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OPTIMIZING THE TIMING OF ETHEPHON APPLICATION TO ENHANCE SUGAR CONTENT AND QUALITY OF EARLY-HARVESTED CANTALOUPE MELONS

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ABSTRACT

Melon (*Cucumis melo* L. var. *cantaloupensis*) is a climacteric fruit that is highly susceptible to postharvest deterioration. Although early harvesting can extend the shelf life of the fruit, it often results in lower sugar content and poorer flesh color. This study investigated the effects of ethephon and its application time on the sugar content and quality of early-harvested 'Red Aroma' cantaloupe fruits during storage. Fruits were treated with 100 ppm ethephon at 0, 3, 6, and 9 days after harvest or left untreated (control). For ethephon treatment, fruits were immersed in the solution for 1 minute and air-dried before storage under ambient conditions (28 ± 1 °C and 80 ± 5% RH) for 21 days. The results showed that ethephon application on day 6 after harvest significantly accelerated sugar accumulation (sucrose, fructose, and glucose) and enhanced flesh coloration, although it also accelerated flesh color degradation. This treatment maintained fruit quality for up to 12 days. Therefore, treatment with 100 ppm ethephon on early-harvested fruit 6 days after harvest is considered most effective in improving sugar content and overall quality of stored fruit.

Key words: *Cucumis melo*, postharvest treatment, storage, flesh color, shelf life

INTRODUCTION

Melon (*Cucumis melo* L.) is an agricultural commodity of high economic value and ranks fifth among the most important fruits in the world (Ortiz-Duarte et al. 2019). Of the various types of melons, cantaloupe is the most popular among consumers (Ayres et al. 2019). Andrade et al. (2022) describe the cantaloupe as having a reticulated skin and a strong aroma. Cantaloupe is classified as a climacteric fruit, making it particularly susceptible to postharvest damage (Amaro et al. 2018). This damage can result from various factors, including physiological, microbiological, chemical, and physical (Brackmann et al. 2014). Common issues include bruising, rotting, chilling or freezing injury, and surface shrinkage. These problems can occur in the field, during storage, and during distribution, significantly reducing commercial value of the fruit. Without proper protection, melons can deteriorate and rot approximately 10 days after storage at room temperature (Zhang et al. 2015).

Postharvest melon management strategies are crucial for achieving the highest quality and extending shelf life. Research by Wardani et al. (2025) indicates that cantaloupe harvested early, specifically 32 days after anthesis (DAA), 10 days before the recommended harvest date, has a longer shelf life

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than fully ripened fruit. However, early-harvested melons are often of lower quality, particularly in terms of sugar content, as their carbohydrates are primarily starch (polysaccharides) (Beaulieu & Lea 2007; Wardani et al. 2025). Furthermore, the flesh color of early-harvested cantaloupe is lighter than that of fully ripe melons, making them less appealing to consumers (Lignou et al. 2014). Consumers prefer cantaloupe with attractive flesh color, adequate moisture content, sweetness, a crisp texture, and a pleasant aroma (Park et al. 2018). The main sugars found in cantaloupe melons are sucrose (58.1%), fructose (25.6%), and glucose (17.5%), with a total soluble solids (TSS) content ranging from 11 to 12 °Bx (Beaulieu et al. 2003; Manchali et al. 2021). Therefore, it is necessary to implement strategies to improve the quality of early-harvested cantaloupe melons after harvest.

One effective technology for improving postharvest melon fruit quality is the use of ethylene. Ethylene is a plant hormone that accelerates fruit ripening. In climacteric fruits, ethylene ensures uniform ripeness and improves fruit quality. Mubarak et al. (2021) reported that ethylene increases carotenoid levels in cantaloupe, resulting in more attractive flesh colors. Controlling ethylene production and exposure can significantly affect the ripening process. Applying ethylene in postharvest treatments can effectively regulate this process. Ethylene concentration is crucial for achieving optimal fruit quality. Gao et al. (2021) reported that the optimal ethylene concentration for postharvest melon fruit treatment is 100 ppm. However, previous studies did not sufficiently consider the timing of ethylene application. Therefore, further research is needed to explore how ethylene application timing affects the postharvest quality of early-harvested melons. The timing should be evaluated primarily in relation to the climacteric peak period of cantaloupe. Therefore, the primary objective of this study was to determine the optimal timing for ethylene application to enhance postharvest quality of early-harvested cantaloupe.

