



The Effects of Active Packaging and High-density Polyethylene (HDPE) Bags on Physicochemical and Sensory Quality of Spring Onions (*Allium cepa* var. *aggregatum*) during Cold Storage

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Abstract

The aim of this study was to evaluate the influence of packaging on the quality and shelf life of spring onions during cold storage. Visual quality, sensory attributes, weight loss, and color values (L^* , a^* , and b^*) of spring onions were monitored throughout storage at 5°C. Visual quality was assessed based on predefined criteria, including color, appearance, and overall acceptability. Spring onions packed in high-density polyethylene (HDPE) bags exhibited visible signs of withering after 4 days of storage, accompanied by yellowing and browning of the green leaves and bulb areas. In addition, water condensation was visually observed inside the packages during storage and was associated with the development of a slimy texture on the stalks. Accordingly, the shelf life of spring onions packed in HDPE bags was determined to be 4 days. In contrast, spring onions packed in active packaging showed reduced wilting and maintained acceptable visual and sensory quality for up to 8 days of storage at 5°C, indicating an extended shelf life of 8 days under the studied conditions. Weight loss in both packaging systems reached approximately 5% after 8 days of storage, which corresponded to the limit of acceptable quality. A negative correlation was observed between weight loss and visual/sensory quality. Color analysis revealed an increase in lightness (L^*) and yellowness (b^*) values, while greenness (a^*) slightly decreased during storage, indicating the gradual yellowing of the spring onions. Overall, active packaging effectively delayed quality deterioration and extended the shelf life of spring onions during refrigerated storage.

Introduction

Spring onions (*Allium cepa* var. *aggregatum*), belonging to the family Amaryllidaceae, are commonly

known in different countries as scallions, green onions, Welsh onions, salad onions, Japanese bunching onions, Spanish onions, two-bladed onions or green trails, and can be consumed either cooked or raw (Sohn et al., 2006).

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Spring onions are valued for their distinctive flavor and aroma and are a rich source of vitamin C, A, and B6, as well as thiamine, folate, and various sugars such as rhamnose, galactose, glucose, arabinose and xylose (Kayat et al., 2021). Moreover, spring onions are a good source of quercetin and flavonoids and exhibit several biological activities, including anticancer, antioxidant, antimicrobial properties (Sharma & Bhat, 2009). In Asian cuisine, spring onions are widely used, particularly the green leafy part, which is often finely sliced for stir-fries or soups. They complement seafood dishes due to their mild flavor and vibrant color, offering a more delicate taste compared to white onions (The Cooking Academy, 2019). However, fresh cut spring onions have a very short shelf life. During storage, discoloration, softening, water loss, ethylene production, and off flavor development commonly occur (Page et al., 2016). Consequently, fresh-cut spring onions are considered highly perishable, despite being an attractive minimally processed and ready-to-use product (Memon et al., 2020). Fresh vegetables remain metabolically active for a long period after harvesting due to both endogenous factors (e.g., respiration) and external influences such as physical injury, microbial contamination, water loss, and storage temperature (Thompson, 1996). To address postharvest deterioration, technologies such as breathable films and active packaging have been developed to regulate gas exchange and water vapor transmission. These technologies help maintain an optimal atmosphere within the package, thereby preserving product freshness. The use of conventional clear or perforated plastic bags in supermarkets often fails to provide adequate control of the package atmosphere, particularly in terms of oxygen, carbon dioxide, and water vapor. This inadequate atmospheric regulation accelerates respiration and moisture-related deterioration, thereby reducing shelf life and contributing to increased post-harvest losses and food waste. To address postharvest losses and food waste, Thai researchers have developed “breathable bags” or active packaging systems for fresh produce (National Science and Technology Development Agency, 2024). Active packaging is designed to interact with the packaged food or its surrounding environment in order to extend shelf life beyond the passive barrier function of conventional materials (Yam et al., 2005; Realini & Marcos, 2014). In this context, breathable bags operate based on the principle of an equilibrium modified atmosphere (EMA), which regulates gas exchange and moisture transfer inside the package.

