 = 19 °C with PFW, A2B2 = 19 °C with VP, A3B1 = 27 °C with PFW, and A3B2 = 27 °C with VP.

The results show that weight loss increased progressively with storage time in all treatments. However, the rate of increase varied significantly depending on storage temperature and packaging method. Broccoli stored at higher temperatures (19°C and room temperature of 26–28°C) experienced the fastest increase in weight loss. In treatment A1B1, weight loss increased rapidly from approximately 6–7% on the third day to about 12% by the fifth day, after which the value stabilized around 12–13% until day 15. A similar trend was observed in A1B2, although the increase was more gradual during the early storage period before sharply rising after day five and reaching approximately 13–14% by the end of storage. The rapid weight reduction under these conditions is primarily caused by increased metabolic activity and higher transpiration rates at elevated temperatures, which accelerate moisture loss from plant tissues.

In contrast, broccoli stored at moderate temperature (19°C) showed slower weight loss compared to room temperature treatments. Treatments A2B1 and A2B2 exhibited gradual increases in weight loss during the first few days of storage, reaching approximately 2–9% by the fifth day. However, the deterioration accelerated afterward, indicating that moderate temperatures can delay but not completely prevent moisture loss and quality degradation.

The lowest weight loss was observed in broccoli stored at 5°C, particularly in treatment A3B2, where the weight loss remained below 2% even after several days of storage. Similarly, treatment A3B1 showed only a moderate increase in weight loss during the early storage period. These results indicate that low-temperature storage effectively slows the physiological processes responsible for water loss.

Packaging methods also influenced weight loss. Plastic film wrapping (PFW) generally resulted in lower weight loss compared to vacuum packaging (VP) under similar temperature conditions. Plastic film packaging creates a semi-permeable barrier that reduces moisture evaporation while maintaining a relatively high humidity level inside the package (Patil et al., 2024) This condition helps minimize transpiration and maintain product freshness. In contrast, vacuum packaging may cause structural stress in delicate vegetables such as broccoli and may not effectively prevent moisture migration when storage temperature is not optimal.

Overall, the results demonstrate that storage temperature is the dominant factor affecting broccoli weight loss, while packaging methods play a complementary role in maintaining moisture balance. The combination of low temperature (5°C) and plastic film wrapping proved to be the most effective treatment in minimizing weight loss during storage.

These findings are consistent with previous studies reporting that low-temperature storage significantly reduces transpiration and respiration rates in broccoli, thereby extending its shelf life and preserving its physical quality (Kader, 2002; Sharma et al., 2021; Guo et al., 2024).

Changes in Broccoli Texture during Storage

Texture is an important indicator of freshness and quality in broccoli during postharvest storage. The changes in broccoli hardness under different storage temperatures and packaging methods are presented in **Figure 2**.

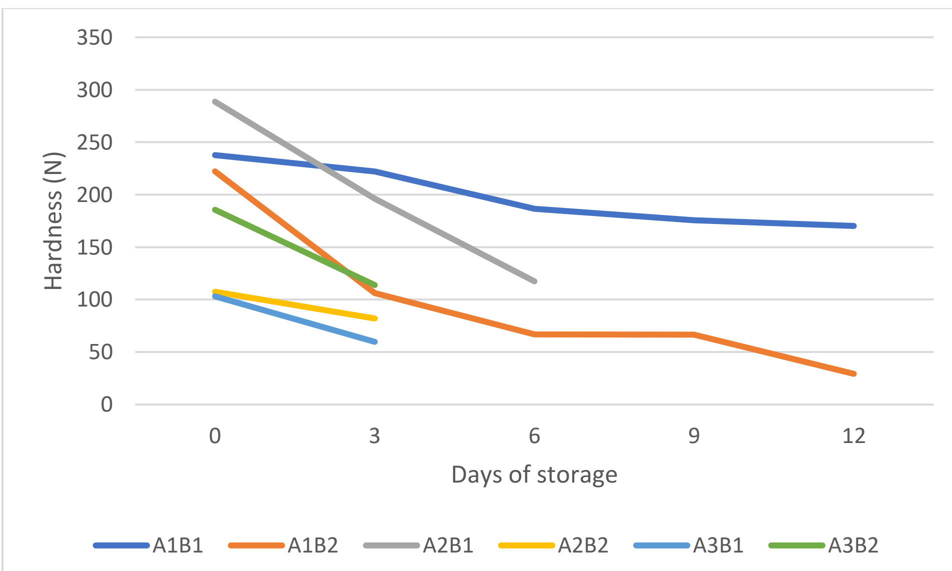


Figure 2. Broccoli texture measured as hardness (N) decline during storage of broccoli. A1B1 = 5 °C with plastic film wrapping (PFW), A1B2 = 5 °C with vacuum packaging (VP), A2B1 = 19 °C with PFW, A2B2 = 19 °C with VP, A3B1 = 27 °C with PFW, and A3B2 = 27 °C with VP.

