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Comparative analysis of ethylene-induced ripening inclimacteric and non-climacteric fruits: implications for post-harvest management

Nor Isnaeni Dwi Arista[1], Siti Azizah Ardiningtyas[1,*]
[1] *Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, Bogor, West Java 16680, Indonesia;*
*Correspondence: sitiazizahardiningtyas@unida.gontor.ac.id

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ABSTRACT

Background: Ethylene gas contained in fruits can increase the respiration rate. Climacteric fruits are those that experience automatic stimulation towards ripening, accompanied by an increase in respiration rate, as seen in bananas. Non-climacteric fruits, such as oranges, do not experience such an increase or change in respiration rate. The rate of fruit ripening is influenced by temperature, storage conditions, and the use of chemical agents to accelerate ripening. The aim of this article is to investigate the effects of closed and open storage environments, as well as the concentration of chemical agents used in the storage process. **Methods:** This study used bananas and tomatoes, which were placed in both open and closed storage, and stored in pairs. Additionally, the article discusses the concentration of carbide as a chemical agent that triggers the ripening of oranges. **Findings:** The results show that bananas and tomatoes are climacteric fruits. The storage treatment of bananas indicated that, across all conditions—whether stored in open or closed environments, or stored together with tomatoes—the outcome was the same: the fruits showed signs of deterioration within one week. For tomatoes, it was observed that storing them in a closed environment led to greater longevity compared to other storage methods. The treatment of oranges showed that ripening occurred more rapidly with the application of carbide compared to without its use. **Conclusion:** Ethylene gas is a crucial factor in the post-harvest management of various fruits and vegetables. Inadequate handling can lead to mechanical damage. In practice, bananas produce the most ethylene gas compared to tomatoes and oranges. Furthermore, bananas can influence the ripening of surrounding fruits. The use of carbide in different concentrations demonstrated that 10 grams of carbide led to faster ripening and yellowing of oranges compared to lower concentrations or the absence of carbide. **Novelty/Originality of this article:** This study uniquely integrates the analysis of natural and chemically-induced ethylene effects on climacteric and non-climacteric fruits under varied storage conditions, providing novel insights for optimizing post-harvest management across diverse fruit types.

KEYWORDS: fruit ripening, ethylene effects, climacteric fruits, ripening agents, storage conditions

1. Introduction

Based on their respiration rates, fruits are classified into two types: climacteric fruits and non-climacteric fruits. Non-climacteric fruits do not experience an increase in respiration rate during the ripening process. In contrast, climacteric fruits undergo continuous ripening even after being harvested. The stages of climacteric fruit ripening generally include the pre-climacteric, climacteric peak, and post-climacteric phases (Gardjito & Swasti, 2017). The climacteric phase is marked by an increase in respiration

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rate, ethylene production, and both physical and chemical changes in the fruit. Respiration is a process that involves the uptake of oxygen and the release of carbon dioxide and energy within the tissue. Ripening represents the final stage but also the initial phase of fruit senescence. Senescence, often referred to as aging, is a period during which the fruit transitions from an anabolic to a catabolic state, leading to tissue death (Sudjatha & Wisaniyasa, 2017).

Climacteric fruit ripening can be accelerated through ripening treatments. Common methods for ripening fruits include composting, the use of carbide, or intentionally wounding the fruit. Farmers often make incisions on the fruit surface to hasten ripening. However, these incisions may cause the fruit to appear less visually appealing and may also allow spoilage microorganisms to enter the fruit tissue, leading to quicker decay. Other substances that can be used to accelerate fruit ripening include ethrel, acetylene gas, ethylene gas, and gamal leaves (Arif et al., 2014).

Local Indonesian fruits that meet food quality standards, cleanliness, fruit labeling, plant protection, and health requirements include climacteric fruits such as bananas, melons, mangosteens, and most types of vegetables like tomatoes. Natural methods of delaying fruit ripening involve the use of inhibitors, cold temperatures, and coating techniques. Additionally, climacteric fruits are often modified to reach consumers in their optimal state.

