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Effects of storage temperatures and packaging films on the physiological quality and storage life of seablite leaves

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Abstract Seablite (*Suaeda maritima* L.) is a local plant that grows only in coastal areas which is used to cook various Thai dishes. The major postharvest problems are the yellowing and decaying of leaves, leading to a short shelf life due to a lack of information on suitable storage temperature and packaging. The result revealed that 4ºC was the best storage temperature to reduce weight loss, respiration rate, ethylene production, chlorophyll breakdown, yellowing of leaves, and decaying. In contrast, the soluble pectin was not different from the control. The storage life at 4ºC was 24 days, whereas at 13 and 25ºC were 12 and 4 days, respectively. Second, the effect of packaging films on the physiological quality of seablite during storage at 4ºC for 28 days was evaluated. Seablite was kept in polypropylene (PP) and low-density polyethylene (PE) films compared to the perforated polyethylene (PPE) film (control). The result showed that leaves kept in a PP film had a significantly lower percentage of yellowing and decaying leaves, weight loss, respiration rate, and ethylene production than those kept in PE and PPE films, respectively. In contrast, there was a non-significant in the antioxidant capacity and soluble pectin content among all film types. Low oxygen concentration inside the package was found in the PP film compared to PE and PPE films. It is suggested that seablite should be kept in a PP film at 4°C, and storage life can be extended to 28 days.

Keywords: Low temperature, Salt marsh plant, Postharvest storage, Packaging

Introduction

Seablite (*Suaeda maritima* L.) is classified as a vegetable or herb and is typically found along seashores in tropical and subtropical areas. It is a salt-tolerant plant growing on the landward margin of mangrove habitats (Pornpitakdamrong and Sudjaroen, 2014), and is found in many countries such as Australia, Bangladesh, India, and Thailand. Seablite is used as a raw material for various approaches, such as making juice, pickled in vinegar, curries, spicy

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soups, salads, and chili paste (Pornpitakdamrong and Sudjaroen, 2014), and animal feeds (Patra *et al*., 2010). It has also been processed into a variety of products such as dry seablite, popcorn, snacks, soap, shampoo, and more. Seablite leaves, stems and other components have the potential to produce low-sodium salt which is important for developing healthy food products (Maflahah *et al*., 2024a). This seablite-derived salt is considered a healthier alternative and can serve as a raw material for functional food formulations (Maflahah *et al*., 2024b; Maflahah *et al*., 2023). Seablite consists of various dietary nutrition (e.g., carbohydrate, protein, dietary fiber, calcium) and bioactive compounds (e.g., vitamin A, vitamin C, alkaloids, phenolics, tannins, flavonoids, terpenoids, and β-carotene) (Patra *et al*., 2011; Sudjaroen, 2012; Bandaranayake, 2002). It contains high antioxidant capacities, such as 328.62 mg GAE/g of total phenolic compounds and 44.91% antioxidant activity (Kaewdongdee and Intrasombat, 2012), which help boost the immune system in the human body and has good analgesic properties (Jithesh *et al*., 2006; Ibrahim *et al*., 2007). Furthermore, some research showed that the leaf and stem extract of seablite has the potential for pharmaceutical application due to its potent antimicrobial properties. The minimal inhibition concentration (MIC) and minimal bacterial concentration (MBC) values of the seablite extract were found to range from 2.5 to 5.0 mg/mL (Patra *et al*., 2011). Seablite root can be used for skin disease and abscess treatments and helps relieve allergic symptoms (Thongkao *et al*., 2022).

In the past, the consumption of fresh seablite in Thailand has ordinarily been found in communities that have stayed near the margin of mangrove areas. It was a plant that was out of sight. However, nowadays, this plant has become an exciting vegetable for making Thai cuisine dishes and serves tourists and city people who want to taste exotic vegetables containing high antioxidant and bioactive compounds. Preparation of seablite leaves for cooking requires boiling and then squeezing 2-3 times to remove the brine from the plant tissue and reduce the saltiness. After boiling and squeezing, the texture of seablite leaves remains fresh and crispy. The crispy texture of seablite makes it a favorite among consumers. Now, the demand for seablite consumption is increasing rapidly, leading to small and medium entrepreneurs selling it at high prices. Its price is higher than that of cabbage 2-3 times. Because of this, seaside communities have increased income from seablite sales. However, the shelf life of seablite is short due to rapid decay and yellowing of leaves within 3-4 days at room temperature. Previous research focused on nutritive values, bioactive compounds, and phytochemical compounds of seablite (Patra *et al*., 2011; Sudjaroen, 2012). To date, there is limited information on the physiological changes of fresh seablite and the proper postharvest storage condition for preserving and extending its shelf life.