MATERIALS AND METHODS

Plant material

Melon (*Cucumis melo* L. var. *cantaloupensis*) 'Red Aroma' was cultivated in a greenhouse in Jasinga, Bogor, Indonesia. Melons were harvested 32 days after anthesis, which was 10 days earlier than in previous studies. After harvest, the fruits were taken to the Department of Agronomy and Horticulture, IPB University, for laboratory analysis. Only undamaged melons of uniform size were selected for the study. The fruits were rinsed with 100 ml·L^{-1} sodium hypochlorite solution for decontamination. Subsequently, the melons were exposed to ethylene according to the assigned treatments and stored at room temperature (25–28 °C). Each treatment group contained approximately 30 fruits, divided into three replications of 10 fruits each.

Ethylene treatments

In this study, ethephon ($C_2H_6ClO_3P$) – Ethrel 480 SL (Bayer Indonesia) was used at 100 ppm as described by Gao et al. (2021). Melon fruits were divided into five groups: control (no ethephon application) and treated with 100 ppm ethephon applied 0, 3, 6, and 9 days after harvest (designated d0, d3, d6, and d9, respectively). In each treatment, fruits were immersed in the ethephon solution for 1 minute, air-dried, and then stored at room temperature (25–28 °C). The treated fruits were observed for 21 days after treatment to evaluate changes in postharvest quality.

Respiration rate and ethylene production measurements

Respiration rate and ethylene production were measured using the method described by Arif et al. (2023). Measurements were made using a gas analyzer (Merck Felix, type F-950). During the measurement, air was circulated in a sealed 6 L glass jar containing two whole melons and directed into the analyzer at an airflow rate of 70 mL·min^{-1}. Incubation period in the closed jar was 60 minutes. Respiration rate was expressed in mL CO_2 per kg per hour, and ethylene production in ppm C_2H_4 per kg per hour.

Total soluble solids and sugar content measurements

Total soluble solids (TSS) were measured in triplicate cantaloupe juice extracts using an Atago DR-A1 digital refractometer (Atago, Japan) at 28 ± 1 °C, following the method proposed by Arif et al. (2023). TSS results were expressed in degrees Brix (°Bx). To measure sugar content (glucose, fructose, and sucrose), the method described by Arif et al. (2023) was used. A 5 g sample of cantaloupe was taken and 20 ml of distilled water was added. The mixture was stirred with ultrasonically for 30 minutes, then filtered using a microfilter. The resulting supernatant was analyzed using a Dionex Ultimate 3000 high-performance liquid chromatograph (HPLC). Glucose, fructose, and sucrose contents were expressed as percentages.

Flesh color measurements

Color was measured according to the method described by Arif et al. (2023), with slight modifications. Analysis was performed in three fruit sections (base, equator, and tip) using a CR-400 chromameter (Minolta, Japan) calibrated on a white field. Cantaloupe rind and flesh color was expressed as L*, a*, b*, and hue values. Averages were then calculated.

Weight loss and softness measurements

Fruit weight loss was calculated using the method proposed by Arif et al. (2023). The percentage weight loss was determined using the following formula:

$$\text{weight loss} = (\text{weight before storage} - \text{weight after storage})/(\text{weight before storage}) \times 100\%.$$

Fruit softness testing was conducted using the method described by Sun et al. (2017). A Stanhope-SETA penetrometer with a total load of 152.5 g, was used, consisting of a 102.5 g cone and a 50 g weight. A 2 mm probe was used for puncturing for 10 seconds. Measurements were taken by inserting the penetrometer needle into the base, middle, and tip of the fruit. To calculate softness (mm per g per s), the penetration depth of the penetrometer needle was recorded, and the following formula was applied:

$$r \times 0.1\ M \times T;$$

where r is the average penetration depth of the penetrometer needle; M – weight of the load; T – penetration time of the penetrometer needle.

Titratable acidity and vitamin C measurements

To measure total acidity (TA), the extract was titrated with 0.1 N NaOH (Arif et al. 2023) and expressed as percent malic acid equivalent (68 equivalent weight). The formula for calculating the TA of cantaloupe is as follows:

$$TA = \frac{V_{NaOH} \times Fp \times 0{,}1\ N \times EW}{\text{Sample weight (g)}} \times 100\%;$$

where V_{NaOH} – volume of NaOH (ml), Fp – dilution factor, EW – equivalent weight of malic acid.

Vitamin C content was assessed using the method described by Ismillayli et al. (2020). First, cantaloupe flesh was mashed to obtain juice, which was then filtered through a cloth. A 10 g sample of juice was transferred to a 100 ml Erlenmeyer volumetric flask. Three drops of starch indicator solution were added, and the mixture was titrated with 0.01 N iodine until a stable dark blue color was obtained. In the vitamin C formula, the equivalent weight (EW) refers to the predominant acid in vitamin C – ascorbic acid (Ismillayli et al. 2020). The ascorbic acid equivalent weight is 0.88.

Data analysis

Data were examined using one-way analysis of variance for each storage day. Significant differences between treatments were determined using Duncan's multiple range test (DMRT) at a 5% significance level. Statistical analyses of data were performed using SAS Portable version 9.1.3. Data were presented as the mean of three replications.

