Original Research Article

Ethylene Management in Fresh Produce Transport

Abstract

Ethylene is a plant hormone that plays a significant role in the ripening and senescence of fruits and vegetables. While ethylene is essential for many agricultural processes, it can also be detrimental to fresh produce during transport and storage. High levels of ethylene exposure can lead to premature ripening, reduced shelf life, and increased spoilage, resulting in significant economic losses for growers, shippers, and retailers. This paper aims to explore the management of ethylene in fresh produce. The objectives of this study are to investigate the ethylene content in various farm produce, identify factors contributing to ethylene production, assess the impact of ethylene exposure on post-harvest quality, explore ethylene management methods and techniques, and make recommendations for ethylene management. The research hypothesis is that ethylene-sensitive produce will exhibit a decreased shelf life and accelerated ripening when exposed to higher ethylene concentrations. Conversely, implementing effective ethylene management strategies, such as reducing ethylene exposure or utilizing ethylene inhibitors, will result in a prolonged lifespan and improved post-harvest quality of the produce. The findings of this study could improve fresh produce's quality and marketability, as well as reduce waste and advance sustainable agriculture practices.

Keywords: Ethylene, hormone, management, storage, transportation, agricultural produce, Nigeria

1.0 Introduction

1.1 Ethylene Management in Fresh Produce Transport

Ethylene is a hormone that naturally exists in plants and plays a significant role in the maturation and ripening of plants (fruits and vegetables) (Ebrahimi et al., 2022a, Adegoroye et al., 2023). While ethylene is essential for many agricultural processes, it can also be detrimental to fresh produce during transport and storage (Adegoroye et al., 2021; Ferrante, 2022, Oladoyin et el., 2023). While it can have relatively positive effects such as inducing ripening in climacteric fruits and enhancing produce aroma, its action may also lead to relatively negative consequences. Consequently, extensive research has focused on reducing ethylene production and safeguarding plants from its adverse effects. In the case of climacteric fruits, ethylene serves as a major factor in prolong the storage and lifespan of fruits and vegetables. High levels of ethylene in mature leaves of leafy greens can cause certain physical problems, negatively impacting their appearance and nutritional quality. Excessive exposure to ethylene can result in premature ripening, shorter shelf life, and higher likelihood of spoilage, leading to significant financial setbacks for farmers, distributors, and sellers (Chang, 2016; Oparinde et al., 2023; Badamosi et al., 2023).

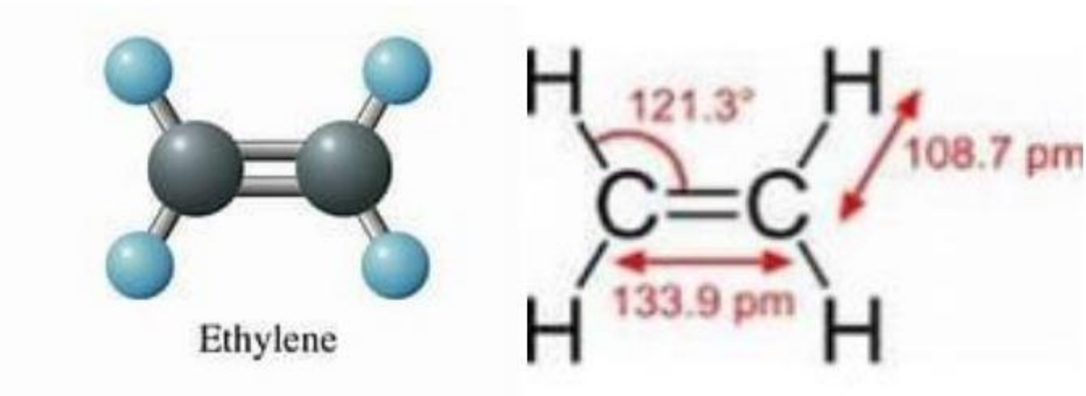


Figure 1: The ethylene Structure

To prevent ethylene damage to fresh produce, it is important to store it in a cool, dark place with good ventilation. To prevent ethylene-related issues, it is crucial to store produce separately from fruits and vegetables that release ethylene, like apples, bananas, and tomatoes.

1.2 Ethylene's Long-Historical Presence

Ethylene is a simple gas that has been used by humans for centuries to induce ripening in farm produce (Qi et al., 2021). The ancient Egyptians knew about the ripening effects of ethylene. Thus, they would cut figs to make them ripen faster (Bottonand Ruperti, 2019). The Chinese in ancient times would also burn incense in an enclosed place to hasten the ripening fruits (Moirangthem and Tucker, 2018; Akinuli et al., 2023; Yahaya et al., 2023). In the 19th century, scientists began to study the effects of ethylene on plants in more detail(Han et al., 2022). In the early 20th century, scientists finally identified ethylene as a plant hormone (Chen et al., 2018). The discovery of Ethylene led to a number of its applications, Ethylene gas is very important in ripening fruits and vegetables in storage (Abbas and Ibrahim, 1996).

1.3 Applications of Ethylene

Ethylene is used in a variety of agricultural applications (Mahapatra et al., 2022), the applications include:

I. Ripening fruits and vegetables

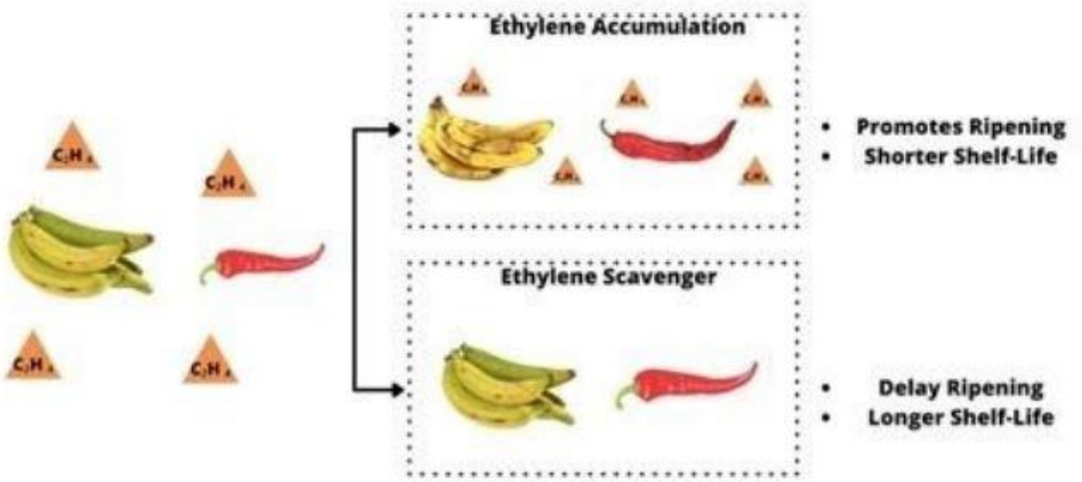


Figure 2: Ethylene promoting ripening and reducing shelf life. Figure adapted from Mariah et al., (2022).

II. Accelerating senescence (aging) of flowers and vegetables (Dar et al., 2021).

III. Promoting flowering in some plants (Dar et al., 2021).

IV. Inducing abscission (leaf fall) (Botton and Ruperti, 2019).
V. Thinning fruit crops (Nautiyal et al., 2022).

From its ancient use by the Egyptians to its modern applications in agriculture and industry, ethylene continues to be a valuable tool for humans. However as valuable as it seems to be it could be challenging if not properly managed especially in farm produce. If ethylene is not properly managed, it could result in several challenges for the farmer of which reduced lifespan of produce is a key problem.

1.4 Aim and Objectives of the Study

This project aims to explore the management of ethylene in fresh produce. The objective of this study is to investigate the ethylene content in various farm produce and propose effective strategies to manage ethylene levels. The primary goal is to extend the shelf life of fruits and vegetables, minimize wastage, and optimize quality throughout the supply chain. The specific objectives are to:

i. Investigate ethylene emissions in different types of produce.
ii. Identify factors contributing to ethylene production.
iii. Assess the impact of ethylene exposure on post-harvest quality.
iv. Explore ethylene management methods and techniques.
v. Make recommendations for ethylene management.

1.5 Hypothesis

Based on the literature, it is hypothesized that ethylene-sensitive produce will exhibit a decreased shelf life and accelerated ripening when exposed to higher ethylene concentrations. Conversely, implementing effective ethylene management strategies, such as reducing ethylene exposure or utilizing ethylene inhibitors, will result in a prolonged lifespan and improved post-harvest quality of the produce. By conducting this research and providing recommendations for ethylene management, this project aims to contribute to the development of practical guidelines for the industry, farmers, and post-harvest professionals. The outcomes of this study have the potential to enhance the quality and marketability of fresh produce, reduce waste, and promote sustainable practices within the agricultural sector.

2.0 Methodology

2.1 Accessing the content of ethylene in different fruits and Vegetables.

In this study, our focus is to ensure ensure proper management of ethylene while transporting the produce. Therefore, for this aim to be achieved, it is important for us to know the quantity of ethylene in different plants. Having this knowledge will help us to make informed decisions when transporting this product. Different plants, there are different ethylene quantity in them, and having understood that Ethylene has a different content composition in different plants, it is important to know the quantity contained in them to make some informed decisions in managing them.

Also, ethylene production in fruits and vegetables can also vary depending on several factors, such as their sensitivity, the temperature of the place where they are kept, light intensity, and storage conditions. Therefore, it is very important to always check the ethylene production levels of specific fruits and vegetables before storing them together. Also, the sensitivity of different fruits and plants to ethylene gas varies widely (Wei et al., 2021; Ogunyemi et al., 2022). Some fruits and vegetables can be very sensitive to ethylene and will start to ripen quickly if they are exposed to even small amounts of the gas or in conditions that enhance their ethylene production, while some other fruits and vegetables are less sensitive to ethylene and can tolerate higher levels of the gas without being affected. In other to reduce the production and damages of ethylene on produce, it is important to ensure the following conditions:

I. Store ethylene-producing fruits and vegetables separately from ethylene-sensitive fruits and vegetables.
II. Store fruits and vegetables in a cool, dark place.
III. Avoid storing fruits and vegetables in plastic bags, as this can trap ethylene gas.
IV. Check fruits and vegetables regularly for signs of spoilage.

This can help to extend the shelf life of the fruits and vegetables even while they are being transported and also prevent them from being damaged by ethylene gas.