The results show that broccoli hardness gradually decreased during the storage period for all treatments. However, the rate of texture degradation varied depending on storage temperature and packaging method. The treatment A1B1 showed the highest initial hardness, approximately 237.68 N, and exhibited a gradual decrease during storage, reaching about 170 N by day 12. This indicates that although softening occurred, the structural integrity of the broccoli tissue was relatively well maintained. In contrast, treatment A1B2 experienced a sharper decline in hardness, decreasing from approximately 220 N at the beginning of storage to around 30 N by day 12, and indicating severe tissue softening.

Broccoli stored under moderate temperature treatments (A2B1 and A2B2) also showed a decrease in hardness. Treatment A2B1 had the highest initial hardness of approximately 290 N, which decreased substantially to about 120 N by day 6. Meanwhile, A2B2 declined from about 105 N to approximately 80 N by day 3, indicating faster loss of firmness compared to A2B1.

The lowest hardness values were observed in A3B1 and A3B2, where hardness decreased rapidly within the first three days of storage. Treatment A3B1 declined from approximately 100 N to around 60 N, while A3B2 decreased from about 185 N to nearly 115 N over the same period. These results indicate that higher storage temperatures accelerate softening in broccoli tissues.

The decrease in broccoli firmness during storage is mainly caused by physiological and biochemical changes in plant tissues. During postharvest storage, enzymatic activities such as pectin degradation and cell wall breakdown lead to softening of vegetable tissues (Nishida et al., 2025). Increased respiration rates at higher temperatures also accelerate these processes, resulting in faster deterioration of texture.

Packaging methods also influenced texture retention. Plastic film wrapping (PFW) generally maintained higher firmness compared to vacuum packaging (VP). The plastic film packaging likely helped retain moisture and maintain a favorable microenvironment around the broccoli, reducing dehydration and tissue collapse. Conversely, vacuum packaging may increase tissue stress in delicate vegetables such as broccoli, potentially accelerating structural damage if not combined with optimal temperature conditions.

These findings are consistent with previous studies reporting that low-temperature storage slows down enzymatic degradation and respiration in broccoli, thereby maintaining tissue firmness and extending shelf life. Low temperatures reduce metabolic activity and delay the breakdown of cell wall components responsible for maintaining plant structure (Kader, 2002; Cantwell & Suslow, 2013). Additionally, maintaining high relative humidity through packaging can help reduce water loss and preserve tissue turgor pressure, which is essential for maintaining vegetable texture (Sharma et al., 2021).

Overall, the results indicate that both storage temperature and packaging method significantly influence broccoli texture during storage. Lower storage temperatures combined with appropriate packaging methods are essential for slowing down tissue softening and preserving broccoli quality.

Changes in Moisture Content during Storage

Moisture content is a critical parameter influencing the quality and shelf life of fresh vegetables during storage. The changes in moisture content and percentage of moisture loss in broccoli under different storage temperatures and packaging methods are presented in **Table 1**.

The results indicate that moisture content decreased in all treatments during storage, although the extent of moisture loss varied significantly depending on storage temperature and packaging method. The lowest moisture loss was observed in treatment A1B1, where the moisture content decreased slightly from 79.5% to 77.0%, corresponding to a 3.1% moisture loss over a storage period of 15 days. This treatment also showed the longest storage life, indicating that the storage conditions were effective in maintaining broccoli freshness.

Similar storage duration was observed in treatment A1B2, which maintained broccoli for 15 days, although the moisture loss was higher (6.9%) compared with A1B1. The final moisture content in this treatment decreased from 80.0% to 74.5%, suggesting that the packaging method influenced water retention during storage.

Table 1. Changes in moisture content, percentage of moisture loss, and storage life of broccoli (*Brassica oleracea* L. var. *italica*) under different combinations of storage temperature and packaging methods

Treatments	Moisture content (%)		Moisture loss (%)	Storage life (days)
	Initial	Final		
A1B1	79.5	77.0	3.1	15
A1B2	80.0	74.5	6.9	15
A2B1	79.5	67.0	15.7	7
A2B2	84.5	75.0	11.2	5
A3B1	78.0	69.0	11.5	4
A3B2	82.5	68.0	17.6	4

In contrast, treatments stored at moderate temperature conditions (A2B1 and A2B2) showed greater moisture loss and shorter storage life. Treatment A2B1 exhibited a decrease in moisture content from 79.5% to 67.0%, corresponding to a 15.7% moisture loss, and the storage life was limited to 7 days. Meanwhile, treatment A2B2 showed moisture loss of 11.2%, with storage lasting only 5 days.

