JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2025, VOL. 8(4), 507-520

Journal of Horticulture and Postharvest Research

Journal homepage: www.jhpr.birjand.ac.ir

University of Birjand

The optimal storage temperature for Ngoc Linh ginseng (*Panax Vietnamensis* Ha et Gush.)

Nhi Yen Dinh[1, 2], Da Uyen Tran Dao[3], Loan Thi Thanh Cao[4], Phu Hong Le [1,2] and Diep Thi Ngoc Tran[1,2,5,*]

1, School of Biotechnology, International University, Ho Chi Minh City, Vietnam; 2, Vietnam National University, Ho Chi Minh City, Vietnam; 3, Research Institute for Biotechnology and Environment, Nong Lam University, Ho Chi Minh City, Vietnam; 4, Faculty of Biological Sciences, Nong Lam University, Ho Chi Minh City, Vietnam; 5, Center for Innovation and Technology Transfer, International University, Ho Chi Minh City, Vietnam.

ARTICLE INFO

Original Article

Article history:
Received 1 January 2025
Revised 2 March 2025
Accepted 2 April 2025

Keywords:
Cold storage
Phytochemicals
Sensory evaluation
Shelf life

DOI: 10.22077/jhpr.2025.8570.1461
P-ISSN: 2588-4883
E-ISSN: 2588-6169

***Corresponding author:**
School of Biotechnology, International University, Ho Chi Minh City, Vietnam.

Email: ttndiep@hcmiu.edu.vn

ABSTRACT

Purpose: This study aimed to determine optimal storage conditions for preserving ten-year-old fresh Ngoc Linh ginseng (*Panax vietnamensis* Ha et Grushv.), a highly valued medicinal plant grown in the Ngoc Linh mountain region of Vietnam. Effective postharvest storage methods are important to maintain Ngoc Linh ginseng's quality and phytochemical integrity. **Research Method:** Ethylene production and respiration rates of Ngoc Linh ginseng were evaluated, followed by a preliminary investigation in the dry season to understand the impact of temperature on its quality and shelf life. Finally, subsequent experiments were implemented in both seasons to determine the optimal storage temperature. **Findings:** Ethylene production and respiration rates of the Ngoc Linh ginseng were consistently low in both the dry and rainy seasons. The ginseng experienced severe dehydration and fungal decay at room temperature, while storage at 0 °C led to chilling injuries. Higher temperatures of 10 °C and 15 °C accelerated the deterioration of the ginseng. In contrast, storage at 3 °C and 6 °C significantly extended the ginseng's shelf life. A follow-up experiment confirmed that 3 °C was the most effective for retaining freshness, skin brightness, visual sensory attributes, and total saponin content in Ngoc Linh ginseng in both seasons over 35 days. **Research limitations:** No limitations were identified. **Originality/Value:** This is the first study on extending the fresh storage of Ngoc Linh ginseng, a highly valuable herb of Vietnam. Identifying 3 °C as the optimal storage temperature provides a potential standard for fresh ginseng preservation and supports future research and commercial applications.

INTRODUCTION

Ngoc Linh ginseng (*Panax vietnamensis* Ha et Grushv.), an herbaceous perennial plant, was initially discovered in 1975 Ngoc Linh mountain of Vietnam, ranging from 14° 44' to 15° 13' latitude north and from 107° 45' to 108° 10' longitude east (Duc et al., 1996; Vu-Huynh et al., 2020). Ginseng contains numerous bioactive compounds standing out for their complex pharmacological properties attributed to their steroid-like structure (Ratan et al., 2021; Titova et al., 2024). Recent studies on Ngoc Linh ginseng have unveiled 52 types of distinct ginsenosides (Nguyen & Phuong, 2021; Tien et al., 2021). Ginsenosides might provide anticancer, immune-boosting, anti-inflammatory, antiallergenic, antiatherosclerosis, blood pressure-regulating, stress-relieving, and blood sugar-lowering effects, and positive impacts on metabolism and the central nervous system (Christensen, 2009; Tien et al., 2021), although clinical data are lacking.

Postharvest technology for Ngoc Linh ginseng has not been investigated. In the cultivation regions of Kon Tum and Quang Nam provinces, traditional methods involve drying Ngoc Linh ginseng to prevent spoilage. While drying extends shelf life and facilitates processing and commercialization, it also reduces water content, potentially changing the morphological, physiological, biochemical, and sensory qualities of the ginseng. This emphasizes the importance of developing postharvest methods that extend shelf life while maintaining product quality.

The lack of published literature providing guidelines for the fresh preservation of Ngoc Linh ginseng urges the need for research in this area. Critical physiological factors influencing postharvest quality and extending the shelf life of horticulture crops are respiration and ethylene rates (Dhall & Dhall, 2013; Wills & Golding, 2016; Kahramanoglu, 2023; Ali et al., 2024). Ethylene is a plant hormone central to the ripening and senescence of many fruits and vegetables (Saltveit, 1999; Pech et al., 2012; Kandasamy, 2022). However, ginseng is not a high ethylene-producing crop (Park et al., 2013), thus its physiological response to ethylene exposure might differ from climacteric fruits. Research on postharvest ethylene management in ginseng has shown that treatments such as 1-methylcyclopropene (1-MCP) effectively delay senescence and preserve freshness (Park et al., 2013). Similarly, using ethylene absorbents in packaging resulted in reducing sprouting and rotting in fresh ginger rhizomes while preserving sensory quality (Chung et al., 2010). Respiration has a significant impact on shelf life of harvested crops by determining the rate at which stored carbohydrates are converted into energy (Kahramanoglu, 2023; Ali et al., 2024). Since the respiration rate is affected by temperature, lowering the temperature reduces metabolic activity, respiration rate, and microbial growth, thereby extending shelf life and preventing spoilage (Eriko et al., 2001; Kandasamy, 2022). However, cold storage may result in chilling injuries, while higher temperatures accelerate the rate of spoilage in perishable commodities (Wills & Scott, 1971). Optimal temperature management is therefore essential to maintain postharvest quality.