Equilibrium modified atmospheres (EMA) are passive packaging systems in which the internal atmosphere is established through the balance between the respiration rate of fresh produce and the gas permeability of the packaging material. Unlike conventional modified atmosphere packaging, EMA do not require gas flushing; instead, oxygen and carbon dioxide concentrations gradually reach equilibrium during storage. This balanced atmosphere can reduce respiration rate, moisture loss, and physiological deterioration, thereby helping to maintain the visual and sensory quality of fresh vegetables during refrigerated storage.

In this study, an EMA-based active packaging system was compared with conventional HDPE packaging, which has limited gas and moisture permeability and does not actively regulate the internal atmosphere. Fresh-cut spring onions are highly perishable, and quality deterioration during storage is mainly associated with moisture loss, wilting, discoloration, and reduced sensory acceptance. Although various preservation techniques have been reported, their application can be limited by regulatory concerns or consumer acceptance. Therefore, this study aimed to evaluate how differences in atmospheric and moisture regulation between the two packaging systems influence the physicochemical and sensory quality of fresh-cut spring onions during cold storage. Although the internal gas composition was not directly measured, the effectiveness of EMA was assessed indirectly through changes in visual quality, wilting, weight loss, color attributes, and sensory acceptability, in order to investigate the potential of EMA-based active packaging as a practical postharvest strategy to maintain quality and extend shelf life under refrigerated conditions.

Materials and methods

1. Preparation of spring onions

Fresh spring onions with bulbs approximately 25–30 cm. in length were purchased from Talaad Thai Market, Pathum Thani Province, Thailand. The spring onions were washed 3 times with tap water to removed soil from the bulbs, and the undesirable parts were trimmed. The cleaned spring onions were drained and left to air-dry for 5 min. High-density polyethylene cold bags (10×15 in, 25 µm thickness; Memento brand) were purchased from a Lotus supermarket, Bangkok, Thailand. Active packaging bags (10×15 in, 33 µm thickness) were

obtained from Central worldwide Co., Ltd, Samut Prakarn Province, Thailand.

2. Effect of packaging on the quality of spring onions

Two types of plastic packaging, active packaging and HDPE cold bags, were used in this study. A 100 g portions of cleaned and semi-dried spring onions were packed into each type of bag, sealed using a heat sealer, and stored in a refrigerator at 5°C for 14 days. The storage temperature of 5°C was selected to simulate typical refrigerated conditions used in commercial storage and retail distribution of fresh vegetables and to minimize quality deterioration without inducing chilling injury (Nunes & Emond, 2007). The quality of the samples was evaluated every 2 days and compared with that of the samples on the initial day of storage (Day 0).

3. Visual quality assessment of spring onions

The visual quality of spring onion samples was evaluated by ten trained panelists based on color, appearance, and overall visual quality. The panelists were selected based on prior experience in food sensory evaluation and their availability to participate throughout the entire study. Before evaluation, all panelists attended a training and familiarization session in which the evaluation procedures, quality attributes, and scoring criteria were clearly explained. Reference samples representing different levels of visual quality were provided to standardize the panelists' perceptions. The assessment was conducted under controlled conditions using a structured scoring system. A five-point hedonic scale was applied to rate the visual quality of the samples, adapted from Laisuan (2009) and Boonkong (2015), as shown in Table 1.

Table 1 Visual quality assessment score and description of spring onions

Score	Description
5	Leaves are bright green, glossy, fresh, and turgid, no signs of decay, bruising, or physiological disorders
4	Leaves are green and slightly wilted, no decay, bruising, or physiological disorders
3	Approximately 25% of leaves have turned yellow, slightly wilted but without decay, bruising, or physiological disorders
2	Approximately 50% of the leaves have turned yellow, leaves show wilting, decay, bruising, and physiological disorders
1	More than 50% of the leaves have turned yellow, severe wilting, decay, bruising, and physiological disorders observed.