RESULTS AND DISCUSSION

Respiration rate and ethylene production

One of the key factors determining fruit shelf life is respiration rate and ethylene production. Ethylene is the primary hormonal trigger for ripening in climacteric fruits such as melons. In this process, both ethylene-dependent and ethylene-independent regulatory pathways interact to regulate ripening. Certain physiological processes during ripening are ethylene-dependent, while others are independent or highly sensitive to low ethylene levels. For instance, in many fruits, including melons, ripening is characterized by a temporary increase in respiration rate and an autocatalytic increase in ethylene production. Specific processes, such as climacteric respiration, stalk abscission zone formation, skin yellowing, and carotenoid content in Charentais cantaloupe melon (‘Védrantais’), are ethylene-dependent (Nuñez-Palenius et al. 2007; Flores et al. 2008). Furthermore, membrane damage and volatile compound synthesis are also partially dependent on ethylene (Nuñez-Palenius et al. 2007; Flores et al. 2008).

Melons treated with 100 ppm ethephon at the beginning of storage (day 0) and on day 3 exhibited an earlier and sharper peak in respiration rate, occurring on days 15 and 9 of storage, respectively (Fig. 1A). In contrast, treatments applied on days 6 and 9 resulted in a delayed and prolonged climacteric phase (Fig. 1A).

Melons treated with ethephon generally produced more ethylene than the control (Fig. 1B). Notably, fruits treated at the beginning of storage (d0–d6) exhibited significantly higher ethylene production compared to untreated fruits. After day 6, both parameters increased markedly, indicating the initiation of ripening processes, which improved fruit quality.

The sharpest increase in ethylene levels was observed in untreated fruit and in fruit treated with ethephon on days 0 and 3 (Fig. 1B). Controlled application of ethylene can modulate respiration, delay starch degradation, and promote the development of desirable flavor attributes while maintaining an acceptable sweetness, thereby extending postharvest longevity (Tipu & Sherif 2024). Consequently, application of 100 ppm ethephon on day 6 was considered optimal for moderately increase ethylene production and respiration in postharvest cantaloupe during storage.

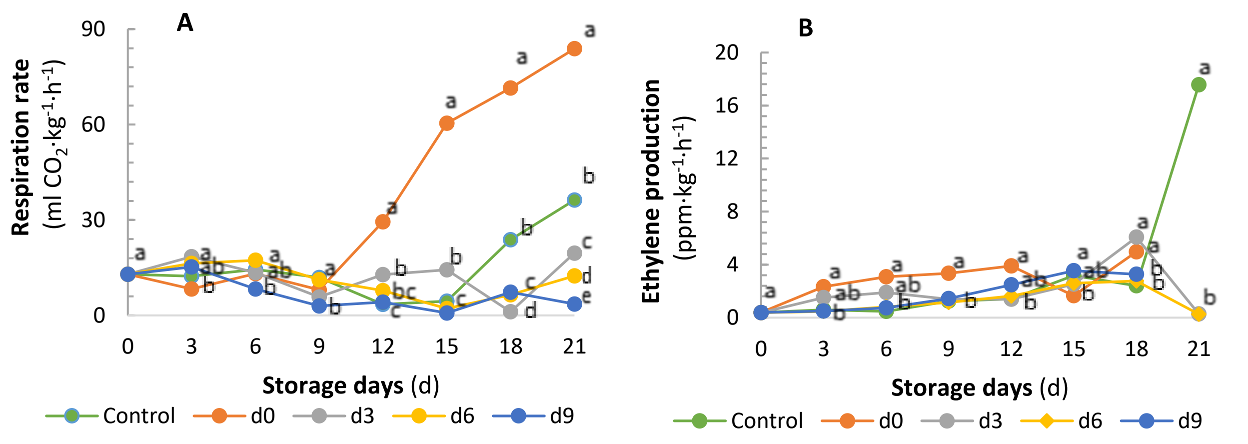

Figure 1. Changes in respiration rate (A) and ethylene production (B) in cantaloupe during the storage
Data are means of three replicates; Different letters on the same day indicate significant difference by Duncan’s multiple range test ($P < 0.05$)

Total soluble solids and sugar content

Total soluble solids (TSS) content in cantaloupe fruits increased during storage, as shown in Figure 2A. All treatments showed an increase, but the control and day 9 showed the least (Fig. 2A). Values increased most on day 14 and then decreased. Sucrose content in cantaloupe fruits followed a similar trend as TSS. The greatest increase was observed in fruits treated on day 6, followed by day 3. In all treatments, sucrose increased rapidly until day 14 of storage and then decreased. (Fig. 2B). Melons treated with ethephon also showed an increase in fructose and sucrose content during storage (Fig. 2C–D), with the highest content recorded after treatment on day 6.