The significance of temperature regulation in postharvest quality preservation has been extensively studied in various horticultural commodities. Research demonstrates that maintaining optimal low temperatures slows deterioration and extends shelf life (Mahangade et al., 2000). For instance, the optimal storage temperatures for Korean and American ginseng have been identified as 0 °C (Hu et al., 2014), 2 °C (Jeon & Lee, 1999; Gao et al., 2019), 4 °C (Jin et al., 2016), and 10 °C (Whang et al., 2008). Effective regulation of temperature and humidity is vital for maintaining the quality and prolonging the shelf life of perishable crops. While controlling humidity helps prevent moisture loss, temperature is the key factor due to its significant impact on metabolism, respiration, and microbial activity (Eriko et al., 2001; Ambuko et al., 2018; Cheng et al., 2023; Wu et al., 2024). Simultaneously conducting

experiments with multiple treatment factors would have required substantial quantities of Ngoc Linh ginseng, specialized equipment, and extensive analytical time. Therefore, determination of the optimal storage temperature was prioritized before implementing additional preservation methods, such as modified atmosphere packaging or controlled atmosphere storage.

In this study, the respiration rates, reflected by CO_2 production, and ethylene production rates of Ngoc Linh ginseng harvested in the dry season was first measured to evaluate its metabolic activity. Then, the effects of various storage temperatures, based on the studies on Korean and American ginseng was investigated. The study examined how low temperatures influence key quality parameters of Ngoc Linh ginseng, including skin color, freshness, fresh weight, and contents of phytochemicals. These preservation methods are critical for ensuring the quality and shelf life of Ngoc Linh ginseng, thereby supporting its value as a medicinal herb in Vietnam.

MATERIALS AND METHODS

Materials

Ngoc Linh ginseng materials

Ten-year-old Ngoc Linh ginseng, supplied by Dak To Forestry Co., Ltd in Kon Tum province, Vietnam, was cultivated on Ngoc Linh mountain (14°59'16" - 14°59'39" N, 107°54'25" - 107°54'52" E). The ginseng showed approximately 10 scars on the rhizome indicating its age, appearing fresh with green stems. Fresh weight correlated positively with diameter but not length, with rainy-season ginseng exhibiting higher fresh weight and larger middle rhizome diameters (Fig. 1). Harvested ginseng was packed in moistened, ice-lined boxes (~12 °C, ~90% RH) to prevent damage during transport to Ho Chi Minh city. At the laboratory, the ginseng was cleaned, dried with cotton linen, and prepared for experiments.

Chemicals

All chemicals used were of analytical grade and bought from the following companies: vanillin, Folin–Denis, 2,2-diphenyl-1-picrylhydrazyl-hydrate (DPPH), oleanolic acid, gallic acid from Sigma Aldrich (Germany); L-Ascorbic acid from Biobasic (Canada); sodium carbonate (Na_2CO_3), sodium chloride (NaCl), sulfuric acid (H_2SO_4, ACS reagent, 97%), ethanol (EtOH, 99.8%), methanol (MeOH, 99.9%), and acetic acid (CH_3COOH) by Xilong Chemical Co., Ltd (China). Deionized water was produced by automatic water stills (Aquatron, A4000D, UK) at The International University.

The equipment used for the experiments were F-950 three gas analyzer (Felix Instrument Applied Food Science, USA), three Aqua 90- liter AQR-D99FA BS fridges (Aqua, Vietnam), and 50-L SR-5KR fridge (Sanyo, Vietnam), the Elitech Temperature Data Logger - Version 6.2.0 (Elitech, USA), the JZ-300 Universal Color Meter (Shenzhen King Well Instrument, China), UV-Vis spectrophotometer (UVD-3500, Labomed, Los Angeles, CA, USA), a water bath shaker (MaXturdy 18 Daihan, Korea), a rotary evaporator (STRIKE 300), miller (IKA A11 Basic), a freeze dryer (FreeZone 6 Liter Benchtop System, Labconco Corporation, USA). They are in the Food Technology Lab and Biomedical Engineering Lab at The International University.