4. Percentage of weight loss

The weight of each sample was measured using a precision balance (Model LT-3200, Acculab-Sartorius Group, Germany). with an accuracy of ± 0.01 g, following the method of Nunes and Emond (2007) and Hassan and

Mahfouz (2012). Weight loss was calculated based on the initial weight (Day 0) and the weight was measured at each sampling interval (every 2 days) using the following equation:

$$\text{Weight loss (\%)} = \frac{W_0 - W_t}{W_0} \times 100$$

Where W_0 is the initial weight (Day 0) and W_t is the weight on the sampling day.

5. Color analysis

Color parameters (L^* , a^* , b^* , and h°) of spring onion samples were measured on the surface at Day 0 and subsequently at two-day intervals throughout storage using a colorimeter (WF30, FRU, USA). The measured parameters were defined as follows: L^* (lightness; 0 = black, 100 = white), a^* ($-a^*$ indicating greenness and $+a^*$ indicating redness), b^* ($-b^*$ indicating blueness and $+b^*$ indicating yellowness), and h° (hue angle, representing color tone). Prior to measurement, the colorimeter was calibrated using a standard white tile. Changes in color during storage were evaluated based on variations in the absolute L^* , a^* , b^* , and h° values rather than color difference parameters (ΔL^* , Δa^* , and Δb^*).

6. Statistical analysis

Statistical analyses were performed using SPSS version 19 software (SPSS Inc., USA). Statistical differences between packaging systems at each storage time were analyzed using an independent sample t-test ($p < 0.05$). Storage time was considered as the independent variable, and day 0 was used as the control. Differences between storage days were analyzed by one-way ANOVA followed by Dunnett's post hoc test ($p < 0.05$). Each treatment was conducted in duplicate. Pearson's correlation coefficient was used to determine the linear relationship between weight loss and visual quality during storage.

Results and Discussion

1. Visual quality of spring onions

The visual quality of spring onions stored in active packaging and HDPE bags is shown in Fig. 1 and Table 1. At the beginning of storage, the samples exhibited fresh characteristics, including bright green leaves, white bulbs, and a firm texture. During storage, initial signs of withering were first observed on Day 6 in active packaging (Fig. 1a) and on Day 4 in HDPE bags (Fig. 1b). Progressive color changes were observed in the leaves, from green to yellow and subsequently to brown

or dark green. Similarly, bulb color changed from white to yellow and eventually brown. Textural deterioration was also noted, characterized by reduced firmness, shrinkage, and deformation. Slime formation was detected after 10 days of storage in active packaging and after 8 days in HDPE bags, which is commonly associated with excessive moisture accumulation and microbial activity in fresh vegetables (Nunes & Emond, 2007; Memon et al., 2020).

During storage, greater condensation was observed in HDPE bags compared to active packaging. Excess moisture and condensation inside sealed packaging are known to accelerate senescence, promote microbial growth, and lead to faster deterioration of fresh produce (Thompson, 1996; Viškelis et al., 2012). In contrast,

active packaging can regulate gas exchange and moisture balance, thereby delaying early physiological deterioration.

Based on the visual quality criteria presented in Table 2, the cut-off point for acceptable color, appearance, and overall visual quality was determined to be 8 days for both packaging types. At this stage, approximately 50% of the leaves had changed from green to yellow and exhibited visible wilting, bruising, rotting, and physiological disorders. Shelf life was therefore defined according to the visual acceptability limit rather than the first appearance of deterioration, following established postharvest evaluation practices (Nunes & Emond, 2007; Laisuwan, 2009). Samples stored beyond this period were considered unacceptable, with complete quality loss observed by Day 14 of storage.