Climacteric melons are fruits that can continue ripening after harvest but cannot increase TSS unless they are treated to induce it (Kader 1999). Exogenous ethylene can increase TSS content. TSS is a crucial indicator of fruit quality and consumer acceptance (Arif et al. 2023). In this study, the TSS and sugar content of cantaloupe was found to increase during storage (Fig. 2). The contents of TSS, sucrose, fructose, and glucose showed the highest level in treatment d6. This increase can occur because exogenous ethylene applied at the beginning of storage allows starch to be metabolized more quickly into sugars, thus accelerating the accumulation of soluble solids. Based on studies by Ezzat (2002) and Lucchetta et al. (2014), the decrease in TSS in cantaloupe fruit at the end of storage occurred because the fruit used sugar to support aerobic respiration and senescence.

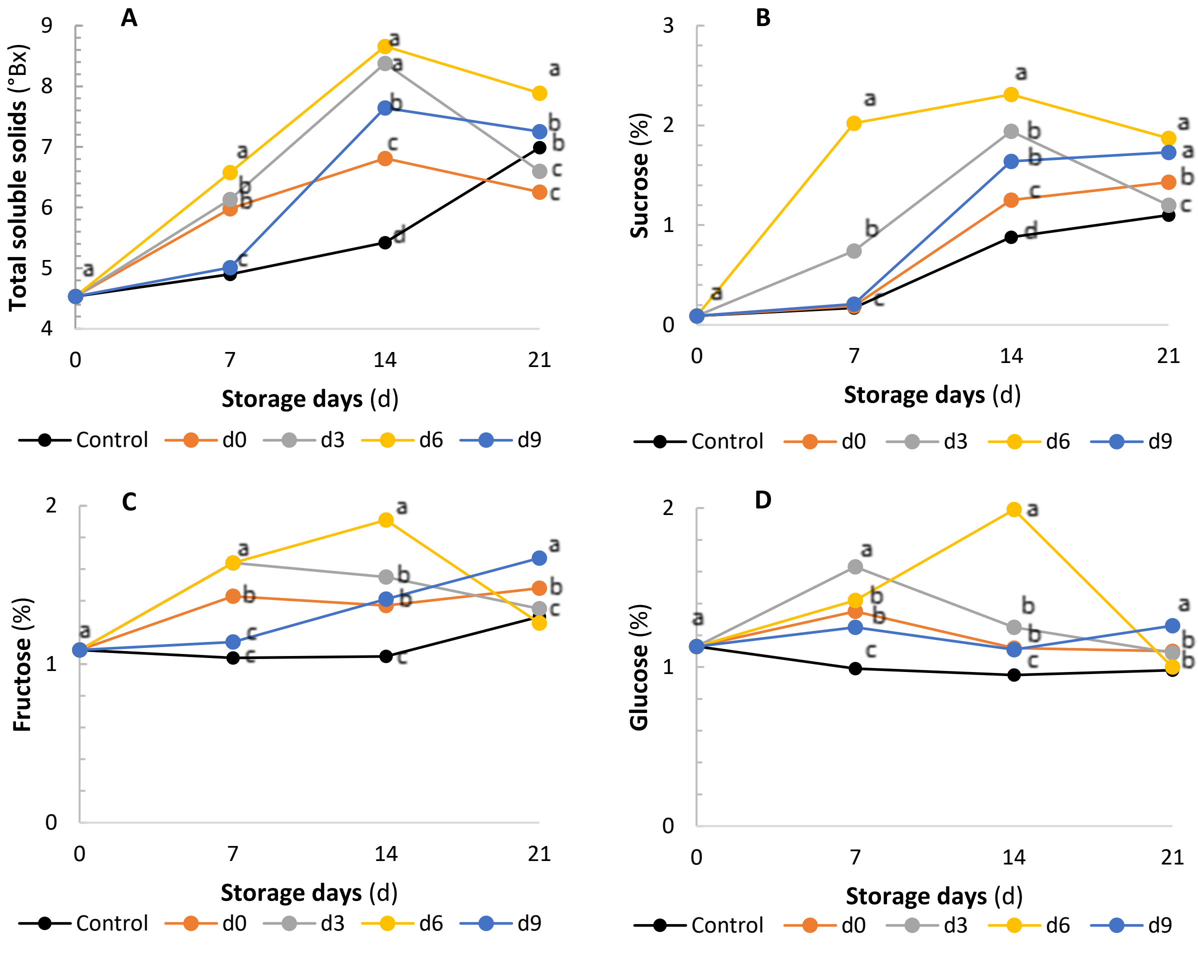

Figure 2. Changes in total soluble solids (A), sucrose (B), fructose (C), and glucose (D) in cantaloupe during the storage
Note: see Figure 1