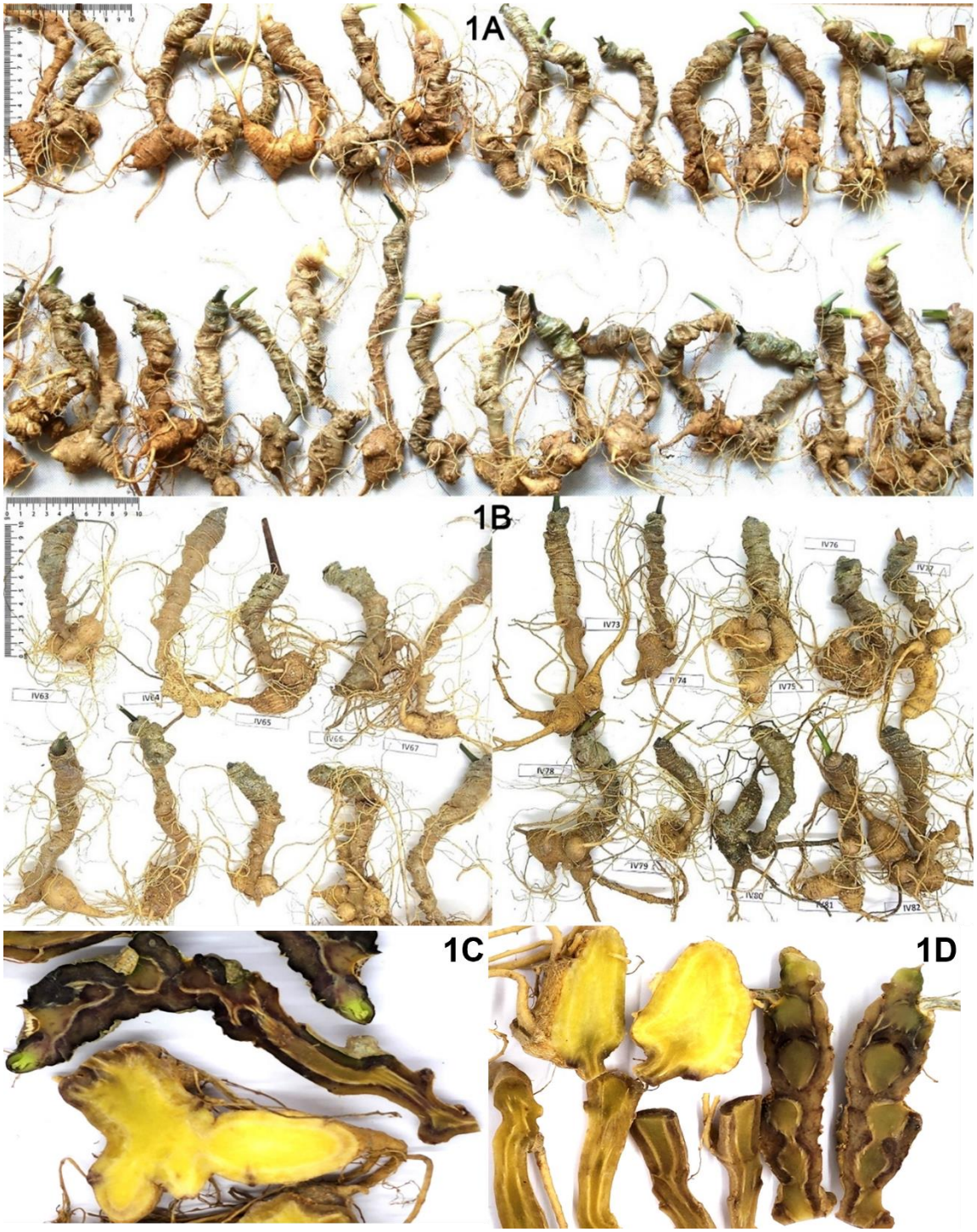

Fig. 1. Ngoc Linh ginseng one day after harvest in the dry season (1A) and in the rainy season (1B), used as materials for the experiments, has an average fresh weight, length, and middle rhizome diameter of 36.67 ± 7.9 g, 161.25 ± 24.33 mm, and 59.53 ± 9.16 mm (n = 32) in the dry season; and 43.93 ± 13.5 g, 164.08 ± 15.2 mm, and 68.58 ± 9.83 mm (n = 12) in the rainy season. The cross-sections of dry-season (1C) and rainy-season (1D) samples show the initial internal appearance.

Table 1. Temperature and relative humidity (RH) measurements at target temperature treatments.

Temperature	Replicate 1[a]		Replicate 2[a]		Replicate 3[a]		Average	
(°C)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)
0	0.03 ± 0.4[a]	23.01 ± 5.4[a]	0.02 ± 0.4[a]	23.72 ± 5.0[a]	0.01 ± 0.4[a]	23.78 ±4.4[a]	0.02 ± 0.4[a]	23.5 ± 4.9[a]
3	2.9 ± 0.4[b]	28.6 ± 3.8[b]	2.9 ± 0.4[b]	29.0 ± 5.6[b]	3.1 ± 0.5[b]	29.2 ± 4.5[b]	3.0 ± 0.4[b]	28.9 ± 4.7[b]
6	5.9 ± 0.6[c]	37.2 ± 4.3[c]	5.9 ± 0.7[c]	37.9 ± 6.4[c]	5.8 ± 0.5[c]	38.8 ± 4.5[c]	5.9 ± 0.6[c]	38.0 ± 5.2[c]
10	9.8 ± 0.7[d]	41.7 ± 10.8[d]	9.9 ± 0.7[d]	40.01 ± 5.1[d]	9.8 ± 0.7[d]	41.9 ± 6.6[d]	9.8 ± 0.7[d]	41.2 ± 7.9[d]
15	15.4 ± 0.4[e]	46.2 ± 7.8[e]	15.5 ± 0.5[e]	47.5 ± 6.1[e]	15.5 ± 0.5[e]	47.9 ± 2.4[e]	15.4 ± 0.5[e]	47.2 ± 5.9[e]
RT	29.8 ± 0.8[f]	74.4 ± 4.8[f]	29.8 ± 0.7[f]	73.0 ± 6.3[f]	30.0 ± 0.9[f]	73.8 ± 2.9[f]	29.9 ± 0.8[f]	73.7 ± 4.9[f]

[a] Within three replicates, no statistical differences (P<0.05) were observed in any of the evaluated temperature and relative humidity values according to The ordinary one-way ANOVA test. The results of each replicate were expressed at the mean and standard deviation of 150 – 200 times of measurement (1 hour each). Within each column, means followed by different superscript letters account for statistical differences (P < 0.05).

Methods

Determination of ethylene production and respiration rates

The experiments, adapted from Kandasamy (2022), measured respiration and ethylene evolution rates in Ngoc Linh ginseng using the F-950 Three Gas Analyzer. Three ginseng samples were placed in three separate 2-liter airtight jars while the control consisted of the empty sealed one. The measurements were taken three times a day at 7:00 AM, 12:00 PM, and 7:00 PM, following the F-950 trigger mode. Each experiment was replicated three times for consistency.

The preliminary investigation into the impact of various storage temperatures on the quality of Ngoc Linh ginseng in the dry season

As no prior documentation on the storage temperature for Ngoc Linh ginseng, a preliminary experiment was conducted using Ngoc Linh ginseng harvested during the dry season. The temperature range selected, from 0 to 15 °C, was based on published data for ginseng varieties (Jeon & Lee, 1999; Whang et al., 2008; Hu et al., 2014; Jin et al., 2016; Gao et al., 2019). The ginseng samples were stored in 50-L SR-5KR fridge set at 15°C and in Aqua 90 – L refrigerators at 10 °C, 6 °C, 3 °C, and 0 °C for which the corresponding relative humidity levels were maintained at about 47.2%, 41.2%, 38%, 28.9%, and 23.5%, respectively (Table 1). The Elitech Temperature Data Loggers - Version 6.2.0 were utilized to monitor and adjust the level of each refrigerator to achieve the desired temperatures. Weight loss, skin brightness, and visual sensory attributes of the ginseng samples were weekly recorded over a 28-day period.