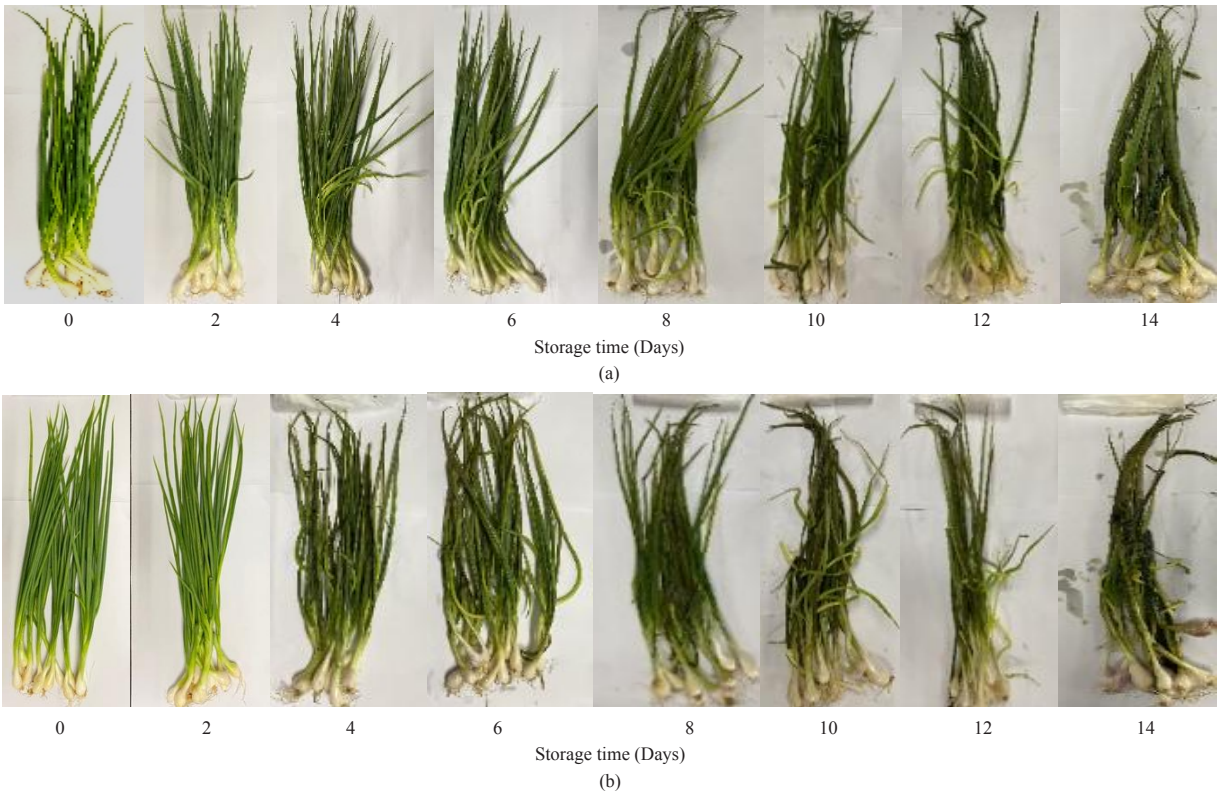


Fig. 1 Visual quality of spring onions during storage in active packaging (a) and HDPE (b) bags at 5°C for 14 days

Table 2 The results of the visual/sensory quality assessment of spring onions during storage in active packaging and HDPE bags at 5°C for 14 days

Packaging	Storage time (Days)							
	0	2	4	6	8	10	12	14
Active packaging	5.00±0.00	5.00±0.00	4.00±0.00	4.00±0.00	2.00±0.00	1.00±0.00	1.00±0.00	not measure
HDPE	5.00±0.00	5.00±0.00	4.00±0.00	4.00±0.00	2.00±0.00	1.00±0.00	1.00±0.00	not measure

Remark: Values represent the mean scores ± SD of color, appearance, and overall quality based on visual/sensory evaluation.