Low temperature is widely used to extend the shelf life of fresh produce. However, most tropical produce is sensitive to low storage temperatures. At low temperatures, but non-freezing temperatures, plant tissues may show physical damage such as surface pitting and discoloration, which these symptoms are called chilling injuries (CI) (Wang, 2009). Moreover, texture changes are a common symptom of the senescence of fresh produce. These changes often lead to softening, which is associated with the loss of polysaccharides from the cell wall, particularly pectin (Goulao and Oliveira, 2008). As insoluble pectin is converted to soluble forms, it enhances cell wall softening, leading to the mushiness and senescence of plant tissue. In that case, the plant tissue may experience rapid senescence caused by a high metabolism rate and accessible decay caused by microorganism infection. Seablite commonly grows well in warm and hot climates; the suitable low storage temperature is still unknown and may not tolerate low storage temperatures.

Suitable packaging can extend the shelf life by protecting the quality and preventing microbiological contamination during transportation and storage (de Aguiar *et al*., 2023). Plastic film packaging is widely used in the market due to its low cost, lightweight, ability to ensure food safety, and permeability to gas exchange (de Aguiar *et al*., 2023; Monacci *et al*., 2023). The shelf life of fresh produce is influenced by the respiration rate and the permeability of gas through the plastic film (Fonseca *et al*., 2002). Currently, seablite is packed in various types of bags, such as perforated plastic bags and plastic bags with handles. However, the proper packaging for storing seablite has not been studied.

The objective was investigated a suitable storage temperatures and packaging films to maintain the physiological quality and extend the shelf life of fresh seablite leaves.

Materials and methods

Sample preparation

The fresh shoots of seablite at the green leaf stage were purchased from the local market in Baan Leam district, Phetchaburi province in June-August 2023. They were transported to the Postharvest Technology Laboratory at King Mongkut's University of Technology, Thonburi, Bangkok, within 2 hr. The stems were removed from the shoot, and the green leaves were collected for this experiment. The leaves were washed with tap water to remove soil and plant debris, then air-dried for 1-2 hr before use.

Effect of storage temperature on physiological quality of seablite

Fresh seablite leaves (100 g) were packed in a plastic tray covered with a perforated polyethylene (PPE) film (4 holes with ∅ 0.5 cm). The samples were separated into 3 treatments and kept at 25(control), 13, and 4 ºC. Each treatment consisted of 32 samples. Four samples were randomly collected to determine respiration rate, ethylene production, weight loss, leave color, soluble pectin, percentage of yellowing leaves, and percentage of decaying leaves at 4-day intervals for 28 days. The storage life of seablite was terminated when the percentage of decaying leaves was higher than 10% of the total fresh weight. Each treatment consisted of 4 replicates.

Effect of packaging film on physiological quality of seablite

Fresh seablite leaves (100 g) were packed in a plastic tray covered with different packaging films: 1) perforated polyethylene (PPE) with 4 holes (∅ 0.5 cm) as the control, 2) low-density polyethylene (PE) with a thickness of 50 μm (Prize Interpack (1999) CO., LTD. Thailand), and 3) polypropylene (PP) with a thickness of 55 μm (Energy Systems International CO., LTD.). All packages were then sealed with a heat sealer. Each film (treatment) consisted of 32 samples. All samples were kept at 4ºC (the best storage temperature from the previous experiment) for 28 days. Four samples were randomly collected to determine respiration rate, ethylene production, weight loss, leave color, percentage of yellowing leaves, percentage of decaying leaves, total chlorophyll content, soluble pectin content, antioxidant activity, and the oxygen concentrations inside the atmosphere of the package at 4-day intervals. Each treatment consisted of 4 replicates.

Analysis of physiological quality

Respiration rate and ethylene production

Respiration rate and ethylene production were measured as described by Nguyen *et al*. (2021). The seablite sample was held in 200 mL of a tightly closed container at the test temperature for 2 hr. A 1 mL gas sample was taken from each container using a syringe and injected into the gas chromatography (Shimadzu, 2014, Tokyo, Japan). The respiration rate was presented as mg kg^{-1} hr^{-1}, and the ethylene production was presented as μL kg^{-1} hr^{-1}.

Weight loss

The initial and final weights of seablite were determined using a digital balance and calculated as the percentage of weight loss using this formula: [(initial weight – final weight) / initial weight] x 100.

Leave color

The color of seablite leaves was recorded using a colorimeter (Model CR300, Minolta, Tokyo, Japan), and results were expressed as L*, a*, and b* values. Three readings were taken at three different times for each sample.

Percentage of yellowing leaves and decaying leaves

The yellow leaves and leaf decay were separated from the typical leaves and weighed as grams. The percentage of yellow leaves was calculated using this formula: [gram of yellowing leaves/grams of total leaves] x 100]. The rate of decay leaves was calculated as the percentage using this formula: [gram of decaying leaves/grams of total leaves] x 100].