2.2 Management of Ethylene

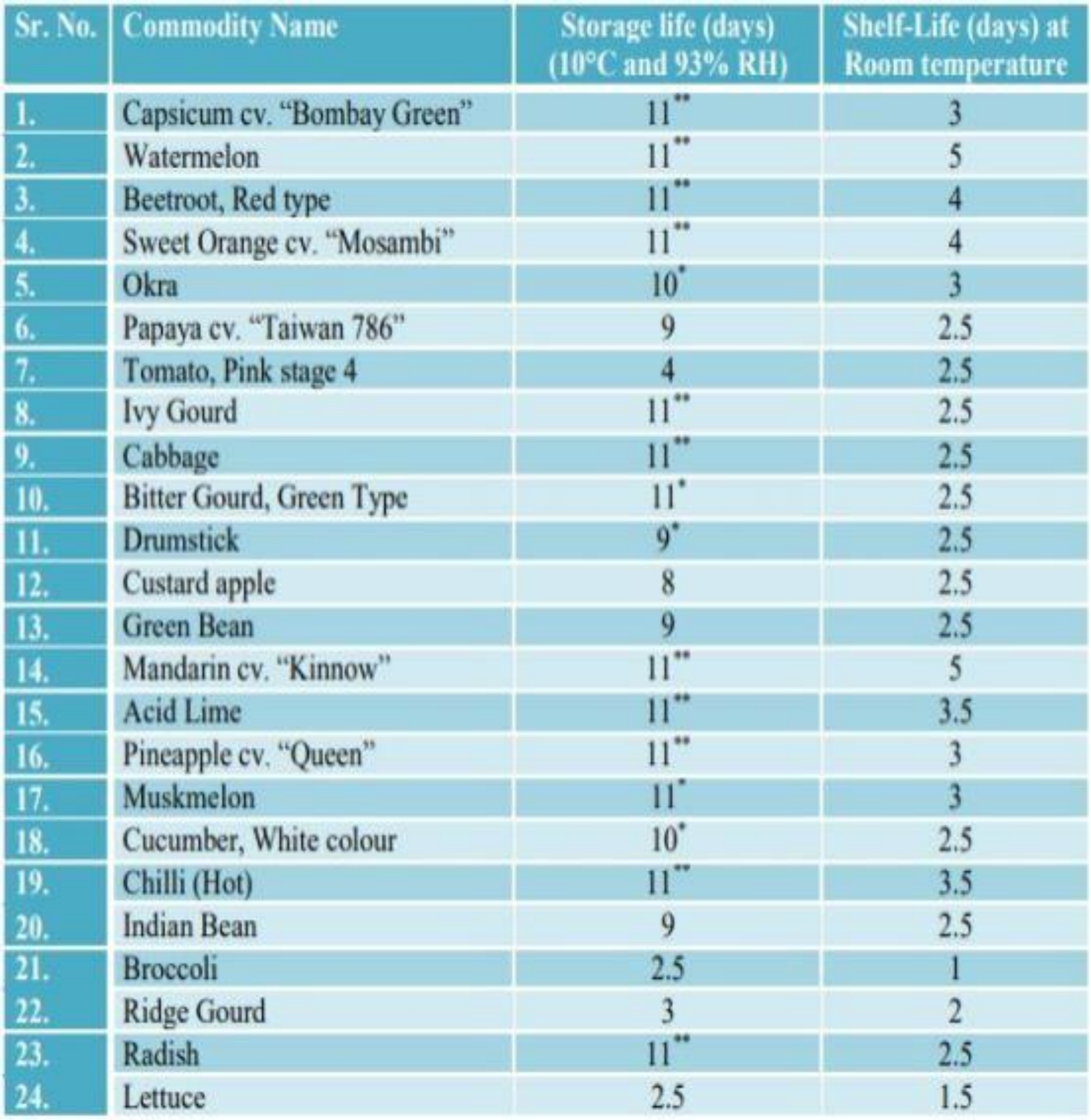
Ethylene can be managed or removed from plants in different ways. For effective Management of Ethylene, we can either ensure the management ethylene or take measures to remove it. The method that will be used will be determined by the current condition. Therefore, to mitigate the effects of ethylene on fresh produce and prolong the shelf life of fresh produce during transport, several methods can be employed which is categorized into two major methods. This includes.

I. Management of the Ethylene
II. Removal of the Ethylene.

2.2.1 Managing Ethylene while transporting farm produce

Some methods that could be used in managing ethylene while transporting farm produce include:

I. Storing ethylene-producing fruits and vegetables separately from ethylene-sensitive fruits and vegetables.
II. Using 1-Methylcyclopropene (1-MCP), a plant regulator used to inhibit ethylene production in cut flowers, potted flowers, bedding, nursery and foliage plants, and stored fruits and vegetables. It is an ethylene inhibitor that protects the plant from both internal and external sources of ethylene such that when plants are in the presence of ethylene, they do not respond to it. Apple, apricot, avocado, banana, broccoli, kiwifruit, pear, mango, melon, peach, nectarine, persimmon, plum, and tomato are among the crops for which 1-MCP is approved for use.
III. Storing fruits and vegetables in a cool, dark place. Maintaining optimal temperature conditions during transportation is crucial for ethylene management. Lowering temperatures can slow down ethylene production and reduce its effects on production (Majid et al., 2018; Oluwalade et al., 2023a,b).



Sr. No.	Commodity Name	Storage life (days) (10°C and 93% RH)	Shelf-Life (days) at Room temperature
1.	Capsicum cv. "Bombay Green"	11^{**}	3
2.	Watermelon	11^{**}	5
3.	Beetroot, Red type	11^{**}	4
4.	Sweet Orange cv. "Mosambi"	11^{**}	4
5.	Okra	10^{*}	3
6.	Papaya cv. "Taiwan 786"	9	2.5
7.	Tomato, Pink stage 4	4	2.5
8.	Ivy Gourd	11^{**}	2.5
9.	Cabbage	11^{**}	2.5
10.	Bitter Gourd, Green Type	11^{*}	2.5
11.	Drumstick	9^{*}	2.5
12.	Custard apple	8	2.5
13.	Green Bean	9	2.5
14.	Mandarin cv. "Kinnow"	11^{**}	5
15.	Acid Lime	11^{**}	3.5
16.	Pineapple cv. "Queen"	11^{**}	3
17.	Muskmelon	11^{*}	3
18.	Cucumber, White colour	10^{*}	2.5
19.	Chilli (Hot)	11^{**}	3.5
20.	Indian Bean	9	2.5
21.	Broccoli	2.5	1
22.	Ridge Gourd	3	2
23.	Radish	11^{**}	2.5
24.	Lettuce	2.5	1.5

Figure 3: Produce conditions: * indicates good condition of produce and ** indicates very good condition of produce. Adapted from Jadhav, (2018).