The main components of the soluble sugar fraction in ripe melon fruit are sucrose, glucose, and fructose. The sugar content of cantaloupe melons at harvest is 23.23–61.40 mg·g^{-1} (Manchali et al. 2021). Other climacteric fruits, such as tomatoes, exhibit a 1.5% increase in total sugar content during the transition from green to red ripeness phase (Sammi & Masud 2007). During storage, mango fruit can experience an increase in total sugar content of up to 28.55% (Lamba et al. 2020). This increase in total sugars is influenced by ethylene, a key factor in the ripening process. According to Gao et al. (2021), exogenous ethylene can increase the sucrose content of the fruit. In this study, the sucrose content of melon fruit in the d6 treatment reached 2.17%, which is 12 times greater than in the control. Applying ethylene to fruits approaching the climacteric peak (after 6 days of storage) can boost the production of both endogenous sucrose and ethylene. Gao et al. (2021) noted that the increase in sucrose content is associated with the expression of the *CmSPS1*, *CmACO1*, and *CmMYB44* genes, which are activated by the regulatory activity of the enzymes sucrose synthase (SS) and sucrose phosphate synthase (SPS). Furthermore, Braun et al. (2014) reported that sucrose serves as a carbon and energy source for the construction of metabolic structures supporting plant growth and development and plays a crucial role in improving the taste quality of melon fruit. Daryono and Genesiska (2012) emphasized that sucrose accumulation mainly contributes to taste quality by increasing the total sugar content of the fruit.

In this study, fructose and sucrose contents in melon fruit increased during storage. Overall, fructose accumulation was lower than sucrose during growth and either decreased or remained unchanged during ripening. The average sucrose content in mesocarp tissue was 58.1%, glucose content 17.5%, and fructose 25.6% (Beaulieu et al. 2003). This trend occurs because fructose accumulation takes place early in fruit development, when the fruit is still immature, and is then converted to sucrose. As a result, sucrose becomes the dominant sugar in ripe fruit (Ofosu-Anim & Yamaki 1994; Villanueva et al. 2004). The increase in glucose content during cantaloupe storage was not as pronounced as the increase in sucrose content. This finding is consistent with the study by Schaffer et al. (1987), in which they indicated that during ripening, the rise in sugar content is primarily due to sucrose accumulation, whereas the increases in glucose and fructose are relatively minimal. The increase in glucose in cantaloupe depends on the sucrose content. Furthermore, exogenous ethylene application can increase sucrose content and boost glucose and fructose levels. According to Yu et al. (2024), in strawberries, the enzyme β-fructofuranosidase catalyzes the breakdown of sucrose to fructose and glucose in fruit cells. Glucose availability in the metabolic process activates the enzyme phosphoglucomutase, whose activity can be stimulated by ethylene. Phosphoglucomutase converts UDP-glucose to glucose-6-phosphate *via* α-D-glucose-1-phosphate, which is then converted to glucose.

Flesh color

The lightness (L*) of melon flesh gradually decreased throughout the storage period, also in the control (Fig. 3A). Application of ethephon at 100 ppm accelerated the decrease in lightness compared with the control. Among the treatments, ethephon application on day 6 caused the smallest decrease in lightness during storage. In contrast, the redness (a*) value of melon flesh increased as storage progressed (Fig. 3B). Treatments applied on days 0, 3, and 6 (d0, d3, and d6) exhibited significantly higher redness after 7 days of storage compared with the control and treatment d9. These results indicate that ethephon at 100 ppm enhanced the color development in melon flesh, making it appear more orange or reddish. Similarly, the yellowness (b*) value was most pronounced at 7 days of storage in all ethephon-treated fruits, ranging from 12.97 to 20.78 (Fig. 3C). The hue angle (h°) of melon flesh showed a steady decreasing trend starting from day 7 of storage (Fig. 3D), except for d3 and d9. Control fruits had a higher hue angle than ethephon-treated fruits, while d6 treatment fruits showed the greatest reduction in hue angle, up to 8.89.