Total chlorophyll analysis

Total chlorophyll content was determined using Moran's method (1982) with slight modification. A 0.1 g fresh sample was homogenized in 10 mL of N, N-dimethylformamide and incubated at 4°C in the dark for 24 hr. The supernatant was harvested by centrifugation at 10,000 rpm for 10 min. The absorption value of the supernatant was measured at 664 and 647 nm using a spectrophotometer (UV-1800; Shimadzu Co., Japan). Total chlorophyll content was calculated as the sum of chlorophyll a and b contents, and the result was expressed as mg kg^{-1} of fresh weight when their formulas are: Chlorophyll a = (12.64 x OD664) – (2.99 x OD647) and chlorophyll b = (-5.6 x OD664) + (23.26 x OD647).

Soluble pectin analysis

Soluble pectin was determined using Maran's method (2015) with a minor modification. Dry seablite leaves were homogenized by a blender (MiniMex, MCG4). A leaf powder (1 g) of seablite was added with 12 ml of 0.05 M HCl and incubated in a hot bath at 95ºC for 1 hr. The samples were cooled at room temperature and filtered with the muslin cloth. The supernatant was precipitated by adding 80% ethanol with a ratio of 1:2 (v/v) and then incubated at 4ºC for 15 hr. The pectin sediment was harvested by filtrating with the muslin cloth and washed with 50 ml of 80% acetone 3 times. The sediment of pectin was dried in a hot air oven at 65 ºC for 12 hr. The extract pectin pellet was weighed and recorded as a gram of dry weight. The soluble pectin content is calculated as %

yield using this formula: [(A/B) x 100], where A = the amount of extract pectin (g) and B = the amount of dried leaf powder.

Antioxidant activity analysis

The DPPH method was used to determine antioxidant activity as Pan *et al*. (2009) described. 5 g seablite was homogenized with 20 mL of 80% ethanol and then centrifuged at 11,000 rpm at 4ºC for 20 min. 500 mL of the supernatant was mixed with 1 mL of working DPPH solution and incubated in the dark for 30 min. The sample was then measured by spectrophotometer at 517 nm compared with the blank (distilled water). DPPH scavenging activity (%) was calculated using the formula [(AC – AE)/AC]*100, where AC and AE are the absorbance values of the blank and sample, respectively.

Gas composition of the atmosphere inside the package

Oxygen concentrations in the headspace of the package were determined using an OxyBaby gas analyzer (Model M-02, Germany), and the result was recorded as v/v percentage. The instrument was calibrated with air.

Statistical analysis

The experiments were conducted in a completely randomized design (CRD) in independent 4 replications. The result was shown as the mean ± standard error (SE). Using the statistical SAS software, Duncan's multiple range test determined a significant difference with the 95% confidential level.

Results

Effect of storage temperature on the physiological quality of seablite

Low-temperature storage is a simple method to reduce quality losses of fresh produce. It extends shelf life by depressing respiration rates, ethylene production, and the activities of microorganisms, which are capable of causing tissue senescence and spoilage. This experiment found that the respiration rate and ethylene production of seablite decreased with decreasing temperature levels. The lowest respiration was found in seablite stored at 4ºC, followed by 13ºC and 25ºC, respectively, and they significantly differed among the treatments (Figure 1A). On the last day of storage, the respiration rates of seablite at 4°C (day 28), 13°C (day 16), and 25°C (day 8) were 0.04, 0.96, and 2.43 mg CO_2 kg^{-1} hr^{-1}, respectively. Ethylene production was the same trend as the respiration rate. On the initial date (day 0), ethylene production ranged from 1.17-1.59 $\mu L.C_2H_4$ kg^{-1} hr^{-1} and then declined throughout the storage period (Figure 1B).

On the last day, its ethylene production at 4°C (day 28), 13°C (day 16), and 25°C (day 8) were 0.023, 0.08, and 0.043 $\mu L.C_2H_4\ kg^{-1}\ hr^{-1}$, respectively.

Low respiration rate was correlated with low weight loss. Seablite stored at 4ºC exhibited the lowest weight loss throughout the storage period compared to those stored at 13ºC and 25ºC (Figure 2A). The leaf color of seablite was determined and presented as L*, a*, and b* values. L* and a* values were non-significant differences among the treatments (data not shown). Whereas the b* value, representing the yellow/blue coordinate was significant different with other treatments. A high positive b* value indicates that the leaf sample becomes more yellow. It was found that the b* value of seablite stored at 25°C increased from 20.53 to 23.75 within 8 days, whereas storing at low temperatures significantly delayed the increase of b* values. On the last day of storage, the b* value of seablite at 4°C (day 28) was the lowest at 20.42, while those at 13°C (day 16) were 23.33, respectively (Figure 2B). This result directly related to the percentage of yellowing leaves (Figure 2C) and total chlorophyll content (Figure 2D). Our result shows that a low yellowing leave percentage was found at 4 and 13°C, respectively. While at the beginning of storage, the total chlorophyll content of seablite in all treatments ranged between 52.12-53.12 $mg.100g\ FW^{-1}$ and declined during storage. Low temperature could delay the chlorophyll degradation, resulting in maintaining the greenness of seablite leaves. At the end of storage, the chlorophyll content of seablite stored at 4°C on day 28 was 49.54 $mg.100g\ FW^{-1}$, whereas at 25°C on day 8 was 46.73 $mg.100g\ FW^{-1}$.