Ethylene is a plant hormone in gaseous form that plays a crucial role in inducing the ripening process of many fruits. Unripe fruits typically have low levels of ethylene. As fruits ripen, ethylene is produced as a signal to initiate the ripening process. Ethylene production continues to increase post-harvest, which reduces the fruit's shelf life, storage duration, and increases its susceptibility to pathogen attacks Fig. 1. (Capino & Farcuh, 2024). Ethylene gas in plants is found in a gaseous state, often referred to simply as ethylene gas. It is colorless and highly volatile at room temperature (Sinha, 2014). Ethylene has volatile properties that are released by fruits and vegetables and is known as an active component in ripening stimulation by breaking down chlorophyll pigments. Ethylene also affects respiration rates, especially in climacteric fruits, and aids in removing the green color. During the ripening process, fruits experience changes in taste, color, and firmness, all of which coincide with an increase in respiration rate.

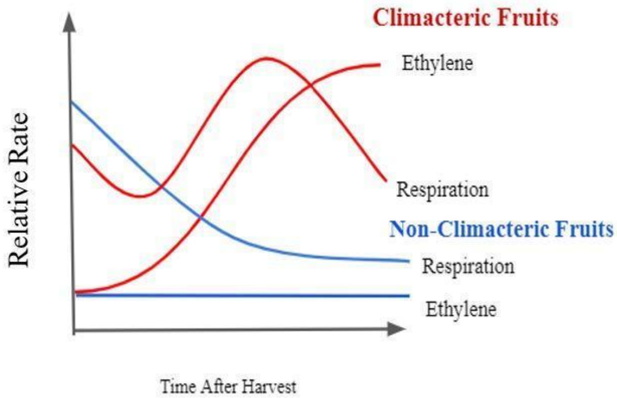

Fig. 1. Ripening patterns of climacteric and non-climacteric fruits
(Capino & Farcuh, 2024)

Exposure to ethylene gas is known to accelerate fruit ripening up to 100 times faster, as illustrated in studies that used ethylene gas for ripening mangoes. These studies demonstrated that using 30 ppm ethylene for 24 hours was the most efficient and effective method to induce uniform ripening in 'Gedong' mangoes. The ripened fruit matured four days faster compared to untreated fruit (Broto et al., 2021). Recent research by Christianah et al. (2024) explores how ethylene gas can be detected during the ripening process of fruits and vegetables. Ethylene serves as a key ripening inducer through a series of biochemical processes. Ethylene released by stored fruits and vegetables is collected and tested. This technology will help determine the suitability for consumption, the stage of ripeness, and the onset of decay in various fruits and vegetables.

However, the use of ethylene also presents challenges. Although ethylene effectively accelerates ripening, an excess of it can cause overripening and shorten the fruit's shelf life. Therefore, precise control over ethylene concentration and exposure duration is essential to achieve optimal results. Fruits such as bananas and tomatoes are often the subjects of research concerning ethylene's effects on ripening (Christianah., 2024; Maduwanthi & Marapana, 2019; Liu et al., 2024). Bananas, as climacteric fruits, show a rapid response to ethylene (Cordenunsi-Lysenko et al., 2019). Tomatoes also belong to the climacteric category, undergoing changes when exposed to ethylene. Ethylene treatment of tomatoes is frequently done to ensure uniform ripening before distribution to the market (Zhou et al., 2024). For citrus fruits, ethylene exposure does not significantly increase respiration rates, as citrus fruits are non-climacteric. Ethylene exposure in citrus fruits only enhances the orange color of the peel (Mitalo et al., 2020).