Determination of the optimal storage temperature for Ngoc Linh ginseng in both seasons

Ngoc Linh ginseng, obtained from both the dry and rainy seasons, was subjected to storage in refrigerators at 3 °C and 6 °C, as identified from the above experiment. The control treatment involved storing the ginseng at room temperature (~30 °C, ~73.7% RH) (Table 1). The measurement of the fresh weight loss, the visual sensory evaluation, and total phytochemical components, including the total saponin content (TSC), the total polyphenol content (TPC), and the total antioxidant capacity (TAC) were conducted on Ngoc Linh ginseng stored at 3 °C, 6 °C, and room temperature after 7, 14, and 35 days of storage.

The loss rate of fresh weight in Ngoc Linh ginseng was recorded using an electronic scale, while sensory evaluation values, reflecting overall visual quality, were rated on a 1 to 9 scale, assessing freshness and smoothness of rhizome skin, stem and root. Color values (L, a, b) of the three parts of ginseng's rhizome (the top, the middle, and the base), were measured using a colorimeter. Methods for determining total phytochemical components (TSC, TPC, and TAC) and calculating quality parameters are detailed in our previous publication (Nguyen et al., 2023). The experiment was replicated four times.

All the experiments will be performed in replicates and listed details for each method. The statistical analysis was performed, and graphs were drawn using GraphPad Prism 9.5. The results are reported as mean ± standard deviation, and a P-value of <0.05 was considered statistically significant.

RESULTS AND DISCUSSIONS

Ethylene production and respiration rates of Ngoc Linh ginsengs

The ethylene production rate of Ngoc Linh ginseng one day after harvest was consistently low, ranging from 0.03 to 0.07 mg·kg·h^{-1}, with no significant variations observed at specific times of the day or between harvests during the dry and rainy seasons (Fig. 2). There has been limited published research on ethylene production in ginseng with the exception of one study on four-year-old fresh Korean ginseng (*Panax ginseng* C.A. Meyer), which found that ethylene production one day after harvest remained relatively low and stable, ranging from 0.3 to 0.6 mL kg.h^{-1} (approximately 0.34 mg kg.h^{-1} to 0.69 mg kg.h^{-1}) (Park et al., 2013). Compared to high ethylene-producing fruits like apples (*Malus domestica*) or tomatoes (*Solanum lycopersicum*) (Dhall & Dhall, 2013; Keller et al., 2013), Ngoc Linh ginseng exhibits minimal ethylene activity, suggesting that its postharvest quality may depend more on other storage factors.

Similarly, the respiration rate of Ngoc Linh ginseng, measured as CO_2 production, ranged from 24.6 to 34.8 mg CO_2·kg.h^{-1}, with no significant differences between seasons. Lower respiration rates in the early morning and late afternoon compared to midday were observed (Fig. 2). These findings are consistent with the respiration rates of other ginseng varieties. In particular, American ginseng had a respiration rate of around 23.4 mL kg.h^{-1}, equivalent to approximately 42.1 mg kg.h^{-1} (Jeon & Lee, 1999). Ngoc Linh ginseng's respiration rate, being lower than those of fruits and vegetables like tomatoes 120 mg·kg^{-1}·h^{-1}; (Kandasamy, 2022), reflects its inherently slower metabolic activity post-harvest. This characteristic could be advantageous for extended storage for Ngoc Linh ginseng, as slower metabolic activity generally leads to reduced deterioration rates in harvested crops (Eriko et al., 2001; Kandasamy, 2022; Kahramanoglu, 2023; Ali et al., 2024).

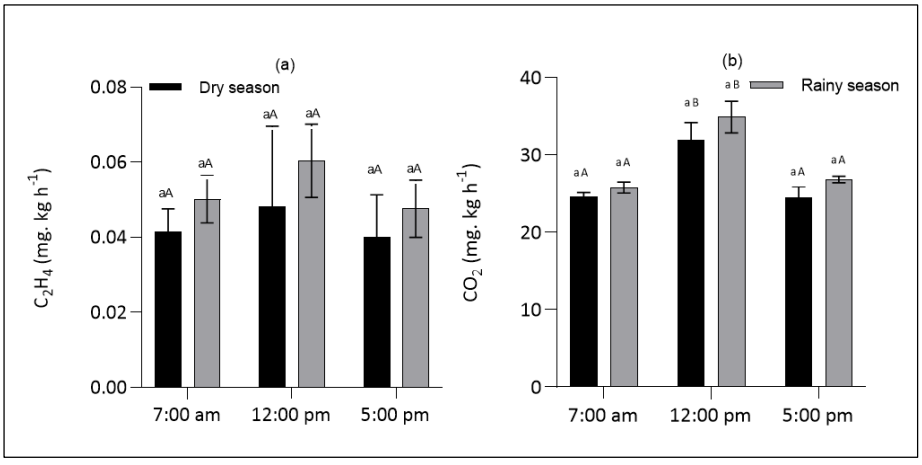

Fig. 2. Changes in the ethylene production rate (a), the respiration rate as CO_2 production (b) of Ngoc Linh ginseng harvested in the dry and the rainy seasons and assessed at specific times of one day after harvest. At each sampling time, means followed by the same letter within a season treatment are not significantly different ($P < 0.05$, n=3).

Preliminary investigation of the effect of different storage temperatures on the quality of Ngoc Linh ginseng in the dry season

The initial color values (L, a, and b) of the three parts of Ngoc Linh ginseng's rhizome (the top, the middle, and the base) were recorded to assess visual quality. Through observation and analysis, the a and b values of Ngoc Linh ginseng remained unchanged significantly across all conditions (data not shown). Therefore, the average L values of the three parts of ginseng's rhizome showing the brightness of Ngoc Linh ginseng's skin was the focus for analysis and depicted in Table 2. Initially, the L values averaged 46.9, representing a fresh appearance. By day 28, brightness had diminished at all storage temperatures and shown no significant differences among temperatures (Table 2).