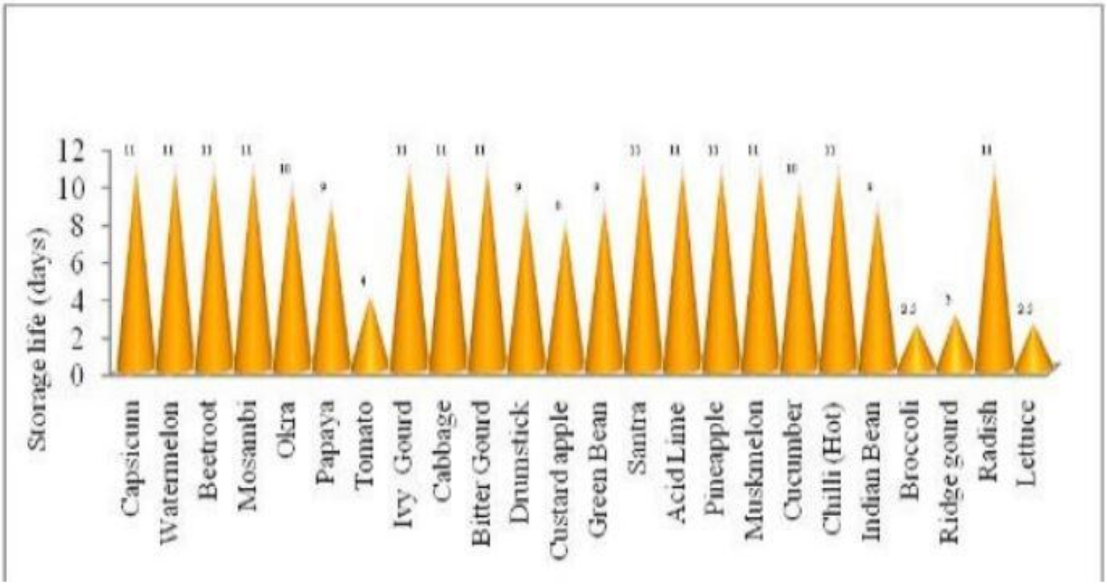


Figure 4: Mixed fruit and vegetables storage life (days) at 10o C and 93% RH inside cold unit Eco frost. Adapted from Jadhav, (2018).

Figure 5:Mixed fruits and vegetables kept at cold storage (10°C and 93%). Adapted from Jadhav, (2018).

IV. Cold storage facilities, refrigerated trucks, and insulated packaging are examples of temperature control measures (Qi et al., 2021). Dark place will help to slow down the production of ethylene and extend its shelf life.

V. Avoid storing fruits and vegetables in plastic bags while transporting them, as this can trap ethylene gas and hasten their ripening (Parven et al., 2020).

VI. Employing the use of modified Atmosphere. Modified Atmosphere refers to altering the air's chemical composition around the produce contained in packaging. Using gas barriers and adjusting oxygen and carbon dioxide levels, helps control ethylene production and slows down the ripening process (Falagán and Terry, 2018; de Siqueira Oliveira et al., 2019; McMillin, 2020).

2.2.2 Removal of Ethylene

Ethylene has both positive and negative effects on post-harvest fruit quality under different storage conditions, although it cannot be completely removed. Some compounds or processes can be used to reduce their presence and increase the life span of the products. The use of ethylene inhibitors like 1-methylcyclopropene (1-MCP) has emerged as a new technology to slow and delay fruit ripening in both climacteric and non-climacteric fruits when stored at low temperatures alone or in combination with modified atmospheres (MAs) and controlled atmospheres (CAs). On fruit physiology and biochemistry, however, the effects of temperature, MA/CA, and 1-MCP are complex and can alter the metabolism of carbohydrates, organic acids, amino acids, and lipids. Furthermore, ethylene-induced changes can also contribute to chilling injuries and carbon dioxide injuries during cold storage and MA/CA conditions. The successful application of these storage technologies requires a comprehensive understanding of the interactions between ethylene and fruit metabolism to maintain fruit quality and prevent physiological disorders (Brizzolara et al., 2020). However,1-MCP as one of the removal methods of ethylene will not be considered in this review.

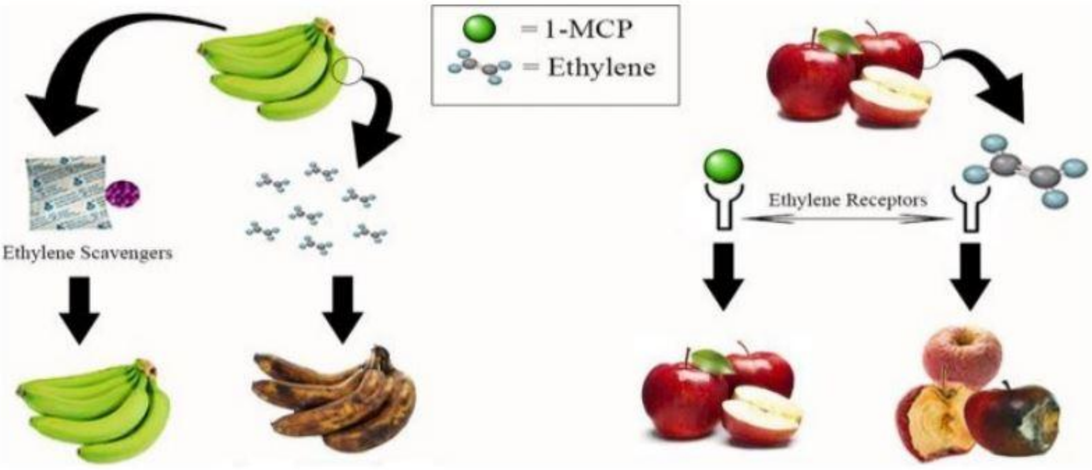


Figure 6: Graphical representation of ethylene removal in some fruits.
Adapted from Ebrahimi et al. (2022).

A variety of methods can be used to eliminate ethylene or reduce its impact on plants. Some of these methods are:

i. Using Ethylene Scrubbers such as potassium permanganate or activated charcoal. Ethylene scrubbers which can also be classified under ethylene scavengers (Gaikwad et al., 2020), are devices that actively remove ethylene from the air through chemical reactions or adsorption (Álvarez-Hernández, Martínez-Hernández, Avalos-Belmontes, Rodríguez-Hernández, et al., 2019; Brecht, 2019). Scrubbers typically use materials such as potassium permanganate (Álvarez-Hernández et al., 2019; Kumar et al., 2023), activated carbon, or zeolite (Aprilliani et al., 2018; de Bruijn et al., 2020) to absorb or oxidize ethylene molecules.