Low-temperature storage could retard the increase in decaying leaves. Decaying leaves first appeared in seablite stored at 25°C on day 4, while at 13 and 4°C, they appeared on day 8 and day 12, respectively (Figure 3A). The soluble pectin content of seablite in all storage treatments remained stable, with no significant differences observed; their contents ranged between 7.51-9.11% (Figure 3B). The storage life of seablite was terminated when the percentage of decaying leaves exceeded 30%. So, the storage life of seablite at 4, 13, and 25ºC was 24, 12, and 4 days, respectively. This result suggests that the appropriate storage temperature of seablite is 4ºC.

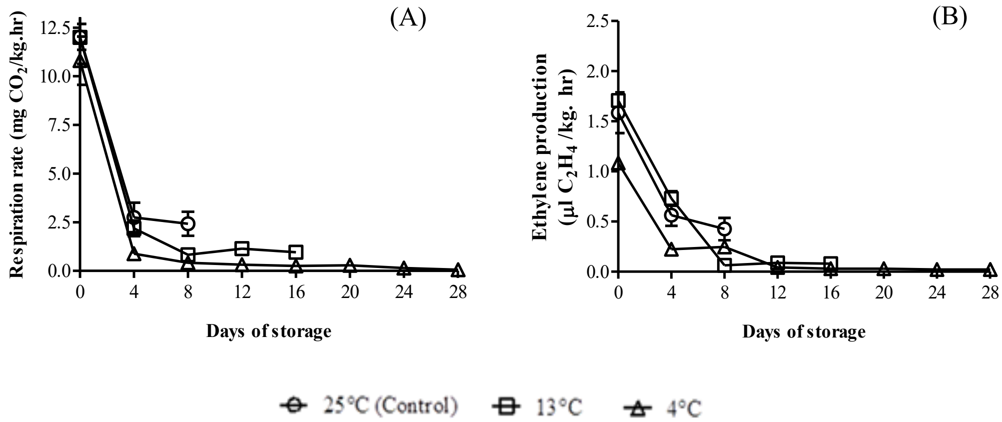

Figure 1. Respiration rate (A) and ethylene production (B) of seablite leaves during storage at 25(control), 13, and 4 ºC

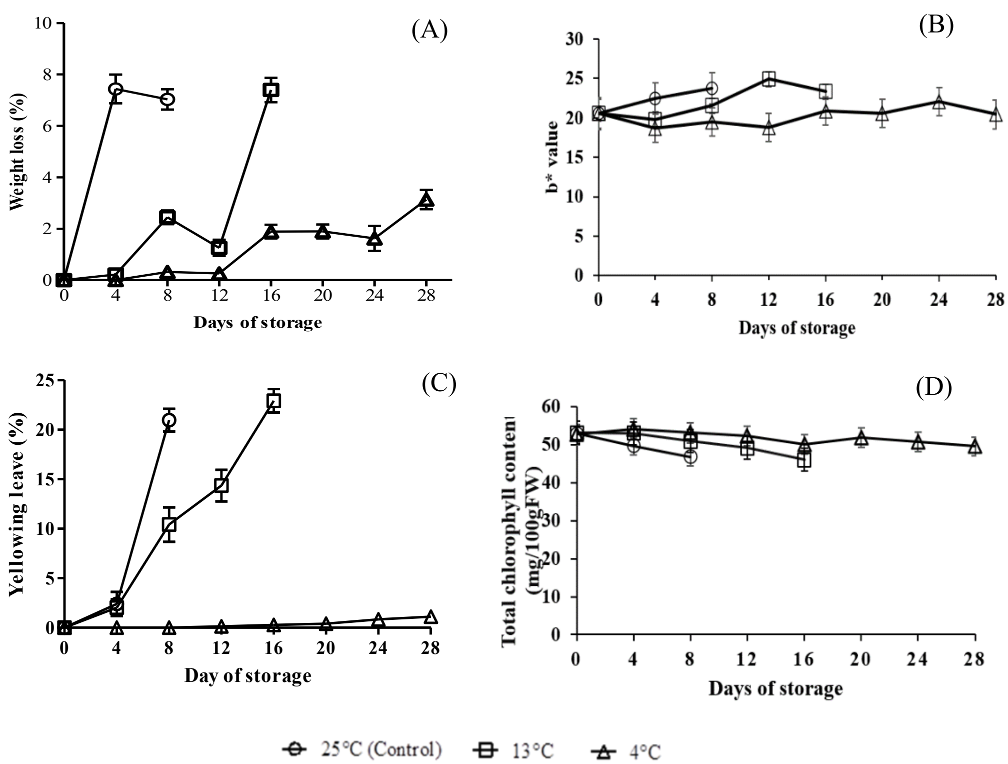

Figure 2. Weight loss (A), b* value (B), yellowing leaves (C), and total chlorophyll content (D) of seablite leaves during storage at 25(control), 13, and 4 ºC