In addition to the effects of ethylene, environmental factors such as temperature and humidity also play a role in the ripening and storage of fruits. Post-harvest technologies, such as controlled atmosphere systems, can regulate oxygen and ethylene levels to extend shelf life (Chen et al., 2024). Low-temperature treatment without packaging has proven to be the most effective method for delaying weight loss in limes (Habibi & Susila, 2024). Based on the above description, a deeper understanding of the role of ethylene in the ripening of climacteric and non-climacteric fruits, as well as environmental factors, is needed to improve fruit quality and shelf life. This article discusses the effects of endogenous and exogenous ethylene on the ripening of bananas, tomatoes, and citrus fruits, as well as the influence of storage conditions on the physico-chemical and physiological changes in the fruits. This research provides insight into simple and eco-friendly technologies to maintain the freshness and quality of climacteric and non-climacteric fruits.

2. Methods

This study used bananas and tomatoes as observation subjects. The selected fruits were at two different ripeness stages, namely mature (ripe) and immature (unripe) fruits. The analysis method used was descriptive, with the observation variables being aroma, color, and texture.

2.1 Experimental design

The treatments applied to the fruits are as follows:
a. In an open container (OC)
b. In a closed container (CC)
c. In an open container with ripe bananas (RB)
d. In a closed container with ripe bananas (CB)
e. In a closed container with ripe tomatoes (RT)
f. In a closed container with limes and carbide (LC)

2.2 Observation variables

The observation variables in this study consist of three main aspects: color, aroma, and texture. These variables were selected because they are the primary indicators of fruit ripeness and quality.

a. Color: The color of the fruit peel is the most visible indicator of ripening. For bananas, changes in color from green to yellow or black, and for tomatoes, from green to red, were recorded as a percentage of the surface area that changed color.

b. Aroma: The aroma produced during the ripening process is an important indicator of fruit quality and ripeness. The study recorded and noted any detected aromas, such as sweet, pleasant, or rotten.
c. Texture: Texture was measured by assessing the softness or firmness of the fruit manually. Changes in texture from hard to soft during the ripening period were recorded as the percentage of fruit that experienced such changes.

2.3 Data analysis

Data from the observations on color, aroma, and texture will be analyzed descriptively. This method was chosen to describe the changes in these variables under various storage conditions. Each treatment will be compared to determine the effect of each condition on the ripening rate and final fruit quality.

3. Results and Discussion

3.1 Bananas

Genetic and biochemical pathways are influenced by internal and external factors. As a climacteric fruit, bananas produce more endogenous ethylene compared to non-climacteric fruits. According to the Agricultural and Food Agency, ethylene gas produced during banana ripening ranges from 0 to 0.05 ppm, increasing up to 130 ppm. Ethylene gas from bananas can also affect other fruits nearby (Paramita, 2010). The rapid color transition of bananas, combined with the emergence of aroma and softening of texture, indicates the onset of accelerated senescence (Table 1). This study demonstrates that ethylene gas from bananas can influence the aroma and color of tomatoes stored in the same place, revealing a "neighbor effect" of bananas on tomatoes. Additionally, the study shows that different levels of banana ripeness and closed versus open storage containers at room temperature had little impact. Hence, research investigating how ethylene gas control in bananas can be inhibited is necessary, as shown by Dafri et al. (2018), where controlling ethylene gas through optimal temperature regulation at 11°C effectively extended banana shelf life.

This study on banana storage under various conditions reveals the ripening process of climacteric fruits and their interaction with the microenvironment. The comparison between open (OC) and closed (CC) containers provides intriguing findings regarding the role of air circulation and ethylene accumulation. It indicates an interaction of oxidants and nutrients, or possibly other metabolites. Data show relatively similar color changes (85% black for OC vs. 80% black for CC), suggesting that endogenous ethylene production may have been sufficiently high to dominate the ripening process, even in open conditions. However, the difference in aroma—fragrant for OC and rotten for CC—suggests that despite similar color changes, biochemical processes in bananas may differ, with closed containers likely fostering anaerobic microbial groCCh leading to spoilage. This contrasts with other studies showing that banana packaging generally helps preserve quality compared to open-air exposure (Hailu et al., 2014). However, the type of packaging significantly impacts bananas. Polyethylene bags, such as HDPE and LDPE wrapped directly around the fruit, are effective in extending shelf life and maintaining banana quality, though ordinary plastic packaging also increases the risk of spoilage (Hailu et al., 2014).