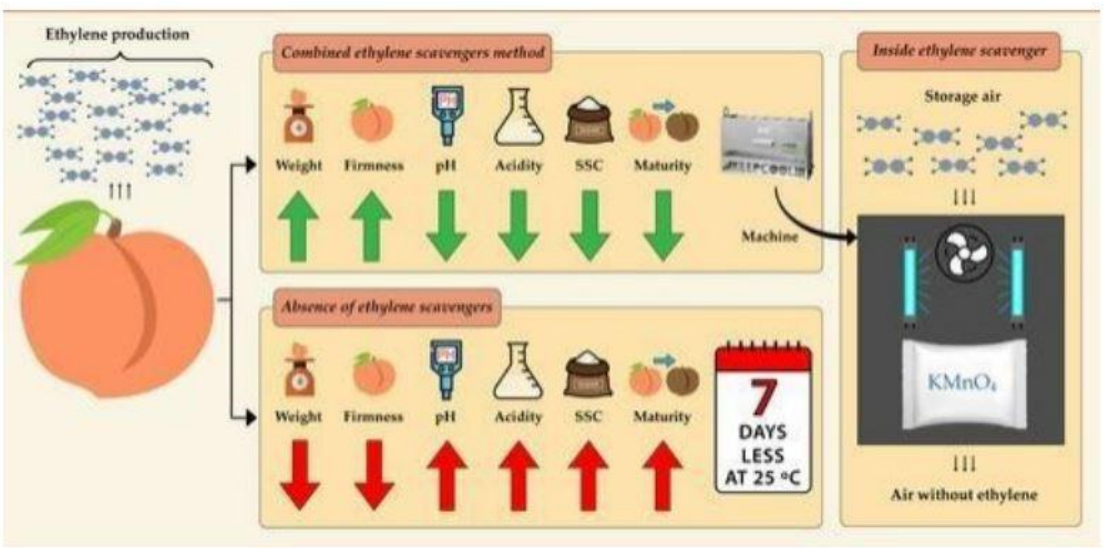


Figure 7: Effect of KMnO2 on produce, at room temperature. Adapted from Alonso-Salinas, Acosta-Motos, Núñez-Delicado, et al., (2022).

Advantages

I. Efficiency: Ethylene scrubbers are very efficient at removing ethylene gas from the air. They can remove up to99%of the ethylene gas in a given area (Álvarez-Hernández et al., 2018).

II. Effectiveness: Ethylene scrubbers are effective at preventing fruits and vegetables from ripening too quickly. This can help to extend their shelf life by several days or even weeks (Álvarez-Hernández et al., 2019.

Limitations

I. Cost-effectiveness: Ethylene scrubbers are relatively cost-effective to operate. They require little maintenance and do not use a lot of energy (Martínez-López et al., 2022).

II. Recycling: The spent cartridges from ethylene scrubbers can be difficult to recycle. This is because they often contain harmful chemicals.

ii. Using ethylene-absorbing compounds

Ethylene absorption filters are passive devices placed within transport containers or storage units. These filters contain absorbent materials that capture and trap ethylene such as potassium permanganate salt loaded on membranes composed of alumina nanofibers (Tirgar et al., 2018), preventing its accumulation and reducing its concentration (Gaikwad et al., 2020; Ebrahimi et al., 2022).

2.2.3 Ventilations

Good airflow and ventilation play a vital role in ethylene management. Proper ventilation helps remove ethylene and other respiratory gases released by fresh produce (Wills, 2021). It can promote heat dissipation and reduce moisture buildup, which can lead to accelerated ripening (Mok et al., 2020).

Figure 8: Ventilation. Adapted from Alonso-Salinas, Acosta-Motos, Núñez-Delicado, et al., (2022).

The best method for managing or removing ethylene from plants will depend on the specific situation. In some cases, it may be necessary to use a combination of methods. In this study, we will explore current research on the use of non-potassium permanganate and we will also focus on the use of Ultra-Violent light and Ozone (O3). We will evaluate the strengths and weaknesses of each method in relation to different types of fresh produce. Finally, we will synthesize our findings and identify gaps in the literature to provide recommendations for future research in this critical area.

2.3 Managing, Controlling, and Measuring Ethylene: Materials and Compounds

Extending the shelf life of fresh produce (fruits and vegetables) has seen the development of various methods and applicable materials in the removal and/or management of ethylene which is a major problem in the storage of fresh produce. Some of the materials designed through extensive research on ethylene control include:

Ethylene-absorbing sachets

These are sachets made with permeable/membranous materials that allow easy gaseous exchange and filled with specially formulated minerals which could be zeolite, activated clay, potassium permanganate, or their combinations, etc., that have a high affinity for ethylene gas. These absorbent minerals are usually placed with the packaging of fresh produce for maximum efficacy. These sachets are commonly used in several industries like agriculture, horticulture, and supply chain.

Figure 9: Ethylene absorption sachet. (Source: Keep-It-Fresh.com).

Ethylene absorption balls

Like the sachets, ethylene absorption balls are made with materials with a high affinity for ethylene gas and neutralize them. Some of the materials used in making these balls include potassium permanganate, zeolite, etc. Likewise, they come in specialized containers and are placed within the packaging of fresh produce for maximum efficacy. They are used in agricultural and horticultural industries, supply chains as well as in individual homes.

Figure 10: Ethylene absorption balls. (Source: Keep-It-Fresh.com).

Ethylene absorbing rods

Commonly known as ethylene absorbers or ethylene scrubbers contain materials that trap and neutralise ethylene gas. These rods have non-woven cloth ethylene absorbers packed inside of them, acting as a membrane with holes for air to pass through. The rods are frequently used in a range of storage environments, including industrial warehouses, supermarkets, reefer containers, cold storage, and even home refrigerators. principally employed to absorb the ethylene gas inside the container.

Figure 11: Ethylene absorbing rods (KIF Curtain) (Source: Keep-It-Fresh.com).

Ethysorb tubes

This is an ethylene control equipment which are metre-long tubs filled with alumina beads infused with potassium permanganate.