The most significant moisture loss occurred in treatments A3B1 and A3B2, which had the shortest storage life of only 4 days. Treatment A3B2 showed the highest moisture loss (17.6%), with moisture content decreasing from 82.5% to 68.0%, while A3B1 experienced 11.5% moisture loss, declining from 78.0% to 69.0%. These results indicate that higher storage temperatures accelerate water loss from broccoli tissues.

The reduction in moisture content during storage is primarily caused by transpiration and respiration processes. Transpiration results in the loss of water vapor from plant tissues to the surrounding environment, while respiration consumes stored substrates and generates heat, further accelerating moisture loss. Higher storage temperatures increase the rate of these physiological processes, leading to faster dehydration and reduced shelf life.

Packaging methods also play an important role in controlling moisture loss. Packaging materials such as plastic film can maintain a high relative humidity around the product, thereby reducing transpiration and slowing water loss. Maintaining high humidity conditions helps preserve cell turgor pressure, which is essential for maintaining the texture and freshness of vegetables.

These findings are consistent with previous studies reporting that low-temperature storage combined with appropriate packaging significantly reduces moisture loss and extends the shelf life of broccoli. Low temperatures slow metabolic activity and reduce vapor pressure differences between the product and the surrounding environment, thereby minimizing water loss (Kader, 2002; Cantwell & Suslow, 2013). Furthermore, appropriate packaging can create a favorable microenvironment that helps maintain product quality during storage (Sharma et al., 2021; Guo et al., 2024; Patil et al., 2024).

Overall, the results demonstrate that both storage temperature and packaging method significantly influence moisture retention in broccoli during storage. Treatments with lower moisture loss were associated with longer storage life, indicating that maintaining moisture content is crucial for preserving broccoli quality during postharvest handling and distribution.

Relationship between Weight Loss, Moisture Content, and Texture

The results of this study indicate that weight loss, moisture content, and texture changes in broccoli during storage are closely interrelated and strongly influenced by storage temperature and packaging method. These parameters collectively reflect the physiological and structural changes occurring in broccoli tissues after harvest.

Weight loss in fresh vegetables is primarily associated with transpiration and respiration processes, which result in the loss of water and organic substrates from plant tissues. As observed in the present study, treatments stored at higher temperatures exhibited greater weight loss during storage. This condition corresponds with the decrease in moisture content observed in the same treatments, indicating that water evaporation from the broccoli tissue was the main contributor to weight reduction. Similar findings have been reported in previous studies showing that higher storage temperatures increase vapor pressure deficits between the product and the surrounding environment, thereby accelerating transpiration and water loss (Kader, 2002; Cantwell & Suslow, 2013).

The reduction in moisture content also had a direct impact on the texture or firmness of broccoli during storage. Moisture plays a critical role in maintaining cell turgor pressure, which is responsible for the crispness and firmness of vegetable tissues. As moisture content decreased, a corresponding decline in hardness was observed in several treatments. This softening of broccoli tissue is caused by the loss of cellular water combined with enzymatic degradation of structural polysaccharides in the cell wall, such as pectin and hemicellulose (Wang et al., 2020). When water is lost from plant cells, turgor pressure decreases, leading to tissue wilting and reduced firmness.

The treatments that exhibited lower weight loss and smaller reductions in moisture content generally maintained higher texture values, indicating better preservation of broccoli quality. In particular, the treatment stored at low temperature with plastic film wrapping showed relatively stable moisture content and lower weight loss, which helped maintain tissue firmness during storage. Plastic film packaging likely created a high-humidity microenvironment, reducing transpiration and preventing excessive dehydration of the broccoli tissues.

Conversely, treatments stored at higher temperatures or under less favorable packaging conditions showed greater moisture loss and more rapid softening. Elevated temperatures accelerate respiration and metabolic activity, which increases the rate of cell wall degradation and moisture evaporation. As a result, broccoli tissues lose structural integrity more rapidly, leading to a significant decline in texture quality.

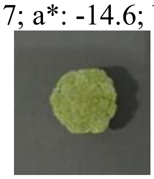
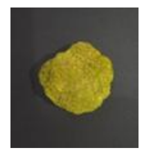
These results are consistent with previous studies indicating that low-temperature storage combined with suitable packaging can effectively reduce transpiration, maintain moisture content, and preserve the structural integrity of fresh vegetables (Sharma et al., 2021; Guo et al., 2024). Maintaining high relative humidity and reducing metabolic activity are therefore essential strategies for prolonging the shelf life of broccoli during postharvest storage.