2. Percentage of weight loss

The percentage of weight loss of spring onions during storage at 5°C for 14 days in both packaging types is shown in Table 3. Both packaging treatments exhibited rates of weight loss during the first 4 days of storage. However, samples stored in HDPE bags showed a higher weight loss after 8 days of storage. The rate of water loss depends on the type of crop and is strongly related to its physiological and morphological characteristics. Moreover, the rate of water loss is influenced by packaging type, storage duration, and environmental conditions (Hassan & Mahfouz, 2012). Wilting development is largely associated with moisture loss, which generally occurs more rapidly in spring onion leaves stored in HDPE bags than in active packaging. This may be attributed to the higher water vapor permeability of HDPE bags. Hassan and Mahfouz (2012) reported that Boston lettuce exhibited initial symptoms of moisture loss, such as wilting and loss of leaf turgidity, when weight loss reached approximately 2.7%, whereas iceberg lettuce stored for 14 days at 2°C showed objectionable wilting when weight loss reached about 6%. In this study, spring onions stored at 5°C for 8 days showed unacceptable visual quality when weight loss reached 5%. Increased weight loss was associated with a greater degree of wilting, particularly in samples stored in HDPE bags. This observation corresponded well with the visual/sensory quality cut-off point. A significant negative correlation ($r = -0.84$) was found between weight loss and visual/sensory quality of spring onions, as shown in Fig. 2. A strong negative relationship was observed between storage time and the visual quality score ($r = -0.84$), indicating that visual quality decreased progressively as storage time increased. Linear regression analysis showed a clear linear trend between the two variables, confirming that storage duration was a major factor influencing quality deterioration. This inverse relationship reflects typical postharvest behavior of leafy vegetables, in which prolonged storage accelerates senescence, moisture loss, and textural degradation

(Thompson, 1996; Nunes & Emond, 2007). Although a regression equation was not the primary focus of this study, the strong correlation coefficient demonstrates a consistent decline in sensory acceptability with increasing storage time. Similar negative relationships between storage duration and visual quality have been reported in previous studies on green onions and other leafy vegetables stored under refrigerated conditions (Viškelis et al., 2012; Laisuwan, 2009).

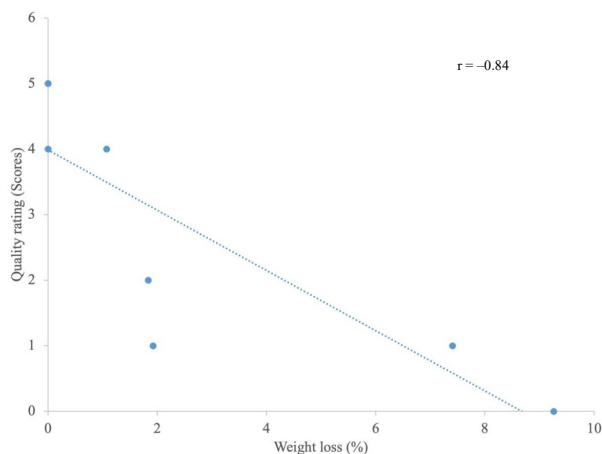


Fig. 2 Relationship between weight loss and visual/sensory quality of spring onions stored at 5°C for 14 days. The dotted line indicates the limit of acceptability, above which the samples were considered unacceptable in quality.

3. Color values

The color values of spring onions during storage at 5°C for 8 days (cut-off date) are presented in Fig. 3. The results showed that the color of spring onions changed progressively during storage, with both packaging types exhibiting similar trends. After 2 days of storage, the spring onions maintained their green color ($-a^*$ value). By day 4, the color had become darkened green, corresponding to a decrease in a^* value.

The most pronounced change in a^* value occurred between days 4 and 8 in samples packed in HDPE bags,

Table 3 Weight loss (%) of spring onions during storage in active packaging and HDPE bags at 5°C for 14 days

Packaging	Storage time (Days)							
	0	2	4	6	8	10	12	14
Active packaging	0.00 ^{aA} ±0.00	0.00 ^{aA} ±0.00	0.00 ^{aA} ±0.00	1.07 ^{bB} ±0.01	1.86 ^{bB} ±0.02	1.93 ^{bB} ±0.01	7.42 ^{bB} ±0.01	9.27 ^{bB} ±0.01
HDPE	0.00 ^{aA} ±0.00	0.00 ^{aA} ±0.00	0.00 ^{aA} ±0.00	1.21 ^{aB} ±0.02	2.02 ^{aB} ±0.04	3.97 ^{aB} ±0.01	19.11 ^{aB} ±0.02	23.41 ^{aB} ±0.02