Figure 12: Ethysorb tube (Source: Keep-It-Fresh.com)

Ethylene meter

Atool for estimating the amount of ethylene gas in the atmosphere. Accurate ethylene levels in storage environments are usually monitored and maintained with the help of these meters. Low ethylene levels are typically found in unripe fruits. However, as fruits mature, ethylene is naturally produced as a signal to initiate the ripening process. Even after harvest, ethylene production continues to rise, resulting in reduced shelf life, decreased storability, and an increased vulnerability to pathogen attacks in fruits. Therefore, it is important to monitor and control the rate of ethylene production to prevent excessive ripening during post-harvest storage.

Ethylene Sensitive

Apples
Asparagus
Avocados
Bananas
Broccoli
Cantaloupe
Collard Greens
Cucumber
Eggplant
Grapes
Honeydew
Kiwi
Lemons
Lettuce
Limes
Mangos
Onions
Peaches
Pears
Peppers
Squash
Sweet Potatoes
Watermelon

Ethylene Producers

Apples
Avocados
Bananas
Cantaloupe
Kiwi
Peaches
Pears
Peppers
Tomatoes

Not Ethylene Sensitive

Blueberries
Cherries
Beans (Snap)
Garlic
Grapefruit
Oranges
Pineapple
Potatoes
Raspberries
Strawberries
Tomatoes
Yucca

Figure 13: Ethylene Sensitivity of different produce. Adapted from (UC San Diego Community Health, 2017).

Figure 14: Handheld ethylene gas detector LEGD-A10 (Source: Multi-gasdetector.com).

3.0 Results and Discussion

Application of Ethylene Removal/ Management

3.1. Avocado Pear

Brecht (2019) examined the profound effects of ethylene, it's the first known gaseous hormone in plants, on plant development, specifically fruit ripening, plant senescence, and stress responses. He also explored the commercial significance of ethylene manipulation in agriculture, focusing on its application, avoidance, and removal to minimize post-harvest effects on fruits and vegetables. Ethylene is utilized in specially designed ripening rooms to promote and coordinate the ripening process of climacteric fruits like banana, Avocados pear and tomato. Methods such as ethylene removal or scrubbing from the post-harvest environment and the application of chemicals blocking ethylene synthesis or action are employed to prevent undesired ethylene-induced ripening, senescence, and other effects. The results highlight the importance of ethylene management in agriculture for optimizing fruit quality and extending shelf life. Ochi et al. (2020) investigated the removal of ethylene in avocados and revealed that various methods have been employed to delay the ripening process and reduce losses. One study investigated the use of biopolymers as a coadjutant in ethylene control. Avocado fruits were coated with a biopolymer film containing active carbon, which acted as an adsorbent material to capture ethylene. The results showed that the biopolymer-coated avocados exhibited reduced ethylene levels compared to untreated fruits. This led to a delay in the ripening process and extended the shelf life of avocados. However, Further research is warranted to explore the long-term effectiveness and practical feasibility of this approach in commercial settings.

3.2. Kiwi

Wang et al. (2023) developed CS/SA/QDs@ZIF-8 nanocomposite films to address the problem of ethylene-induced deterioration in kiwi fruits. The films were prepared by incorporating QDs@ZIF-8 nanoparticles into a chitosan and sodium alginate matrix using the layer-by-layer assembly method. The nanocomposite films demonstrated excellent antibacterial activity (>99% antibacterial ratio) and efficient ethylene scavenging properties (>40% scavenging ratio) due to the synergistic effect of visible-light-induced reactive oxygen species and the high specific surface area of ZIF-8. The preservation performance of the CS/SA/QDs@ZIF-8 nanocomposite films was validated by the extended shelf life of the kiwifruits. It was found that the addition of QDs@ZIF-8 NPs improved the mechanical strength, thermal stability, hydrophobicity, and barrier properties of the films, although it slightly decreased their color and transparency. An edible metal-organic framework (MOF) named γ-CD-MOF-K was developed by Li et al. (2023) using K+ and γ-cyclodextrin (γ-CD), with the aim of removing ethylene gas and delaying kiwifruit ripening. The MOF was synthesized through ultrasonication, and its structure was analyzed to confirm its adsorption capability for ethylene gas, which was found to be 56% ± 0.67% (w/w). Molecular docking technology revealed that the γ-CD-MOF-K possessed a spindle cavity structure that effectively adsorbed and stored ethylene gas. The experimental results demonstrated that this material successfully absorbed ethylene gas in storage packaging and consequently delayed the ripening process of red kiwi fruit. This research indicates the great potential of MOF in improving the post-harvest quality of fruits and vegetables by reducing ethylene levels. Mok et al. (2020) investigated the removal of ethylene in kiwi fruit to enhance its storage stability. They employed a plasma-catalytic process consisting of two steps: adsorption and plasma catalysis. Pd/ZSM-5 catalytic adsorbent, prepared through ion exchange at room temperature without pH adjustment using PdCl2 as the precursor, efficiently adsorbed highly volatile ethylene, even under humid conditions. The adsorbed ethylene was subsequently decomposed to carbon dioxide during plasma-catalyzed oxidation. Experimental results demonstrated that ethylene removal significantly improved the storage stability of kiwi fruit. However, limitations or further details regarding the specific experimental conditions, duration, or other factors were not mentioned in the provided information. After investigating the effect of modified atmosphere packaging (MAP) on kiwifruit qualityand ethylene management, Han et al. (2022) stored 'Hayward' kiwifruits in MAP or air at 1°C with 60-70% relative humidity for 35 days. Subsequently, the fruits were repacked in perforated film (air), non-perforated retail bags (MAP), or MAP with an ethylene scrubber (ES) and stored at 20°C with 67-70% relative humidity for 10 days to simulate retail conditions. The MAP maintained fruit firmness during cool storage and throughout the subsequent shelf life. However, in retail conditions, MAP only provided benefits in terms of reducing weight loss and maintaining soluble solids content (SSC). Ethylene was detected only in retail bags containing rotten fruit, including one with an ES, suggesting that the ES might not be sufficient for ethylene management in retail environments.

