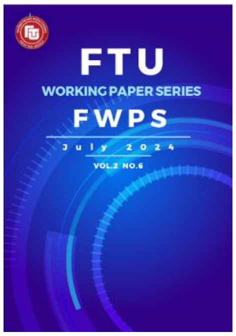

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PHÂN TÍCH CÔNG NGHỆ KIỂM SOÁT KHÍ QUYỂN TRONG BẢO QUẢN KHO ĐỐI VỚI MẶT HÀNG RAU CỦ QUẢ VÀ ỨNG DỤNG CHO VIỆT NAM

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Tóm tắt

Với nhu cầu và yêu cầu ngày càng tăng đối với các sản phẩm nông nghiệp, đặc biệt là rau củ quả, không chỉ phục vụ thị trường trong nước mà còn thu hút thương mại quốc tế, thì việc bảo quản kho rau củ quả là hết sức quan trọng. Phương pháp kiểm soát khí quyển (CA) - một phương pháp quản lý thành phần khí trong kho, điển hình là oxy, carbon dioxide và nitơ, nhằm ngăn chặn quá trình chín của trái cây và rau quả để tăng thời hạn sử dụng, là giải pháp đột phá giải quyết vấn đề. Nghiên cứu này, sử dụng phương pháp định tính, cung cấp cái nhìn tổng quan về công nghệ CA trong bảo quản kho rau củ quả từ quá trình vận hành đến ảnh hưởng lên chất lượng sản phẩm. Từ đó, nhóm tác giả, căn cứ vào thực trạng bảo quản kho của rau củ quả tại Việt Nam hiện nay, đánh giá tiềm năng cũng như hạn chế của Việt Nam trong việc áp dụng công nghệ CA và đưa ra một số kiến nghị. Kết quả bài nghiên cứu chỉ ra rằng việc xử lý sơ bộ trước khi đưa vào bảo quản là cần thiết và có các phương pháp tiếp cận khác nhau đối với các nhóm trái cây và rau quả riêng biệt. Ngoài ra, lượng thành phần khí tối ưu được thiết lập cho kho CA phải thay đổi tùy theo các phương pháp CA cụ thể để tạo ra tác động tích cực đến chất lượng thông qua quá trình chín chậm, bảo quản màu sắc và giữ lại chất dinh dưỡng. Cân nhắc tầm quan trọng của giải pháp CA, nhóm tác

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giả khuyến nghị Việt Nam nên nắm bắt công nghệ CA vì có tiềm năng lớn về bảo quản rau củ quả trong kho mặc dù vẫn còn những hạn chế trong việc áp dụng.

Từ khóa: Kiểm soát khí quyển, bảo quản kho, rau củ quả, ứng dụng, Việt Nam

ANALYSIS OF CONTROLLED-ATMOSPHERE TECHNOLOGY IN THE WAREHOUSE STORAGE OF FRUITS AND VEGETABLES AND APPLICATIONS FOR VIETNAM

Abstract

With the increased demand and requirements for agricultural products, especially fruits and vegetables, not only in serving the domestic market but also in attracting international trade, the warehouse storage of fruits and vegetables is of paramount importance. Controlled-atmosphere (CA) method acts as a breakthrough solution in the field, which manages gas composition in the warehouse, typically oxygen, carbon dioxide and nitrogen, to prevent the ripening process of fruits and vegetables for longer shelf life. This study, using qualitative methodology, offers an overview of CA technology in the warehouse storage of fruits and vegetables from operational process to effects on quality of horticultural produce. From that, the authors, basing on the current situation of fruits and vegetables warehouse storage in Vietnam, evaluate potentials and limitations of Vietnam for the application of CA and provide some recommendations. The findings indicate that pretreatment for storage is essential and has different approaches for distinct groups of fruits and vegetables. Besides, the optimal levels of gas composition set for a CA warehouse should vary according to specific CA methods to generate positive effects on quality via delayed ripening, color preservation and nutrient retention. Taking into consideration the importance of CA technique, it is recommended for Vietnam, with large potentials in fruits and vegetables warehouse storage although still having limitations for application, to seize the CA technology.