Fresh weight loss rate increased steadily over the 28 days. Storage at 3 °C and 6 °C mitigated weight loss (13.8% and 19.1%, respectively) compared to higher temperatures (10 °C and 15 °C) and the lowest one (0 °C), which ranged from 25% to 28% (Table 2). Sensory evaluations corroborated these findings, as shown in Table 2. Specifically, ginseng stored at 3 °C and 6 °C maintained high scores, exhibiting minimal wrinkling and visual defects. In contrast, samples stored at 0 °C with the lowest score exhibited dryness, shriveling, and skin darkening (Fig. 3G). Lower storage temperatures typically decrease metabolic activity (Silip et al., 2022; Wu et al., 2024), but excessively low temperatures can cause chilling injury, as observed at 0 °C, emphasizing the sensitivity of Ngoc Linh ginseng (Fig. 3G). Strategies to extend the shelf life of horticultural crops often involve manipulating storage conditions to slow metabolism. Controlling temperature levels can significantly impact respiration rates, extending crops' post-harvest shelf life (Watkins, 2007; Kahramanoglu, 2023; Ali et al., 2024). For instance, fresh Korean ginseng (*Panax ginseng* C.A. Meyer) exhibited reduced respiration rates and ethylene production when stored at 4 °C (Park et al., 2013).

Determination of the optimal storage temperature for Ngoc Linh ginseng in both seasons

Room temperature storage (~30 °C) caused rapid quality deterioration for Ngoc Linh ginseng harvested in both seasons. By day 7, significant dehydration and fungal growth were observed, leading to complete shriveling and flesh rot by day 14 (Fig. 3A and 3B). In contrast, ginseng stored at 6 °C remained fresh for up to 14 days, with only minor stem browning. By day 35, moderate shriveling occurred in the top and middle rhizome sections, while the base remained relatively fresh (Fig. 3C and 3D). Storage at 3 °C yielded the best results. After 14 days, ginseng across all rhizome parts remained fresh, with green stems and no fungal symptoms. Even by day 35, minor shriveling was limited to the top and middle sections, while the base retained its firmness and closely resembled freshly harvested ginseng (Fig. 3E and 3F). This superior preservation at 3 °C is attributed to the suppression of metabolic activity without causing significant quality loss.

Fresh weight loss patterns of the samples supported these observations. Room temperature storage resulted in rapid weight loss, reaching 21.5% by day 14 and 37.2% by day 35 (Fig. 4). In comparison, ginseng stored at 3 °C and 6 °C exhibited significantly lower weight loss rates of 14.3% and 23.1%, respectively, underscoring the effectiveness of cold storage in minimizing moisture loss and maintaining product integrity. Skin brightness (L values) also declined over time but was better preserved at lower temperatures. By day 35, room temperature storage led to a 63% reduction in brightness, while samples stored at 6 °C and 3 °C showed reductions of only 16% and 5%, respectively (Fig. 4). Sensory evaluation scores aligned with these findings; with ginseng stored at 3 °C achieving the highest scores (7 to 8 points) after 14 days, compared to 3 points for room temperature storage. Even after 35 days, sensory scores for ginseng stored at 3 °C remained acceptable (6 points), whereas scores for 6 °C and room temperature dropped to 3 and 2, respectively.

Fig. 3. Skin and flesh changes in Ngoc Linh ginseng harvested in the dry (A, C, E, G) and rainy (B, D, F) seasons and stored at different temperatures: room temperature (~30 °C) for 14 days (3A and 3B); 6 °C for 35 days (3C and 3D); 3 °C for 35 days (3E and 3F); and Ngoc Linh ginseng harvested in the dry season and stored at 0 °C for 28 days (3G). The initial appearance of all ginseng samples was shown in **Figure 1**.

Prolonged exposure to low humidity exacerbates issues such as dry rhizome skin and tissue damage (Couey, 1982; Marangoni et al., 1996). Storage at 3 °C and 6 °C significantly reduced moisture loss and maintained skin brightness and visual sensory quality. These findings align with studies on Korean and American ginseng, which also demonstrate optimal storage between 3 °C and 6 °C (Jeon & Lee, 1999; Park et al., 2013; Hu et al., 2014; Jin et al., 2016; Gao et al., 2019).

Phytochemical components, including total saponin content (TSC), total polyphenol content (TPC), and total antioxidant capacity (TAC), were analyzed to assess the impact of storage temperatures on ginseng's medicinal value. Initially, the TSC of Ngoc Linh ginseng was approximately 168.45 mg/g dry weight (dw). Over 35 days, TSC decreased significantly at room temperature (51% reduction), while losses at 6 °C and 3 °C were limited to 24.2% and 18.8%, respectively (Fig. 5). Similar trends were observed for TPC, which decreased by 42.1%, 25.4%, and 22.7% at room temperature, 6 °C, and 3 °C, respectively. Although TAC decreased across all treatments, reductions were less observed at 3 °C (63.1%) compared to room temperature (68.5%) (Fig. 5).

Table 2. Changes in fresh weight loss rate, skin brightness, and visual sensory evaluation of Ngoc Linh ginseng stored at different cold temperatures after 28 days.

Storage temperature (°C)	Weight loss rate (%) [a]	Skin brightness (L)[b]	Sensory evaluation (Score)[c]
15	28.1 ± 1.9[a]	37.0 ±3.1[a]	2.2 ± 1.0[b]
10	26.2 ± 2.5[b]	34.9 ± 0.9[a]	4.2 ± 1.0[ad]
6	19.1 ± 1.4[c]	35.7 ± 2.7[a]	5.4 ± 0.2[a]
3	13.8 ± 3.1[d]	37.0 ± 1.8[a]	6.5 ± 0.2[ac]
0	25.2 ± 2.1[e]	33.4 ± 0.5[a]	3.3 ± 0.6[b]

At each index, means followed by the same letter within a temperature treatment are not significantly different ($P < 0.05$, n=4).
[a] Initial average fresh weight (g) = 37.07g ± 6.2 (n=20)
[b] Initial average skin brightness (L) = 46.9 ± 3 (n=20). L: 0 (dark) – 100 (brightness)
[c] Initial sensory average skin brightness expressed by the overall visual quality (score) = 8.8 ± 0.2. Score: 9 (excellent), 5 (fair), 1 (extremely poor).