Changes in Broccoli Color during Storage

Color is one of the most important visual indicators of freshness and quality in broccoli during postharvest storage. The changes in color parameters (L*, a*, and b*) observed during storage under different treatments are presented in **Table 2**. Fresh broccoli is typically characterized by a bright green color, which corresponds to negative a* values (green), moderate L* values (lightness), and moderate b* values indicating slight yellowness.

At the initial day of storage, all treatments showed typical fresh green broccoli color with L* values ranging from 49.9 to 54.9, a* values between −13.1 and −18.1, and b* values between 25.6 and 39.8, indicating strong green pigmentation due to high chlorophyll content.

Table 2. Changes in color parameters (L*, a*, b*) of broccoli (*Brassica oleracea* L.) during storage under different combinations of storage temperatures and packaging methods

Treatments	Initial day of storage	Final day of storage
A1B1	 Green. L*: 53.9; a*: -15.8; b*: 39.8	 Green. L*: 40; a*: -11.2; b*: 28
A1B2	 Green L*: 53.7; a*: -14.6; b*: 31.8	 Brownish-green L*: 40.5; a*: -12.7; b*: 20
A2B1	 Green L*: 53.4; a*: -13.1; b*: 32.5	 Yellowish-green L*: 41; a*: -12.5; b*: 28.8
A2B2	 Green L*: 54.9; a*: -18.1; b*: 25.6	 Brownish-green L*: 40.5; a*: -4.5; b*: 36.5
A3B1	 Green L*: 49.9; a*: -14; b*: 31.9	 Greenish-yellow L*: 63.4; a*: -5.9; b*: 59.4
A3B2	 Green L*: 54.9; a*: -18.1; b*: 25.6	 Yellowish-brown L*: 40.5; a*: -4.5; b*: 36.4

During storage, noticeable changes in color occurred across all treatments. The L* values generally decreased in several treatments, indicating darkening of the broccoli surface. For example, treatment A1B1 decreased from 53.9 to 40, while A1B2 declined from 53.7 to 40.5. These reductions in brightness are associated with pigment degradation and tissue aging during storage.

Changes in the a* values indicate the shift from green toward yellow or brown tones. Treatments such as A3B2 showed a strong shift toward less negative a* values (from −18.1 to −4.5), indicating a significant loss of green color. Similarly, A3B1 changed from −14 to −5.9, reflecting chlorophyll degradation and the onset of yellowing.

The b* values, which represent yellowness, generally increased in treatments with higher storage temperatures. For instance, A3B1 showed a dramatic increase from 31.9 to 59.4, indicating strong yellow discoloration. This change corresponds with the visual observation of greenish-yellow florets, which is a common symptom of broccoli senescence.

Among the treatments, A1B1 maintained the most stable green color, with only moderate changes in L*, a*, and b* values. The broccoli remained visually green at the end of storage, indicating slower chlorophyll degradation compared with other treatments. In contrast, treatments such as A3B1 and A3B2 showed more severe color deterioration, transitioning to yellowish-green or brownish-yellow, and indicating rapid quality decline.

The color changes observed during storage are primarily associated with chlorophyll degradation and carotenoid accumulation. Chlorophyll is responsible for the green color of broccoli, but during storage it gradually breaks down due to enzymatic activity and oxidative reactions. When chlorophyll degrades, underlying pigments such as carotenoids become more visible, resulting in yellow discoloration.

Temperature plays a crucial role in this process. Higher storage temperatures accelerate metabolic activity and enzyme reactions responsible for pigment degradation. As a result, broccoli stored at higher temperatures tends to lose its green color more rapidly. Packaging conditions may also influence color retention by affecting gas exchange and humidity levels around the product (Zhang et al., 2021; Zhang et al., 2022).

These findings are consistent with previous studies reporting that low-temperature storage effectively delays chlorophyll degradation and maintains green color in broccoli during postharvest storage (Kader, 2002; Cantwell & Suslow, 2013). Maintaining low temperatures reduces respiration rates and slows enzymatic processes involved in pigment breakdown. Additionally, proper packaging can help maintain product quality by creating a favorable microenvironment that reduces physiological stress (Sharma et al., 2021; Guo et al., 2024).

Overall, the results demonstrate that storage temperature and packaging method significantly influence color stability in broccoli during storage. Treatments with lower temperature conditions were more effective in maintaining green color and delaying the visual symptoms of senescence.

Conclusion

The combination of low-temperature storage (5 °C) with either plastic film wrapping or vacuum packaging proved to be the most effective strategy for preserving the freshness and physical quality of broccoli for up to 15 days. These findings highlight the importance of integrating low-temperature storage with appropriate packaging techniques to extend the shelf life of broccoli. Beyond laboratory conditions, this approach has potential applications in the fresh produce supply chain, particularly for distribution and retail systems seeking to minimize postharvest losses.

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