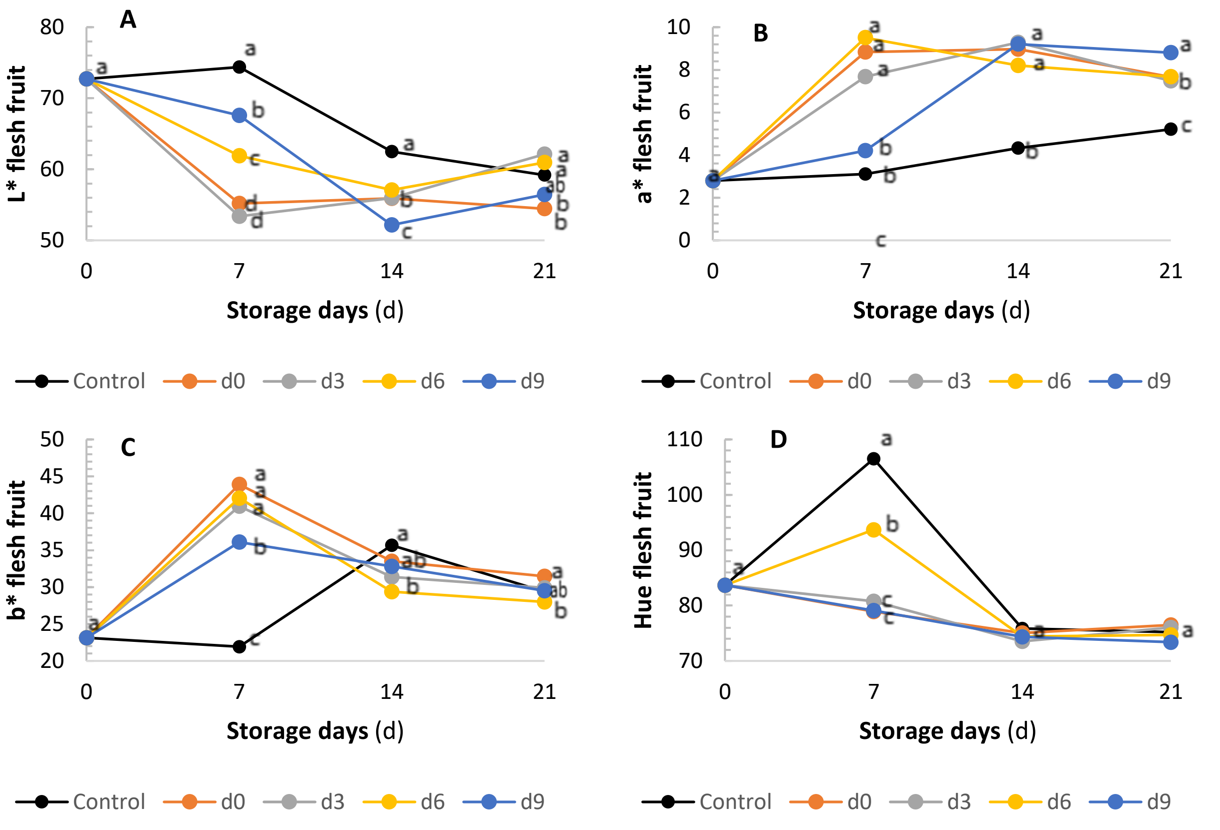

Figure 3. Changes in lightness – L* (A), redness – a* (B), yellowness – b* (C), and hue (D) in the color of cantaloupe flesh during storage
Note: see Figure 1

Fruit color is a key attribute influencing consumer preferences. During ripening, changes in both rind and flesh pigmentation contribute to the overall color development of the fruit (Penchaiya et al. 2020). Fruit hue generally decreases with increasing storage time. In this study, melons treated with ethephon on day 6 of storage (d6) showed the smallest reduction in hue value among all treatments. Ethephon application significantly affected flesh hue, with the day 6 treatment at 100 ppm proving the most effective in reducing hue. This treatment resulted in a noticeable change in the flesh color from yellow to orange.

The hypothesis is that applying ethephon at 100 ppm on day 6 of storage is optimal because the fruit is then approaching its climacteric peak. According to Wardani et al. (2025), early-harvested cantaloupe typically reach their climacteric peak around the day 8 after harvest. The change in flesh color from yellowish to orange in climacteric fruits during storage is primarily determined by both endogenous and exogenous ethylene. Paul et al. (2012) reported that exogenous application of ethylene in cantaloupe accelerates the degradation of flesh tissues and increases internal ethylene production, accelerating ripening.

In this study, the lightness (L*) value of melon flesh decreased during storage. This decrease indicates the progression of fruit ripening, as the flesh color of ripe fruit typically becomes deeper and less vibrant. This result is consistent with the findings of Vanoli et al. (2023), who observed a decrease in L* value corresponding to an increase in fruit ripeness. Similarly, Kasim and Kasim (2014) explained that the decrease in L* after several days of storage is due to the change in the color of the melon flesh from light green to yellow-orange. Therefore, the application of ethephon at 100 ppm on day 6 is recommended to improve the color development of cantaloupe melon during storage.