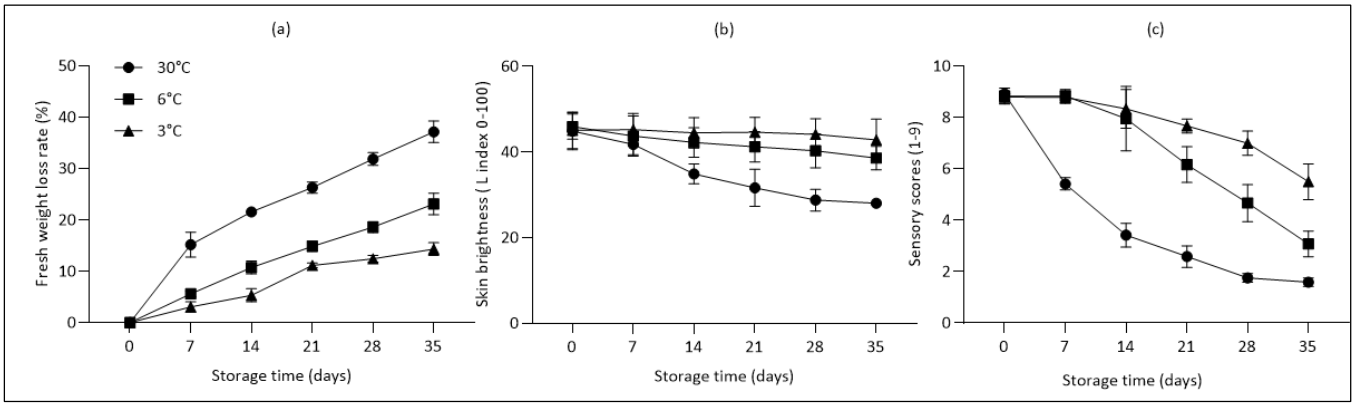

Fig. 4. Changes in fresh weight (a), skin brightness (b), and visual sensory evaluation (c) of Ngoc Linh ginseng stored at 3 °C, 6 °C, and room temperature (~30 °C) (n=8 on the first 28 storage days and n=4 on the day 35th).

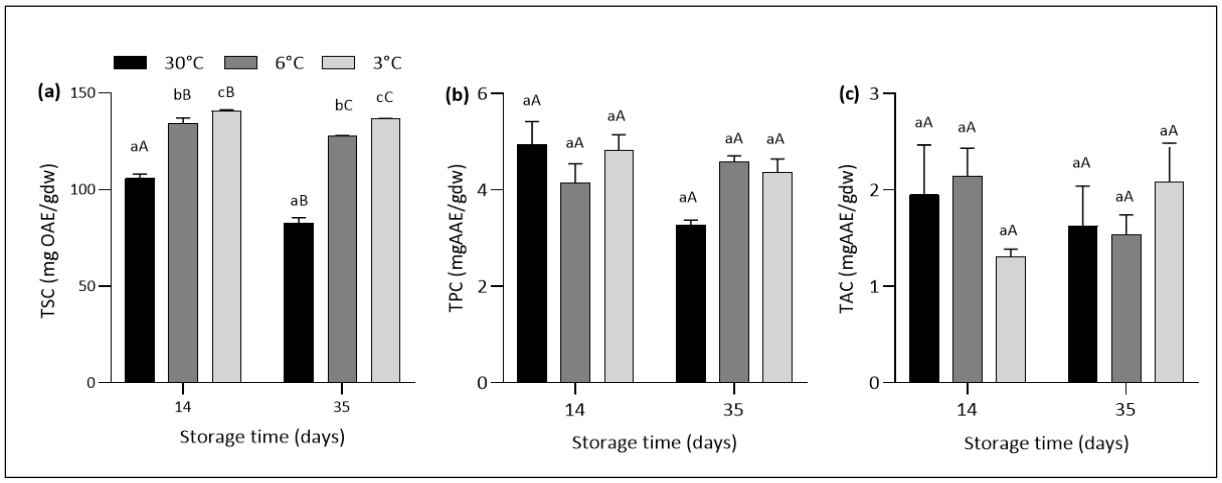

Fig. 5. Changes in total phytochemical components, including the total saponin content (TSC) (a), the total polyphenol content (TPC) (b), and the total antioxidant capacity (TAC) (c) of Ngoc Linh ginseng stored at room temperatures (~30 °C), 6 °C, and 3 °C. The initial values of TSC, TPC, and TAC were 168.45 mg/g dw, 5.66 mg/g dw, and 4.88 mg/g dw, respectively. The small letter shows the statistical difference in temperature factor while the capital letter shows the statistical difference in storage time factor ($P < 0.05$, n =4).

Preservation of phytochemicals at 3 °C is essential for maintaining the therapeutic efficacy of Ngoc Linh ginseng. Saponins and polyphenols contribute significantly to their antioxidant properties, critical for medicinal applications (Nguyen & Phuong, 2021; Tien et al., 2021). These findings are consistent with studies on Korean ginseng, where higher storage temperatures accelerated bioactive compound degradation (Park et al., 2013). The results demonstrate that storage at 3 °C effectively preserves the visual, sensory, and phytochemical qualities of Ngoc Linh ginseng. Compared to room temperature, which leads to rapid quality deterioration, 3 °C minimizes weight loss, maintains skin brightness and retains key bioactive compounds. Similar findings in other medicinal roots reinforce the importance of low-temperature storage (Chung et al., 2010).

CONCLUSION

This study emphasizes the importance of storing Ngoc Linh ginseng at an optimal cold temperature to minimize weight loss, maintain visual sensory quality, and avoid chilling injuries at 0 °C or rapid deterioration at higher temperatures. While humidity also plays a role in mitigating moisture loss, it was not included in this research because temperature regulation was prioritized as the fundamental step before integrating additional preservation methods, in which humidity will be a key focus.

Based on evaluations of phytochemical components, fresh weight loss, skin brightness, and sensory quality in both dry and rainy seasons, 3 °C is recommended as the optimal storage temperature. This conclusion was achieved through a stepwise experimental approach, beginning with a preliminary study, followed by experiments conducted across two harvest seasons, establishing a strong foundation for further postharvest research. However, weight loss averaged 14.3%, and saponin content declined by 18.8% after 35 days, with sensory scores around 6 points, indicating good but suboptimal market quality. Therefore, a combination of low storage temperature at 3 °C with other postharvest technologies, such as high humidity or modified atmosphere packaging, is recommended for future studies to improve the preservation and market readiness of Ngoc Linh ginseng.

Conflict of interest

No potential conflict of interest was reported by the authors.