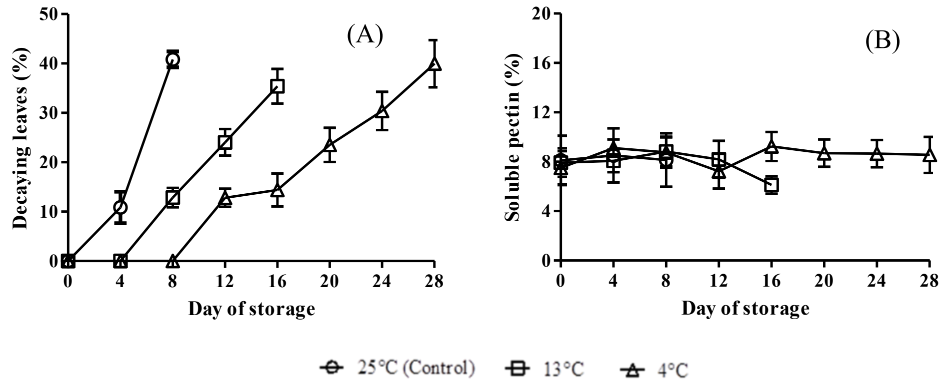

Figure 3. Percentages of decaying leaves (A) and soluble pectin (B) of seablite leaves during storage at 25 (control), 13, and 4 ºC

Effect of packaging film on the physiological quality of seablite

Proper packaging can significantly affect the physiological quality of fresh produce. Three different types of packaging films were used to store seablite, including PPE (control), PE, and PP films. A low storage temperature at 4°C was selected from Experiment 1 and used for storing the seablite. The changes in postharvest physiology and quality of seablite in various packaging films were determined during storage at 4°C. The results show that at the beginning stage of storage (day 0), the respiration rate of seablite ranged from 2.45-2.57 mg CO_2 kg^{-1} hr^{-1} and declined rapidly by day 4 (0.61-0.87 mg CO_2 kg^{-1} hr^{-1}) and then slightly declined until day 28. Seablite stored in PP film had a significantly lower respiration rate than PE film and PPE (control) from day 0 to day 16 of the storage period (Figure 4A). The ethylene production of seablite showed a similar trend to the respiration rate. On the initial day of storage, ethylene production of all treatments ranged from 0.58 to 0.63 $\mu L C_2H_4$ kg^{-1} hr^{-1} and declined to 0.17 to 0.30 μL C_2H_4 kg^{-1} hr^{-1} on the last day of storage. However, their ethylene production did differ significantly among the packaging films throughout the storage period (Figure 4B).

Weight loss of seablite increased throughout storage, especially seablite in PPE film, which had the highest weight loss, whereas PP film showed the lowest weight loss, followed by PE film. On the last day of storage (day 28), the weight losses of seablite in PP, PE, and PPE films were 2.34, 4.55, and 4.76%, respectively (Figure 5A). The b* values and yellowing leaves of seablite in all treatments slightly increased throughout the storage period, but their values did not change much during storage. Keeping seablite in PP film could slow the increase in b* value and yellowing leaf percentage compared to the control (PPE film) (Figure 5B and 5C). However, on the last day of storage, the percentages of yellowing leaves of seablite in PP, PE, and PPE film were lower than 1%. Thus, the total chlorophyll contents of seablite in all packaging films did not show significant differences (data not shown). The DPPH activity was investigated to assess the antioxidant capacity in seablite. The result showed that the DPPH activity of seablite did not significantly differ from the first day to the last day of storage. The DPPH activity of seablite in all package films on day 0 was 40.03-40.11% inhibition, whereas on day 28, it was 37.87-39.89% (Figure 5D).

Decaying of leaves was first found on day 8 of storage in all treatments and increased during storage at 4C°. The lowest percentage of decaying leaves was found in the seablite kept in PP film, followed by PE and PPE films, respectively. On the last day of storage, the decaying leaf percentages of seablite in PP, PE, and PPE films were 1.84, 4.72, and 4.97%, respectively (Figure 6A). Soluble pectin contents of seablite in all treatments slightly increased but were non-significant differences. Its contents during storage ranged between 7.18-9.60% (Figure 6B).

Oxygen concentrations in the atmosphere of packages covered with various films were not significantly different on the initial day of storage (day 0); they ranged between 16.90% to19.17%. Subsequently, they decreased rapidly to 3.87%-5.20% by day 4. The oxygen concentrations changed little or remained relatively constant from day 8 to 28. The oxygen concentration inside the package covered with PP film was the lowest compared to that of other films. On the last day (day 28), the oxygen concentration in PP film was 1.78%, while in PE and PPE films were 3.72 and 4.90% (Figure 7A). The appearance of seablite samples was evaluated and reported as the overall acceptant score. Seablite kept in PP film had the highest score throughout the storage period. On the last day of storage, the overall acceptance score was 3.75 for PP film, while it was 3 for PE film and 2 for PPE films (Figure 7B).