Table 1. Observation results of banana storage

Observation	Variable	Banana Treatment				
		OC	CC	RB	CB	RT
Week 1	Color	85% black	80% black	75% black	Mature : 75% black Ripe : 100% black	Banana: 75 % black Tomato : 100 % red

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	Aroma	Fragrant	Rotten	Fragrant	Mature: Rotten Ripe: Pleasant	Banana: Pleasant Tomato: -
	Texture	Soft	Soft	Soft	Mature: Soft Ripe: 75% soft	Banana: Soft Tomato: Fragrant

Bananas are a climacteric fruit type, characterized by a high respiration rate during the ripening process. Initially, the bananas were at two different ripening stages: mature (yellow) and unripe (green). After one week of observation, the bananas showed changes in color, aroma, and texture. The color shifted from yellow or green to black, the aroma became strongly pungent, and the texture softened (Figure 2). These changes are attributed to over-ripening. According to Giovannoni (2004), fruit ripening is a complex genetically programmed process that results in significant changes in color, flavor, aroma, texture, and nutritional value.

Fig. 2. Condition of bananas and tomatoes on the seventh day

3.2 Tomatoes

Observations on tomato plants indicated a color change from green to red during the first week. Aromatic changes occurred in the second week, with the bananas stored alongside ripe tomatoes developing a rotten smell and soft texture, which in turn caused the tomatoes to be affected by spoilage fungi from the bananas. Textural changes were observed in the third week, showing that storage conditions had an impact (Table 2).

According to the SNI table, the maturity levels of tomatoes can be classified into green mature, breaker, turning, pink, and red (Nofriati, 2018). Tomatoes are climacteric fruits with a respiration pattern marked by a rapid increase in respiration rate and ethylene production during ripening. Typically, fully ripe tomatoes are 90-100% red and appear fresh. Post-harvest physiology reveals that tomatoes are prone to mechanical damage during transport and packaging. Consequently, tomatoes are often harvested while still green or yellowish.

Textural differences observed weekly suggest that varying storage conditions influence the quality retention of tomatoes. The wrinkled texture in OC in week 3 was caused by excessive transpiration due to direct air exposure, while the hard texture in CC indicated inhibited ripening. Aloe vera Nanomultilayer Coating significantly reduced O_2 consumption and CO_2 production in tomatoes, inhibiting ethylene synthesis and being more effective in maintaining post-harvest quality, including the pink color, compared to uncoated tomatoes (Flores-López et al., 2023). This clearly shows that tomatoes kept closed fare better than those exposed. On the other hand, the soft texture of tomatoes stored with bananas resulted from the "neighbor effect," as excessive ethylene exposure from other fruits increased the activity of enzymes that break down the cell walls of tomatoes. Post-harvest handling is a crucial factor in tomato production outcomes. High water content in climacteric plants leads to increased respiration rates and accelerated aging (Mubarok et al., 2015). Ethylene gas, a climacteric compound, negatively impacts fruit quality.