Acknowledgments

The authors thank the International University and Research Institute for Biotechnology and Environment of Nong Lam University - Ho Chi Minh City for their valuable support in facilities during the accomplishment of this project. The author is deeply grateful to Dr. Randolph Beaudry, Professor in the Department of Horticulture at Michigan State University, for his valuable and insightful comments on the manuscript. Appreciation is also extended to Mr. Hoang Nhat Truong, PhD candidate at Chulalongkorn University, for capturing and editing the photographs of Ngoc Linh ginseng.

This work was supported by The Department of Science and Technology of Kon Tum Province in Vietnam under grant number 09/2020/HD-KHCN.

REFERENCES

Ali, S., Mir, S. A., Dar, B. N., & Ejaz, S. (Eds.). (2024). *Sustainable postharvest technologies for fruits and vegetables*. CRC Press. https://doi.org/10.1201/9781003370376

Ambuko, J., Wanjiru, F., Karithi, E., Hutchinson, M., Chemining'wa, G., Mwachoni, E., Hansen, B., Wasilwa, L., Owino, W., & Nenguwo, N. (2018). Cold chain management in horticultural crops value chains: Options for smallholder farmers in Africa. *Acta Horticulturae, 1225*, 85–91. https://doi.org/10.17660/ActaHortic.2018.1225.9

Cheng, Y., Gao, C., Luo, S., Yao, Z., Ye, Q., Wan, H., Zhou, G., & Liu, C. (2023). Effects of storage temperature at the early postharvest stage on the firmness, bioactive substances, and amino acid compositions of chili pepper (*Capsicum annuum* L.). *Metabolites, 13*(7), 820. https://doi.org/10.3390/metabo13070820

Christensen, L. P. (2009). Ginsenosides: Chemistry, biosynthesis, analysis, and potential health effects. *Advances in Food and Nutrition Research, 55*, 1–99. https://doi.org/10.1016/S1043-4526(08)00401-4

Chung, H. S., Lee, H. J., & Moon, K. (2010). Effects of ethylene absorbent on quality changes of fresh ginger rhizomes during modified atmosphere storage. *Korean Journal of Horticultural Science and Technology*, *28*(1), 82–88. https://koreascience.kr/article/JAKO201010102405064.page

Couey, H. M. (1982). Chilling injury of crops of tropical and subtropical origin. *HortScience, 17*(2), 162–165. https://doi.org/10.21273/HORTSCI.17.2.162

Dhall, R. K., & Dhall, R. K. (2013). Ethylene in post-harvest quality management of horticultural crops: a review. *Research & Reviews: A Journal of Crop Science and Technology*, *2*(2), 9–25. Retrieved from https://www.researchgate.net/publication/292151893

Duc, N. M., Kasai, R., Ohtani, K., Ito, A., Yamasaki, K., Nham, N. T., & Tanaka, O. (1996). New saponins from Vietnamese ginseng: Highlights on biogenesis of dammarane triterpenoids. In Waller, G. R., & Yamasaki, K. (Eds.), *Saponins used in traditional and modern medicine*. *Advances in Experimental Medicine and Biology* (Vol. 404, pp. 129–149). Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-1367-8_13

Eriko, Y., Keiko, T., Daisuke, H., Wenzhong, H., & Toshitaka, U. (2001, October). Effect of temperature on the respiration rate of some vegetables. *In IFAC Proceedings Volumes*, *34*(28) Tokyo, Japan. (pp. 205–210). Elsevier. https://doi.org/10.1016/s1474-6670(17)32849-5

Fugate, K. K., Suttle, J. C., & Campbell, L. G. (2010). Ethylene production and ethylene effects on respiration rate of postharvest sugarbeet roots. *Postharvest Biology and Technology*, *56*(1), 71–76. https://doi.org/10.1016/j.postharvbio.2009.12.004

Gao, K., Liu, Z., Chen, J., Chen, L., Qi, Y., Wang, Z., & Sun, Y. (2019). Effects of different substrates on low-temperature storage of fresh ginseng. *Journal of the Science of Food and Agriculture, 99*(14), 6258–6266. https://doi.org/10.1002/jsfa.9899

Hu, W. Z., Jiang, A. L., & Qi, H. P. (2014). Physiological behavior and quality of fresh ginseng stored in modified atmospheres generated by several package films. *Journal of Food Science and Technology*, *51*(12), 3862–3869. https://doi.org/10.1007/s13197-012-0922-6

Jeon, B. S., & Lee, C. Y. (1999). Shelf-life extension of American fresh ginseng by controlled atmosphere storage and modified atmosphere packaging. *Journal of Food Science*, *64*(2), 328–331. https://doi.org/10.1111/j.1365-2621.1999.tb15893.x

Jin, T. Z., Huang, M., Niemira, B. A., & Cheng, L. (2016). Shelf life extension of fresh ginseng roots using sanitizer washing, edible antimicrobial coating, and modified atmosphere packaging. *International Journal of Food Science and Technology*, *51*(9), 2132–2139. https://doi.org/10.1111/ijfs.13201

Kahramanoglu, I. (Ed.). (2023). *Postharvest physiology and handling of horticultural crops* (1st ed.). Boca Raton: CRC Press. https://doi.org/10.1201/9781003452355

Kandasamy, P. (2022). Respiration rate of fruits and vegetables for modified atmosphere packaging: A mathematical approach. *Journal of Postharvest Technology*, *10*(1), 88–102. Retrieved from https://www.researchgate.net/publication/358532606

Keller, N., Ducamp, M. N., Robert, D., & Keller, V. (2013). Ethylene removal and fresh product storage: A challenge at the frontiers of chemistry. Toward an approach by photocatalytic oxidation. *Chemical Reviews*, *113*(7), 5029–5070. https://doi.org/10.1021/cr900398v

Mahangade, P. S., Mani, I., Beaudry, R., Müller, N., & Chopra, S. (2020). Using amaranth as a model plant for evaluating imperfect storages: Assessment of solar-refrigerated and evaporatively-cooled structures in India. *HortScience*, *55*(11), 1759–1765. https://doi.org/10.21273/HORTSCI15249-20

Marangoni, A. G., Palma, T., & Stanley, D. W. (1996). Membrane effects in postharvest physiology. *Postharvest Biology and Technology*, *7*(3), 193–217. https://doi.org/10.1016/0925-5214(95)00042-9