3.3 Strawberries

Alamar et al. (2017) investigated the effect of controlled atmospheres (CA) on British-grown strawberries cv. Sonata during post-harvest storage. Specifically, they examined how ethylene, a plant hormone known to accelerate fruit ripening and senescence, was removed using CA treatment. The strawberries were exposed to CA conditions of 15 kPa CO2 + 5 kPa O2 at an early and middle stage of storage. Real-time respiration rate (RR), disease severity, objective color, and firmness were measured. The results showed that the strawberries treated with CA for 2.5 days in the middle of the storage period had reduced ethylene production and maintained a firmer texture and vibrant color, despite occasional bursts of increased RR. Also, the CA treatment extended the shelf-life of strawberries by an additional 3 days compared to the control group, as indicated by a lower incidence of disease. Reis et al. (2020) aimed to investigate the effect of ethylene and its inhibitor, 1-methylcyclopropene (1-MCP), on various physical-chemical attributes of ripe 'Albion' strawberries at different developmental stages. They conducted experiments using strawberries that were still attached to the plant and dipped them in three treatment solutions: Ethephon (a source of ethylene), 1-methylcyclopropene, and water (control). They assessed several physicochemical properties of the ripe fruits, including mass, size, firmness, color, acidity, sugar content, organic acids, amino acids, and volatile composition. They also recorded the time taken for the fruit to ripen. The results showed that the treatments did not affect the ripening rate or several measured attributes of the ripe fruit. However, ethylene treatment with Ethephon had stage-specific effects on fruit development and metabolism. Green fruit treated with Ethephon resulted in a larger diameter and mass in ripe fruit, while white fruit showed increased anthocyanin content. Pink fruit treatment led to smaller size and greater firmness in ripe fruit. While investigating the regulatory mechanisms of arginine (Arg) in strawberry fruit development, Lv et al. (2020) examined the effect of exogenous Arg on ethylene emissions and ripening. They treated 'Sweet Charlie' strawberry fruits with Arg and analyzed their transcriptome and physiological parameters. The results revealed that exogenous Arg inhibited fruit coloration and ripening, accompanied by a decrease in Arg content and changes in several physiological parameters including firmness, anthocyanin content, sugar content, indole-acetic acid (IAA) content, abscisic acid (ABA) content, and ethylene emissions. Furthermore, the researchers observed an induction of heat-shock proteins (HSPs) and antioxidant enzyme genes, leading to improved stress resistance in strawberries. Mabusela et al. (2022) focused on ethylene management in strawberries, they investigated the use of vacuum ultraviolet (VUV) photolysis technology to remove ethylene and inhibit microbial activity. The experiment involved subjecting strawberries to VUV photolysis treatment, which generated highly reactive radicals capable of oxidizing ethylene into carbon dioxide and water. Simultaneously, the treatment successfully inactivated pathogenic microorganisms present in the fruit. The results indicated that VUV photolysis effectively reduced ethylene levels, leading to extended shelf life and reduced post-harvest losses in strawberries.

3.4 Tomatoes

Mansourbahmani et al. (2018) conducted a study that aimed to determine the most effective ethylene scavenger and evaluate its impact on the quality of stored tomatoes. Four levels of treatments were applied: palladium-promoted nano zeolite, KMnO4-promoted nano zeolite, 1-MCP, CaCl2, salicylic acid (SA), and UV-C. Sampling was conducted at various time points during cold storage. The results demonstrated that the 5% palladium-promoted nanozeolite, 20% KMnO4-promotenano zeolite,30ppm 1-MCP, 2% CaCl2, 1% SA, and 15 minutes of UV-C treatment exhibited the highest ethylene scavenging activity. The effectiveness of the treatments in ethylene removal followed this order: palladium > KMnO4 > 1-MCP > SA = CaCl2 > UV-C. Furthermore, the 5% palladium-promoted nano zeolite displayed positive effects on phenol content, polygalacturonase activity, lycopene content, fruit firmness, and weight loss, while the 15 minutes of UV-C treatment reduced decay severity. Consequently, the 5% palladium-promoted nano zeolite could be considered a valuable approach for extending the shelf life of tomatoes and preserving their quality characteristics during storage. Additionally, the 15 minutes of UV-C treatment proved effective in reducing decay severity and maintaining post-harvest quality. Basso et al. (2018) investigated the photocatalytic degradation of ethylene in a continuous flow reactor using TiO2 under UV-A light, with a focus on its application for maintaining the shelf life of cherry tomatoes. The experiments revealed that an increase in the thickness of the TiO2 catalyst deposited on the reactor's inner wall led to a linear improvement in ethylene degradation until reaching a constant value. The reaction rate was found to be influenced by both the flow rate and ethylene gas concentration, with higher rates observed at higher flow rates and lower ethylene concentrations. Increasing incident irradiance also resulted in a linear increase in ethylene conversion. Notably, the reactor with a TiO2 film thickness of 0.419 μm and an incident irradiance of 5.18 W m−2 effectively maintained ethylene concentration close to zero and reduced carbon dioxide levels. This indicated a decrease in the respiration rate of tomatoes, demonstrating the efficacy of this technology in improving the shelf life of cherry tomatoes. Jia et al. (2018) investigated the interaction between hydrogen sulfide (H2S) and ethylene in tomato plants under osmotic stress. They observed that ethylene-induced the production of H2S in guard cells. To understand the role of H2S in ethylene-induced stomatal closure, they used hypo taurine (HT), an H2S scavenger, and DL-pro-pargylglycine (PAG), a synthetic inhibitor of H2S. The supply of HT or PAG removed the effect of ethylene or osmotic stress on stomatal closure, indicating that H2S is required for ethylene-induced stomatal closure under osmotic stress.