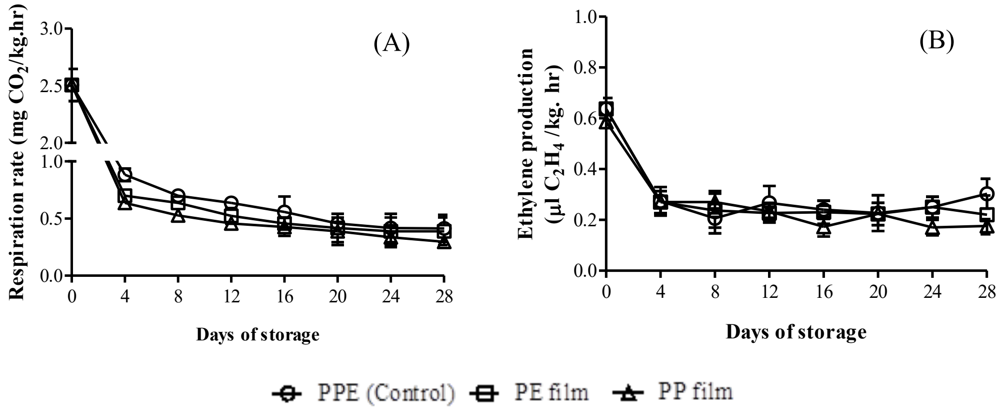

Figure 4. Respiration rate (A) and ethylene production (B) of seablite leaves kept in a tray covered with PPE film (control), AP film, and PP film during storage at 4ºC

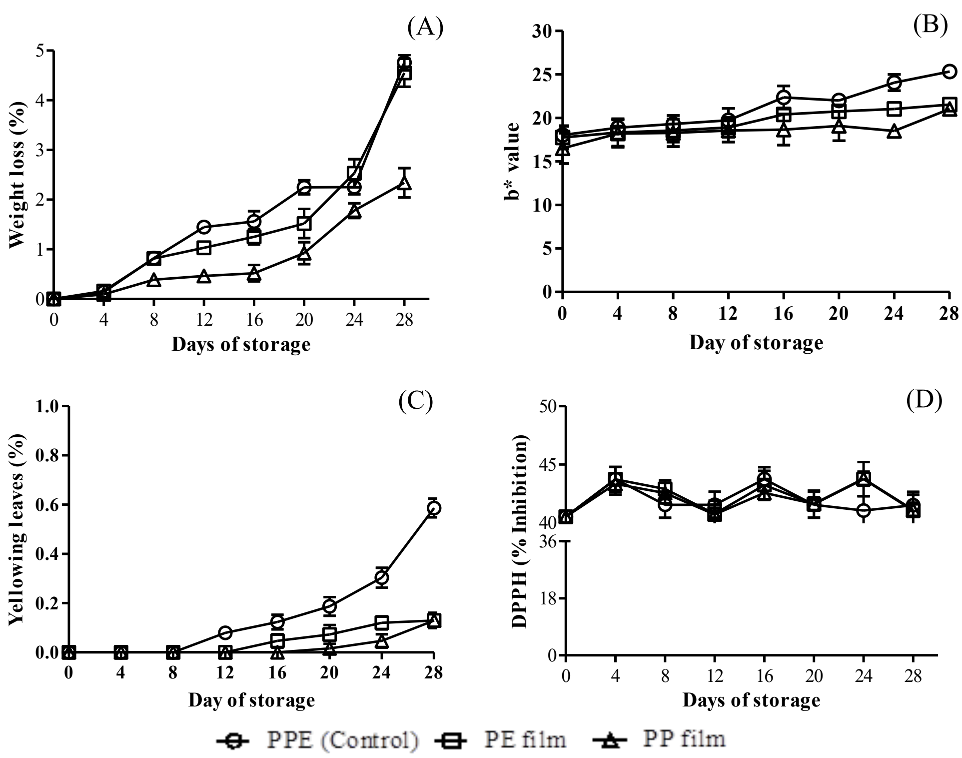

Figure 5. Weight loss (A), b* value (B), yellowing leaves (C), and DPPH activity (D) of seablite leaves kept in a tray covered with PPE film (control), PE film, and PP film during storage at 4ºC