Nguyen, T. H., & Phuong, T. T. (2021). Vietnamese ginseng (*Panax vietnamensis* Ha and Grushv.): Phylogenetic, phytochemical, and pharmacological profiles. *Pharmacognosy Reviews*, *13*(26), 59–62. https://doi.org/10.5530/phrev.2019.2.5

Nguyen, N., Nguyen, T., Le Hong, P., Ta, T. K. H., Phan, B. T., Ngoc, H. N. T., Bich, H. P. T., Yen, N. D., Van, T. V., Nguyen, H. T., & others. (2023). Application of coating chitosan derivatives (N,O–Carboxymethyl chitosan/chitosan oligomer saccharide) in combination with polyvinyl alcohol solutions to preserve fresh Ngoc Linh ginseng quality. *Foods*, *12*(21), 1–22. https://doi.org/10.3390/foods12214012

Park, M. H., Shin, Y. S., Kim, S. J., & Kim, J. G. (2013). Effect of 1-methylcyclopropene treatment on extension of freshness and storage potential of fresh ginseng. *Korean Journal of Horticultural Science and Technology*, *31*(3), 308–316. http://dx.doi.org/10.7235/hort.2013.12212

Pech, J. C., Purgatto, E., Bouzayen, M., & Latché, A. (2012). Ethylene and fruit ripening. In *Annual Plant Reviews Volume 44: The Plant Hormone Ethylene* (McManus M. T. Ed.), Wiley-Blackwell, Oxford, UK, 275–304. https://doi.org/10.1002/9781118223086.ch11

Ratan, Z. A., Haidere, M. F., Hong, Y. H., Park, S. H., Lee, J. O., Lee, J., & Cho, J. Y. (2021). Pharmacological potential of ginseng and its major component ginsenosides. *Journal of Ginseng Research*, *45*(2), 199–210. https://doi.org/10.1016/j.jgr.2020.02.004

Rosenfeld, H. J., Røed Meberg, K., Haffner, K., & Sundell, H. A. (1999). MAP of highbush blueberries: Sensory quality in relation to storage temperature, film type, and initial high oxygen atmosphere. *Postharvest Biology and Technology*, *16*(1), 27–36. https://doi.org/10.1016/S0925-5214(98)00102-1

Saftner, R., Polashock, J., Ehlenfeldt, M., & Vinyard, B. (2008). Instrumental and sensory quality characteristics of blueberry fruit from twelve cultivars. *Postharvest Biology and Technology*, *49*(1), 19–26. https://doi.org/10.1016/j.postharvbio.2008.01.008

Saltveit, M. E. (1999). Effect of ethylene on quality of fresh fruits and vegetables. *Postharvest Biology and Technology*, *15*(3), 279–292. https://doi.org/10.1016/S0925-5214(98)00091-X

Silip, J. J., Supramaniam, J., Mijan, S., Gobilik, J., & Elsabagh, A. S. (2022). The effect of hydro cooling time, storage temperature, and storage duration on Saba banana. *Journal of Physics: Conference Series*, *2314*(1). https://doi.org/10.1088/1742-6596/2314/1/012015

Tien, N. Q. D., Ma, X., Man, L. Q., Chi, D. T. K., Huy, N. X., Nhut, D. T., Rombauts, S., Ut, T., & Loc, N. H. (2021). De novo whole-genome assembly and discovery of genes involved in triterpenoid saponin biosynthesis of Vietnamese ginseng (*Panax vietnamensis* Ha et Grushv.). *Physiology and Molecular Biology of Plants*, *27*, 2215–2229. https://doi.org/10.1007/s12298-021-01076-1

Titova, M. V., Lunkova, M. K., Tyurina, T. M., Prudnikova, O. N., Popova, E. V., Klychnikov, O. I., Metalnikov, P. S., Ikhalaynen, Y. A., Vasileva, E. N., Rodin, I. A., & others. (2024). Suspension cell cultures of *Panax vietnamensis* as a biotechnological source of ginsenosides: Growth, cytology, and ginsenoside profile assessment. *Frontiers in Plant Science*, *15*, 1–15. https://doi.org/10.3389/fpls.2024.1349494

Vu-Huynh, K. L., Nguyen, H. T., van Le, T. H., Ma, C. T., Lee, G. J., Kwon, S. W., Park, J. H., & Nguyen, M. D. (2020). Accumulation of saponins in underground parts of *Panax vietnamensis* at different ages analyzed by HPLC-UV/ELSD. *Molecules*, *25*(13), 3086. https://doi.org/10.3390/molecules25133086

Watkins, C. B. (2007). The effect of 1-MCP on the development of physiological storage disorders in horticultural crops. *Stewart Postharvest Review*, *3*(2), 11. https://doi.org/10.2212/spr.2007.2.11

Whang, J. H., Yu, K. W., Park, S. S., Koh, J. H., Oh, S. H., Suh, H. J., & Lee, S. H. (2008). Prevention of quality changes in the cultured wild ginseng during storage. *Journal of the Korean Society of Food Science and Nutrition*, *37*(10), 1312–1317. https://doi.org/10.3746/jkfn.2008.37.10.1312

Wills, R. B. H., & Golding, J. (Eds.). (2016). *Advances in postharvest fruit and vegetable technology*. Boca Raton, Florida: CRC Press. https://doi.org/10.1201/b18489

Wills, R. B. H., & Scott, K. J. (1971). Chemical induction of low temperature breakdown in apples. *Phytochemistry*, *10*(8), 1783–1785. https://doi.org/10.1016/S0031-9422(00)86438-9

Wu, J., Tang, R., & Fan, K. (2024). Recent advances in postharvest technologies for reducing chilling injury symptoms of fruits and vegetables: A review. *Food Chemistry: X*, *21*, 101080. https://doi.org/10.1016/j.fochx.2023.101080

Zhang, J., Cheng, D., Wang, B., Khan, I., & Ni, Y. (2017). Ethylene control technologies in extending postharvest shelf life of climacteric fruit. *Journal of Agricultural and Food Chemistry*, *65*(34), 7308–7319. https://doi.org/10.1021/acs.jafc.7b02616