Weight loss and softness

Weight loss is a key factor in fruit storage because it affects their visual quality and marketability (Ribeiro & de Freitas 2020). Melon fruits lose water during storage through respiration and evaporation. This respiration process requires energy from the breakdown of starch, amino acids, pectin, and other compounds. Consequently, faster respiration and ethylene production lead to greater weight loss (Kowitcharoen et al. 2018). In this study, weight loss of melon fruits increased with longer storage (Fig. 4A). However, melons treated with ethephon on day 6 (d6) exhibited less weight loss than other treatments, with a reduction of approximately 2–6%. Overall, the weight loss of cantaloupe remained below 15%, indicating relatively good postharvest stability. The application of exogenous ethylene accelerates the degradation of cell wall components because covalently bound pectin is converted into water-soluble pectin. This process intensifies the decomposition of hemicellulose and cellulose and breaks the ionic bonds in pectin, which causes the fruit to soften and increases water loss (Yan et al. 2023; Wang et al. 2024).

As one of the primary postharvest quality parameters, fruit softness significantly influences shelf life and consumer acceptance. Ethylene plays a crucial role in fruit softening and firmness by activating cell wall-degrading enzymes, such as polygalacturonase, which hydrolyzes pectin in the cell wall, thereby contributing to softening. Melon fruits experience a decline in fruit firmness associated with ripening and a dramatic increase in internal ethylene (Rose et al. 1998). Increased fruit softening during storage occurs because melon fruits are stimulated by ethylene during storage, so softening can increase with increasing ethylene concentration (Cocco et al. 2022). In this study, cantaloupe fruit softness increased during storage in all treatments (Fig. 4B). Melon fruits softness increased after day 7 of storage, with the greatest increase noted in the group not treated with ethylene or treated on day 3. In contrast, the slowest increase in softness occurred in fruits treated with ethylene on days 6 and 9. Therefore, treatment with ethephon at 100 ppm on day 6 and under control conditions can result in less weight loss and maintained firmness of melon flesh with improved quality.

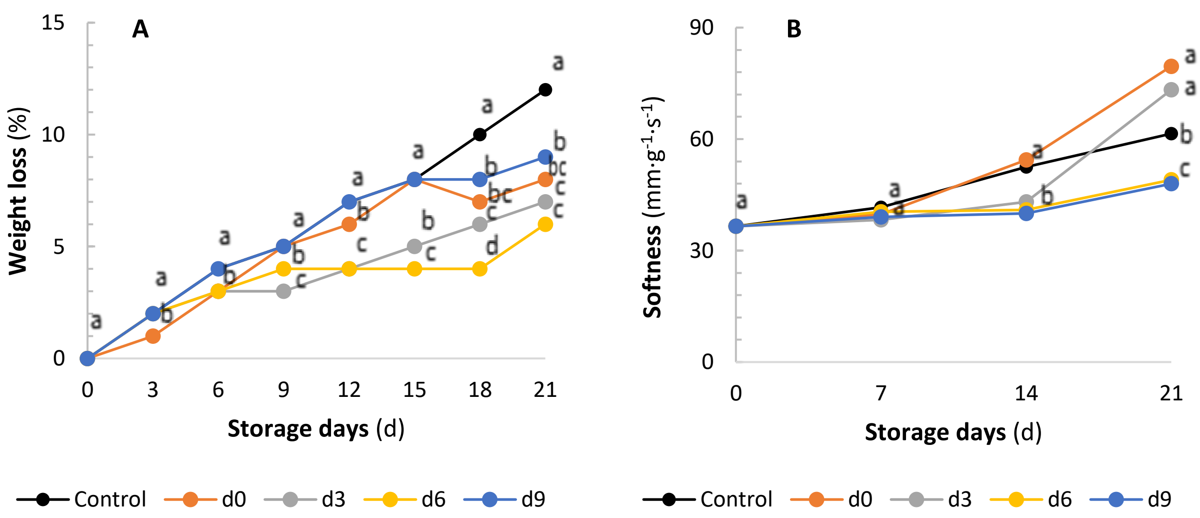

Figure 4. Changes in weight loss (A) and softness (B) of cantaloupe during storage
Note: see Figure 1

Titratable acidity and vitamin C

TA and vitamin C content are important indicators of fruit quality. In this study (Fig. 5), both TA and vitamin C contents of melon fruit generally decreased during storage in all treatments. Notably, melon fruits in the d6 treatment exhibited the lowest TA throughout the storage period (Fig. 5A). However, the d6 treatment retained higher vitamin C content than the other treatments during storage (Fig. 5B).

The decrease in TA suggests ongoing respiratory activity, in which organic acids are metabolized to produce sugars and other compounds. As ethylene production increases, sugar accumulation typically increases, while TA decreases. The higher ethylene levels observed in the d6 treatment may have accelerated ripening, thereby enhancing sugar content and decreasing TA. According to Arif et al. (2022), the conversion or utilization of organic acids during respiration contributes to the decrease in TA during storage. Similarly, TA often increases in the early ripening stage but decreases as the fruit approaches full ripeness (Gebregziabher et al. 2021). Moreover, Cocco et al. (2022) reported the application of exogenous ethylene can reduce TA in climacteric fruits by accelerating ripening and promoting sugar accumulation.