Table 2. Observation results of tomato storage

Observation	Variable	Treatment				
		OC	CC	RB	CB	RT
Week 1	Color	100 % Red	100 % Red	100% Red	Mature : 100 % Ripe : 100%	Tomato100 % Banana : 100 %
	Aroma	-	-	-	-	Tomato: - Banana Fragrant
	Texture	Firm	Firm	Firm	Mature : Firm Ripe : Wrinkled	Tomato: Firm Banana : Firm
Week 2	Color	100 % Red	100 % Red	100 % Red	Mature : 100 % Red Ripe : 100% Red	Tomato100 % Red Banana : 100 % Black
	Aroma	Fragrant	Fragrant	Fragrant	Fragrant	Tomato: Fragrant Banana : Rotten
	Texture	Firm	Firm	Firm	Mature : Firm Ripe : Soft	Tomato: Firm Banana : Soft
Week 3	Color	100 % Red	100 % Red	100 Red	Mature : 100 % Red Ripe : 100% Red	Tomato100 % Red
	Aroma	Fragrant	Fragrant	Fragrant	Fragrant	Tomato: Fragrant Banana : Rotten
	Texture	Wrinkled	Firm	Soft	Mature : Soft Ripe : Rotten	Tomato: Soft

3.3 Oranges

Degreening is a method used to achieve more uniform yellow coloring of the fruit peel. This process involves the breakdown of green pigments (chlorophyll) in the peel and the formation of orange-yellow pigments (carotenoids). Degreening does not affect the internal quality of the orange, such as sugar content, acidity, and juice (Rimayanti et al., 2016), as oranges are non-climacteric fruits. The effectiveness of degreening is influenced by several factors, including ethylene, temperature, and fruit cultivar. The use of ethylene as a metabolic stimulant for oranges is intended to enhance the external color of the fruit. Non-climacteric fruits, such as grapes, demonstrate that proper exposure duration can produce uniform skin color while acting as an exogenous regulator to combat pathogens (Dong et al., 2020).

Oranges, being non-climacteric fruits, exhibit a decrease in respiration rate after harvest, entering the senescence phase. Oranges treated with 5 grams and 10 grams of carbide, as well as those without treatment, showed nearly simultaneous color changes (Table 3). Oranges without carbide took longer to turn completely yellow compared to those treated with carbide. The flavor of untreated oranges remained sour, while those treated with carbide became sweet. The use of carbide requires careful attention because, according to USDA (2023), water is added to carbide stones to produce ethylene gas.

Table 3. Observation results of orange storage

Observation	Variable	Treatment		
		Control	Carbide 5g	Carbide 10g
Week 0	Color	Green	Green	Green
	Aroma	Fragrant	Fragrant	Fragrant
	Texture	Firm 100%	Firm 100%	Firm 100%

Week 1	Color Aroma Texture	25% Yellow Fragrant Firm 100%	25% Yellow Fragrant Firm 100%	25% Yellow Fragrant Firm 100%
Week 2	Color Aroma Texture	50% Yellow Fragrant Firm 75%	25% Yellow Fragrant Firm 75%	25% Yellow Fragrant Firm 75%
Week 3	Color Aroma Texture	75% Yellow Fragrant Firm 75%	100% Yellow Fragrant Firm 50%	100% Yellow Fragrant Firm 50%

The consistency in aroma across all treatments presents interesting findings regarding the ripening physiology of oranges. The persistence of fragrance in oranges exposed to external treatments suggests that the biochemical processes responsible for volatile compound production may be isolated from metabolic pathways affected by exogenous ethylene. This aligns with Paul & Pandey (2014), who note that volatile compound release from plant organs with low transpiration rates, such as large fruits with strong diffusion barriers on their surfaces or peels, tends to be minimal. Consequently, volatile compounds accumulate within the tissues of these organs.

The initially hard texture of oranges treated with carbide gradually softened over time. The faster rate of softening in oranges treated with carbide—reaching 50% softness by the third week, compared to 75% in the control group—indicates a trade-off between ripening speed and fruit resilience. Texture changes during ripening and storage are well-documented (Pott et al., 2020). As fruit ripens, it softens, and pectin content increases. This is because pectin dissolution affects the physical properties of the cell walls, impacting the fruit's structural integrity (Paniagua et al., 2014). This process accelerates in warmer conditions. Therefore, the use of carbide can soften the fruit as it raises the temperature, causing more rapid ripening.