Key words: Controlled-atmosphere, warehouse storage, fruits and vegetables, application, Vietnam

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1. Introduction

Horticultural produce tends to be highly decayable since, upon harvest, fruits and vegetables retain their metabolic processes that cause ripening and senescence, which renders them unmarketable for sale. However, traditional cold storage techniques, that focus mainly on altering temperature, are not fully effective, thus do not strictly meet current demanding market requirements that yearn for lengthened postharvest periods where both quality and safety of fruits and vegetables for consumption and trade are guaranteed.

In order to solve the problem, another technique named controlled-atmosphere (CA) is utilized in the warehouse storage of fruits and vegetables and has proven its efficiency in the preservation aspect with its success in many regions such as the United States, Canada, Australia, Western countries, etc. (Haginuma, S., 1972). The method mainly concentrates on controlling the atmospheric environment, including O_2, CO_2 and N_2, along with maintaining temperature and humidity at an optimal level to prolong the shelf life of fruits and vegetables without using any chemical substances.

Taking into consideration the importance of CA measure, the authors decided to choose the topic “Analysis of controlled-atmosphere technology in the warehouse storage of fruits and vegetables and applications for Vietnam” that aims to clarify two research questions: Understanding the implementation of CA in warehouse storage of fruits and vegetables and Providing recommendations for Vietnamese application based on the country’s current storage situation. Through a qualitative analysis, our study offers details about the process of CA warehouse storage of fruits and vegetables from pretreatment of horticultural produce which is different with various kinds to the operational principle of CA warehouse. Besides, we elaborate on the significance of CA technique via its impacts on the quality of fruits and vegetables. From that, our study assesses the lack of CA storage in Vietnam and offers insights about potential as well as limitations of Vietnam for CA application; therefore, proposing recommendations for Vietnamese stakeholders and policymakers to grasp CA technology in solving storage problems of fruits and vegetables.

2. Literature review

Research on the topic “Controlled-atmosphere (CA)” has been of significant concern not only in the past but also in recent years with a wide range of research subjects and solving various research questions.

In terms of overall knowledge of CA technology, a qualitative study conducted by Bodbodak, S. and Moshfeghifar, M. in 2016 discussed general theories related to CA preservation of fruits and vegetables in the whole supply chain including definition, controlled variables in CA technology, different CA methods to generate controlled gas environment and the benefits of CA measure on the preservation of fruits and vegetables. Moreover, Khanh, T. B. did research in 2018 about CA warehouse storage of agricultural products using the same methodology. The research focused on standard conditions for CA agricultural conservation according to several countries and species, requirements for CA warehouse and facilities needed along with the overall procedure in the implementation of CA technology.

Regarding specific aspects of CA method, in 2014, a quantitative study conducted by Tuan, P. A. and Tinh, P. T. T. investigated changes in physiological and biochemical characteristics of Thanh Ha lychees, grown in Luc Ngan district, Bac Giang province, Vietnam, in CA storage to form a basis for building a technological process for preserving lychees using this method. Additionally, Fragoso, A. V. and Mújica-Paz, H. (2016), applying qualitative methodology, researched on possible effects of CA technology in warehouse storage on fruits and vegetables in optimal and out-of-range storage conditions based on each temperature, O_2 level and CO_2 level. Furthermore, Pace et al. (2020) compared the quality of 60 surveyed Italian table grapes stored in CA containers and the traditional SO_2-pad storage to see the advantage of CA technology over the traditional one in marine transportation by applying both qualitative and quantitative methodology. In contrast, Arshad et al. conducted a qualitative article in 2022 with the purpose of analyzing two modern methods used in CA storage of fruits and vegetables, namely Dynamic controlled-atmosphere storage and Synthetic Plant Growth Regulator integration, in terms of overview, advantages, and limitations. Meanwhile, a study carried out by Butkeviciute et al. in 2022 used quantitative methodology on ten different apple cultivars to examine the impact of CA storage on phenolic acids and antioxidant activity of apples; therefore, determining optimal storage conditions for apples.