Vitamin C is susceptible to oxidation during storage (Arif et al. 2023). It is susceptible to oxidative stress and is rapidly absorbed as a key antioxidant. It neutralizes reactive oxygen species (ROS) produced during active respiration and ethylene-induced ripening. By limiting ROS, it delays senescence (Razzaq et al. 2015). Application of ethephon on day 0 (d0) and day 3 (d3) induced an earlier climacteric response, as evidenced by accelerated respiration rates and ethylene production. Early stimulation of ripening and premature increase in ethylene production likely could have increased oxidative metabolism and respiratory activity earlier in storage, thereby increasing ascorbic acid degradation, leading to a more rapid depletion of vitamin C stores by day 14. Consequently, only a relatively small increase or stabilization of vitamin C content was observed at later stages of storage (days 14 and 21), which can be explained by the timing of ethephon application in relation to the physiological phase of the fruit (Fig. 5B).

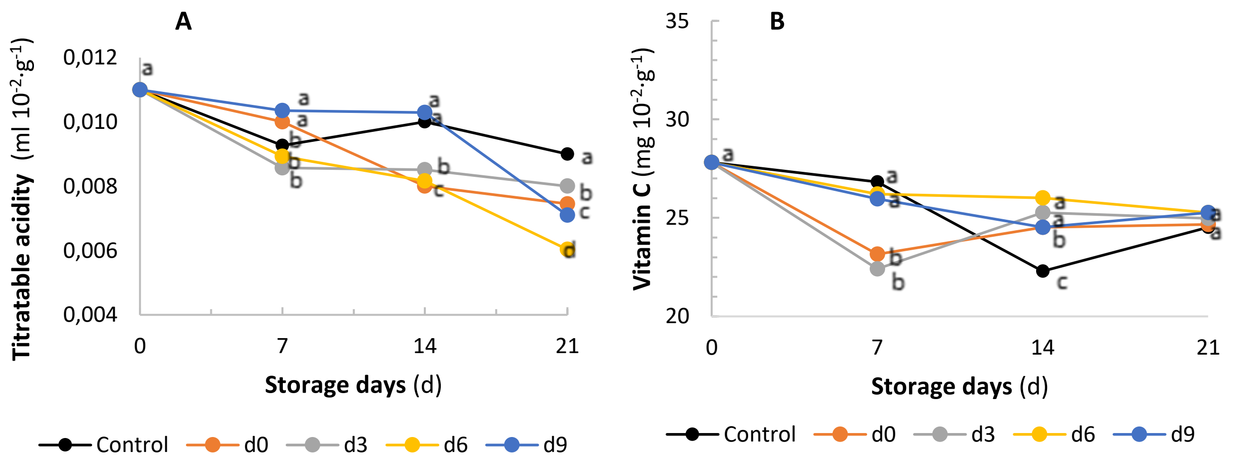

Figure 5. Changes in titratable acidity (A) and vitamin C (B) in cantaloupe during the storage period
Note: see Figure 1

In contrast, fruits from the d6 treatment retained higher levels of vitamin C during storage than those from the other treatments (Fig. 5B). In the d6 treatment, the later application of ethephon helped the fruit maintain lower metabolic activity during the first part of storage, which reduced oxidative stress and maintained higher ascorbic acid levels. When ethephon was applied near the peak of the climacteric phase, the ripening process began more synchronously with the fruit's natural ripeness, helping to retain more vitamin C during longer storage. For other self-ripening fruits, such as climacteric fruits, waiting some time before exposing them to ethylene helps the fruit ripen properly while retaining some of its antioxidant properties (Razzaq et al. 2015; Arif et al. 2023). Therefore, the d6 treatment effectively maintained vitamin C levels, helping the cantaloupes maintain freshness and good quality.

CONCLUSION

Ethephon treatment at 100 ppm, applied 6 days after harvest of unripe melon fruits, significantly improved the quality and shelf life of early-harvested cantaloupe. It accelerated sugar accumulation and induced flesh degradation. The sucrose content of fruit treated on day 6 was 12 times higher by day 7 of storage than in the other treatments. This treatment maintained titratable acidity and vitamin C content, extending melon shelf life to 12 days. In summary, the application of 100 ppm ethephon on day 6 after harvest proved effective in enhancing sugar content and maintaining postharvest quality of early-harvested cantaloupe melons.

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Author contribution statement

KS – A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article

NW – A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article

AA – A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article

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