3.4 Influence of other factors in post-harvest handling

In addition to storage conditions, several other factors influence post-harvest fruit quality and shelf life. One of the main factors is post-harvest handling, which includes harvesting, transportation, and storage processes before the fruit reaches consumers. Poor handling can lead to mechanical damage, accelerating ripening and increasing the risk of spoilage. By improving handling and storage practices, farmers can prevent damage to their crops, which can potentially cause spoilage and financial loss (Valenzuela, 2023).

Proper handling during harvest and transportation is critical to ensuring that fruit remains in good condition. Efficient transportation and adequate infrastructure are essential to ensure that horticultural products reach their destination in optimal condition, healthy, and free from damage (Valenzuela, 2023). Fruits damaged during this process are more vulnerable to pathogen attacks and spoilage and may be rejected by markets and consumers. Colletotrichum spp. and Fusarium spp. cause significant fruit losses in Jimma and Bishishe markets, Ethiopia, with mechanical damage and poor sanitation being the main causes. Therefore, stakeholder integration along the value chain is needed to reduce losses (Kuyu & Tola, 2018). Thus, careful harvesting techniques, appropriate packaging, and well-controlled transportation are crucial for maintaining fruit quality.

Moreover, advanced storage technologies, such as controlled atmosphere storage and low-temperature application, play a crucial role in extending fruit shelf life. These technologies allow for the regulation of oxygen, carbon dioxide, and ethylene levels in storage environments, slowing down ripening processes and reducing the risk of spoilage. Packaging solutions, including coatings, smart and active packaging, and modified atmosphere packaging, play an important role in monitoring and controlling the internal atmosphere of the fruit, protecting it from external contaminants (Lalpekhlua et al., 2024). Ripening and aging can be controlled during storage using controlled atmosphere storage, particularly by inhibiting ethylene production through the use of CO_2, silver thiosulfate

(STS), and 1-methylcyclopropene (1-MCP) (Chen et al., 2024). Packaging materials that regulate humidity and absorb ethylene have also proven effective in maintaining fruit quality during long-term storage. The combined effect of low temperatures and newspaper wrapping was found to extend the shelf life of lime fruits (Habibi & Susila, 2024).

4. Conclusions

The two fruits studied, bananas and tomatoes, are climacteric fruits that influence aroma, color, and texture. Bananas release ethylene gas that accelerates the ripening process of both themselves and other nearby fruits. The findings of this study also indicate that closed containers tend to promote aerobic microbial groCCh, leading to rapid spoilage of the fruit. In contrast, the storage of tomatoes alongside bananas affected the quality and longevity of the tomatoes themselves. Storing tomatoes in closed environments caused the fruit to harden due to limited air circulation, while open storage led to increased transpiration, resulting in wrinkled tomatoes. Oranges, as non-climacteric fruits, require ripening post-harvest. Factors influencing oranges can alter quality, such as external appearance, flavor, and texture. The use of carbide and ethylene is essential during ripening. The results of this study show that the color change in oranges treated with carbide occurs more rapidly than in those without. Additionally, carbide accelerates the softening of the fruit's texture. The use of 10 grams of carbide sped up the ripening of the peel and led to a faster decline in texture.

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Author Contribution

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Biographies of Authors

Arista, N.I.D., Researcher in Environmental Science with a Master of Science in Agronomy and Horticulture from Bogor Agricultural University, Indonesia

- Email: dewi.arista@apps.ipb.ac.id
- ORCID: https://orcid.org/0000-0001-7196-2838
- Web of Science ResearcherID: JJC-4527-2023
- Scopus Author ID: 57855279200
- Homepage: https://journal-iasssf.com/index.php/JASSU/editorial

Ardiningtyas, S.A., Lecturer in University of Darussalam Gontor, Indonesia

- Email: sitiazizahardiningtyas@unida.gontor.ac.id
- ORCID: https://orcid.org/0009-0002-1642-6113
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A