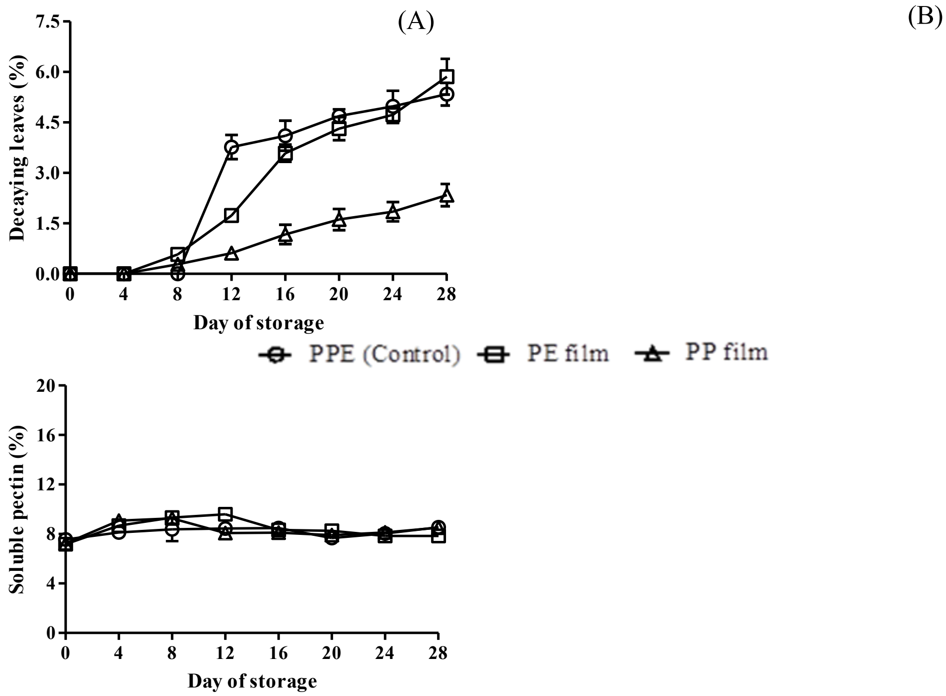

Figure 6. Decaying leaves (A) and soluble pectin (B) of seablite leaves kept in a tray covered with PPE film (control), PE film, and PP film during storage at 4ºC

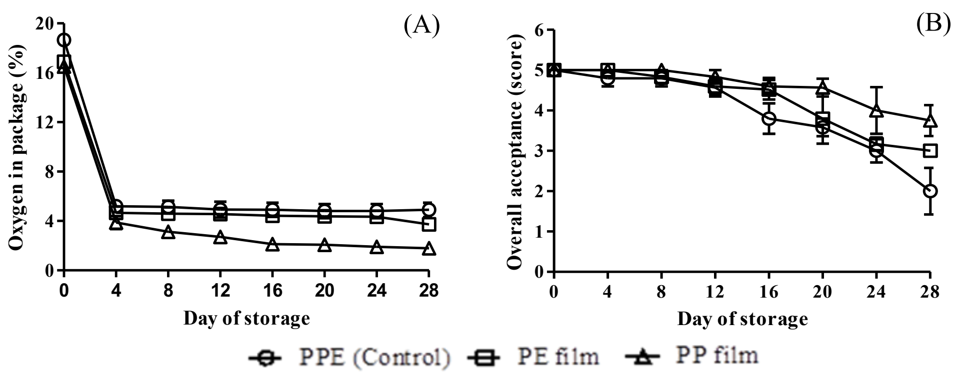

Figure 7. Oxygen concentrations in the atmosphere of packages (A) and overall acceptance (B) of seablite leaves kept in a tray covered with PPE film (control), PE film, and PP film during storage at 4ºC

Discussion

Cold storage is commonly used to slow the physiological and biochemical processes of fresh produce and microorganisms, leading to delay the deterioration and microbial spoilage. However, the optimal storage temperature varies depending on the type of produce and maturity stage (Dayarathna *et al*., 2023). Fresh produce stored at temperatures lower or higher than ideal may cause a shortened shelf life due to cell damage caused by chilling or heat injuries (Oliveira *et al*., 2015). Storing each type of produce at the appropriate low temperature is essential to maximize its shelf life. However, most tropical and subtropical produce are susceptible to low storage temperatures, which develop physiological disorders called chilling injuries and cause severe economic losses. Seablite commonly grows in tropical to temperate areas (Schenk and Ferren, 2001), and it may be sensitive to low storage temperatures. However, our experiment showed that the seablite leaves could be stored at 4ºC without chilling injury symptoms, and its storage life was extended to 24 days, whereas at 13ºC and 25ºC (control), it was 12 and 4 days, respectively. Thus, this result shows that at 4°C and 13°C, the extended storage life of the seablite was 6-fold and 3-fold compared to those of 25°C.

The extension of the storage life of seablite stored at 4°C in this experiment is due to the optimal low storage temperatures, which can slow the plant's respiration, ethylene production, metabolic, and transpiration rates, resulting in a decrease in weight loss and extending storage life. Cold storage reduces enzyme activity in the glycolytic and tricarboxylic acid pathways, leading to low carbon dioxide production (respiration rate) and transpiration (loss of water) (Wills *et al*., 2007). Delaying these metabolic processes not only reduces water loss but also helps maintain the quality of fresh produce (Gast, 1914). Similar results were reported that cold storage temperature could reduce the respiration rate, ethylene production, weight loss, and physical properties changes in pineapples (Rahmadhanni *et al*., 2020), cabbage (Kramchote *et al*., 2012), citrus (Rab *et al*., 2012), coconuts (Luengwilai *et al*., 2014), and pomegranates (Jadhav *et al*., 2019). Some study shows that the storage temperature of 4ºC was better than 10ºC for preserving the nutrients and reducing the respiration rate in minimally processed spinach (Akan, 2022).