Remark: Values are expressed as mean ± SD. For each storage time, means followed by different letters (a–b) within the same column indicate significant differences between packaging systems as determined by an independent samples t-test ($p < 0.05$). Within each packaging system, means followed by different letters (A–B) indicate significant differences compared with day 0 as determined by one-way ANOVA followed by Dunnett's test ($p < 0.05$).

whereas samples stored in active packaging remained relatively stable during this period. Changes in L^* (lightness) and b^* (yellowness) values followed similar patterns for both packaging types. The increase in b^* values from day 2 to day 8 was associated with an increase in L^* values, indicating that the green color of the spring onions gradually shifted toward yellow during storage. This color shift resulted in higher L^* (whiteness) and b^* (yellowness) values in both packaging types. These findings are consistent with the previous study by Viškelis et al. (2012), who reported that after storage in a modified atmosphere, the lightness index of spring onions slightly increased (from 49.07 to 49.92), indicating that the onions became lighter, whereas the greenness intensity slightly decreased (from -12.98 to -12.52). During storage, the yellowness coordinates increased (from 27.53 to 28.61), suggesting that spring onions became slightly more yellow over time.

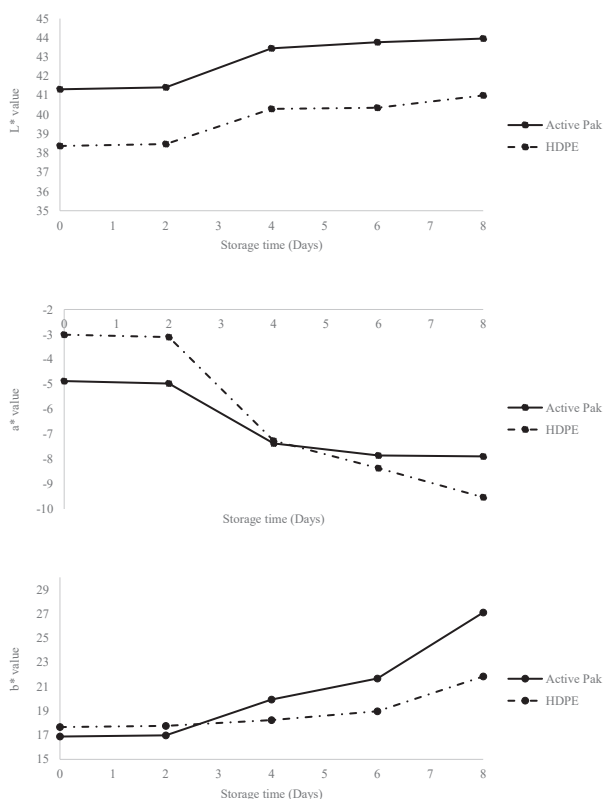


Fig. 3 Color values of Spring onions during storage at 5°C for 8 days.

Conclusion

Active packaging effectively delayed the early onset of visual deterioration in spring onions stored at 5°C, reducing wilting and better preserving overall appearance compared with HDPE packaging. Samples packed in the active system retained a fresher visual quality for a longer period, indicating its ability to slow early physiological deterioration under refrigerated conditions. Notably, this study provides novel insight by clearly distinguishing between early visual quality preservation and actual shelf-life extension when sensory acceptability is applied as the primary criterion. Although active packaging improved visual appearance, both packaging systems maintained acceptable quality for only up to 6 days, based on sensory cut-off values. Beyond this period, sensory scores declined to unacceptable levels, even when some samples still appeared visually acceptable. This discrepancy between visual appearance and sensory perception represents a key novel contribution of the study, highlighting the risk of overestimating shelf life when relying solely on visual indicators. Overall, the findings emphasize the importance of integrating both visual and sensory criteria to achieve a more accurate and consumer-relevant evaluation of fresh produce quality during refrigerated storage.

Conflict of interests

The authors declare no conflict of interests.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT to enhance language clarity and improve grammar. The final content was reviewed and edited by the corresponding author, who takes full responsibility for the accuracy and integrity of the publication.

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