Furthermore, they discovered that H2S inhibits ethylene synthesis by persulfidation of 1-aminocyclopropane-1-carboxylic acid (ACC) oxidases (ACOs), which are enzymes involved in ethylene biosynthesis. The modified biotin-switch method revealed that H2S induces persulfidation of LeACO1 and LeACO2, inhibiting their activity. They identified cysteine60as the persulfided siteon LeACO1. Additionally, H2S was found to inhibit the expression of LeACO genes. These findings demonstrate that ethylene-induced H2S negatively regulates ethylene biosynthesis through persulfidation of LeACOs in tomato plants.

3.5 Banana

Tzeng et al. (2019) used a nanocomposite-based palladium-modified zeolite (Pd/zeolite) by impregnating Pd into zeolite and evaluated its performance as an adsorbent/catalyst for ethylene removal and banana ripening delay. They characterized the Pd/zeolite by various techniques, such as surface area measurement, X-ray diffraction, and transmission electron microscopy, and tested its ethylene removal efficiency and reusability by using a fixed-bed reactor system. They also measured the ethylene concentration, firmness, and peel colour of banana stored with or without Pd/zeolite for 18 days at 20 ± 2 °C. They found that Pd/zeolite had a high surface area, a multi-pore structure, and a good dispersion of Pd particles over the zeolite support. They also found that Pd/zeolite could remove ethylene effectively and repeatedly, even after reaching the breakthrough point, and could delay the ripening of banana significantly. They concluded that Pd/zeolite is an effective and reusable material for ethylene removal and post-harvest preservation of banana. Zhu et al. (2019) synthesized nanofibers containing TiO2 nanoparticles (1 wt%, 5 wt%, and 10 wt%) by electrospinning method, and evaluated their performance as photocatalysts for ethylene degradation and banana ripening delay. They characterized the nanofibers by various techniques, such as scanning electron microscopy, energy dispersive X-ray spectrometer, transmission electron microscopy, and X-ray diffraction, and tested their photocatalytic activity for ethylene degradation by using aphotocatalytic reactor. They also measured the colour change and softening of bananas stored with or without nanofibers for 10 days at 25 °C. They found that nanofibers containing 5 wt% TiO2 had a nano-scale structure, good nanoparticle uniformity, and an anatase phase. They also found that nanofibers containing 5 wt% TiO2 had higher photocatalytic activity for ethylene degradation than other nanofibers. They also found that nanofibers containing 5 wt% TiO2 could delay the ripening of bananas significantly. They concluded that nanofibers containing 5 wt% TiO2 are effective and potential materials for photocatalytic degradation of ethylene and post-harvest preservation of bananas. Fan et al. (2022) developed a bio-based film that can scavenge ethylene, a gas that causes fruits and vegetables to rot. They used electro-spraying to coat paper towel microfibers with nanoparticles made of zein and Artemisia sphaerocephala Krasch. gum, which has core-shell structures and many active functional groups. They tested the film on bananas and found that it reduced browning, increased hardness, and extended shelf life. They also showed that the film had high surface area, porosity, hydrophobicity, and mechanical strength, which made it suitable for fruit preservation. The film offers an efficient, safe, and sustainable solution to reduce post-harvest food waste. Nooun et al. (2023) made bio-composite foam sheets from natural rubber and rice starch and added activated carbon as a filler to improve mechanical properties and ethylene absorption. They studied how different amounts of activated carbon affected the physical, morphological, mechanical, and thermal properties of the foam sheets. They found that more activated carbon increased the size, density, hardness, strength, and glass transition temperature of the foam cells, but decreased their number and rebound resilience. The thermal stability was not affected by the activated carbon. They also tested the foam sheet with 15 phr activated carbon on bananas and found that it reduced ethylene levels, delayed ripening, and maintained quality better than a commercial foam and a control. The bio-composite foam could be used as a packaging material for fresh fruits.

4. Conclusion and Recommendations

4.1 Conclusion

This study has explored various methods and materials for managing ethylene in fresh produce with the overarching aim of extending shelf life, minimizing wastage, and optimizing quality throughout the supply chain. The objectives of the study were successfully achieved, and the hypothesis that ethylene-sensitive produce would exhibit decreased shelf life and accelerated ripening when exposed to higher ethylene concentrations, while effective ethylene management strategies would result in a prolonged lifespan and improved post-harvest quality, was supported by the findings. The investigation into ethylene emissions in different types of produce highlighted the variability in ethylene content among various plant species. Factors contributing to ethylene production, such as temperature, light intensity, and storage conditions, were identified, emphasizing the need for tailored ethylene management strategies. The impact of ethylene exposure on post-harvest quality was substantiated through multiple studies on fruits like kiwi, strawberries, tomatoes, and bananas. Ethylene-induced ripening and senescence were found to be significant factors leading to reduced shelf life and quality deterioration. However, innovative techniques like photocatalytic degradation, the use of nanocomposites, and the application of bio-based films showed promise in mitigating these effects. Ethylene management methods and techniques were thoroughly explored, encompassing both ethylene removal and ethylene absorption approaches. Zeolite-based systems exhibited effectiveness in reducing ethylene levels during storage and transportation, though challenges related to moisture and saturation were noted. Ultraviolet (UV) light emerged as a non-conventional technique capable of breaking down ethylene molecules, preserving fruit firmness, and maintaining colour. Nevertheless,further research is required to address long-term impacts and overcome limitations.

4.2 Recommendation for future works

We recommend the investigation of the use of zeolite in combination with other technologies, such as modified atmosphere packaging and coatings, to further enhance its effectiveness in ethylene removal. There is a need to evaluate the long-term effects of zeolite treatment on the quality and safety of fruits and vegetables. Additionally, there is a need to optimize UV light treatment parameters, such as wavelength, intensity, and exposure time, to maximize ethylene removal and minimize negative impacts on production quality. It is also necessary to investigate ways to make ozone more affordable and available for use. Moreso, there is a need to provide education and training to farmers, suppliers, and post-harvest professionals on the importance of ethylene management. Promote awareness of ethylene's effects on produce and the benefits of implementing effective management strategies. Also, a need for improvement in the measurement of Ozone and a more user-friendly way of getting the measurement which will be of great help to farmers andproduce transporters.

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