The color of fresh produce indicates its freshness and nutritional quality. Yellow leaves of seablite are not an undesirable characteristic of customers. The yellowing of green leaves is involved with chlorophyll breakdown. The increase in storage temperature affected the increase in chlorophyll degradation rate and color degradation (Manolopoulou and Varzakas, 2016). This present study shows that seablite stored at 4°C had a lower value of b* (yellow/blue) than seablite stored at 13°C and 25°C, respectively. Furthermore, at 4°C, chlorophyll content could be maintained throughout storage. It means that the green color of seablite leaves is still retained. The report of Kramchote *et al*. (2012) also showed that the storage of cabbage at 4°C and 10°C significantly delayed leaf yellowing and maintained leaf chlorophyll content.

Cold storage delays fungal decay through several mechanisms, such as reducing fungal growth and reproduction by slowing down metabolic activities. This slowdown can significantly inhibit fungal development and decay (Rab *et al*., 2012; Mattick, 1951). This agrees with our result, which shows that the decay of seablite was delayed when it was stored at 4°C. In contrast, storage at 25 ºC (control) promoted leaf decay due to fungal mycelium observed on leaves after 4 days of storage. Pectin is a polysaccharide in plant cell walls that plays a role in plant cell adhesion and rigidity (Voragen *et al*., 2009). Our result found that the storage temperatures did not significantly affect the stability of the solution pectin content because the soluble pectin content was retained and stable throughout storage.

The quality of fresh produce is significantly influenced by the choice of packaging, which plays a crucial role in preserving the quality and quantity of the produce during storage. Proper packaging can create an environment that minimizes physical damage, regulates temperature and humidity, controls gas exchange, and protects against external contaminants (i.e., dust, dirt, and microorganisms) (Verghese *et al*., 2015). Our result showed that the respiration rate of seablite packed in PP films was lower than PE and PPE (control). The low rate of respiration can be explained by the fact that films like PP serve as practical gas barriers, preventing oxygen from the environment from entering the package (Caleb *et al*., 2013), thus leading to limiting the availability of oxygen for plant respiration. This is because if the film property, the oxygen permeability of PP film (622 cc.µm $m^{-2}d^{-1}kPa^{-1}$) is lower than low-density PE film (1,940 cc.µm $m^{-2}d^{-1}$ kPa^{-1}) (Hernandez, 1997).

Ethylene is a plant hormone that plays a significant role in regulating plant deterioration and senescence. Ethylene production of seablite in all types of packaging films ranged between 0.17-0.63 µL C_2H_4 kg^{-1} hr^{-1}, classified as a low level of ethylene production as same as cucumber, eggplant, pepper, and pumpkin. The ethylene production of these vegetables at 20°C ranges from 0.1-1.0 µL C_2H_4 kg^{-1} hr^{-1} (Kader, 2002). Seablite in all packaging films had low ethylene levels during storage; they were non significantly different throughout storage time. This result can explain that cold storage inhibits the activity of 1-aminocyclopropane-1-carboxylic acid synthase (ACS) and 1-aminocyclopropane-1-carboxylic acid oxidase (ACO), key enzymes in ethylene biosynthesis. A direct decrease in ethylene production results in a delay in the senescence of plant tissue (Wills *et al*., 2007).

The process of respiration can lead to water loss through transpiration. As water evaporates from the surface of the produce, the overall weight decreases. Thus, weight loss is directly related to the rate of respiration (Kochhar and Gujral, 2020). This finding is consistent with the result of this study; the lowest weight loss was observed in seablite stored in PP film. This can be attributed to in fact that PP film in this experiment was 55 µm, which is thicker than the 50 µm PE film. Furthermore, PP films also serve as a moisture barrier to prevent water loss from fresh produce (Mangaraj *et al*., 2009; Fellows, 2020). Leave color is an important indicator, especially during leaf senescence, such as leaf yellowing and decay during prolonged storage. It was found that PP film helped to slow down leaf yellowing and decay. Using films can create a modified atmosphere inside the package by limiting the oxygen concentration, resulting in the suppression of respiration and enzymatic degradation of the complex substances in fresh produce (Saltveit, 2003; Caleb *et al*., 2013). Moreover, all types of packaging films did not significantly affect the total chlorophyll content, antioxidant activity (DPPH), and soluble pectin content of seablite.

Conclusion: The appropriate storage temperature for fresh seablite leaves kept in PPE film was 4 ºC, which extended the storage life from 4 days at 25°C to 24 days. The optimal packaging film for seablite leaves was PP film when stored at 4ºC; extending its shelf life to 28 days. Proper packaging film and storage temperature could help to retard the respiration rate, reduce weight loss, and delay leaf yellowing and leaf decay, with no negative effects on the antioxidant activity and soluble pectin content of seablite leaves.

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