As opposed to particular case studies, in 1972, Haginuma, S. qualitatively researched the application of CA technology in the warehouse storage of five fruit groups namely Apple, Kaki, Pear, Satsuma mandarin and Other fruits in Japan in terms of standard conditions for temperature, relative humidity, O_2 and CO_2 levels. Also, a qualitative study in 2016 on the solution Opto 22 of California controlled-atmosphere Company (CalCA), headquartered in the USA, that offers hardware and software products related to industrial automation and control, energy management, remote monitoring, and data acquisition in the implementation of CA method.

Research gap:

By conducting a literature review on previous research, it is concluded that although there is a plethora of research papers ranging from articles, journals, studies, etc. revolving around the topic "Controlled-atmosphere", there is a notable scarcity of in-depth research papers that specifically investigate CA technology in the warehouse storage of fruits and vegetables and applications for Vietnam. Previous research mainly focuses on CA implementation in general not particularly in warehouse storage, the research subjects are either too specific (specific species of fruits and vegetables or in specific countries) or too large (agricultural products) or the research purpose does not include the application of this method for Vietnam.

Therefore, our research aims to address these critical gaps by conducting a thorough examination of CA technology used in warehouse storage of fruits and vegetables. Our study seeks to provide a detailed analysis of characteristics of the fruits and vegetables industry for the application of CA technology, controlled variables in CA method, operational process of CA warehouse storage, especially the operational principle, and the importance of CA technology on the quality of fruits and vegetables storage. Based on these, we analyze the current situation of warehouse storage measures for fruits and vegetables in Vietnam, evaluate and offer some recommendations for the country.

3. Theoretical framework

3.1. Overview of controlled-atmosphere technology in cold supply chain

Controlled-atmosphere (CA) technology is an agricultural preservation technique that does not use any preservative chemicals but only changes the atmospheric composition by adjusting the ratio of gasses, including oxygen, carbon dioxide and nitrogen, in the direction of reducing O_2, increasing CO_2 and N_2 to appropriate levels to minimize the respiration of agricultural products, kill or inhibit the growth of microorganisms and harmful organisms, maintain nutritional content and prevent bacterial damage, prolonging the shelf life of agricultural products (Linh, P., 2022).

This method helps lengthen the freshness of agricultural produce 2-4 times compared to current normal cold storage conditions (High-tech industry, 2022). It works best with climacteric fruits including apples, pears, apricots, mangos, tomatoes, bananas, papayas, etc. and can also preserve vegetables with high respiration levels well. However, the CA method is less used for non-climacteric fruit and horticultural produce with sluggish rates of respiration (Fragoso, A. V. & Mújica-Paz, H., 2016).

CA measure is now typical practice in the packaging, storage and transportation of a variety of food products from fresh produce to frozen goods, but it is more often to be used in warehouse storage rather than in other phases in the cold supply chain (Edinburgh Sensors, 2019). This is due to high requirements in terms of technology and facilities in the implementation of CA technique, while in transport or distribution, this kind of installment can lead to increased cost. Moreover, storage in warehouses normally involves longer preservation duration which makes it more essential to effectively conserve post-harvest products and maintain the quality over time, triggering the application of CA for a better solution. Because of these reasons, our study aims to specifically research CA technology in the warehouse storage of fruits and vegetables, therefore grasping the trend and providing more updated recommendations for the situation of Vietnam. Besides, by conducting this topic, we can take advantage of a wide range of relevant research for stronger research results.

3.2. Overview of controlled-atmosphere technology in the warehouse storage of fruits and vegetables

3.2.1. Definition of CA warehouse storage of fruits and vegetables

The fruit and vegetable industry's introduction of controlled-atmosphere (CA) storage is arguably the most successful technological advancement of the 20th century. Low oxygen (O_2) and high carbon dioxide (CO_2) concentrations in the storage environment are frequently used in conjunction with refrigeration for CA storage. It's possible that very early storage techniques made use of a modified environment that was devoid of oxygen and enriched with CO_2 to prolong the shelf life of grains, fruits, and other goods (Dilley, D. R., 2006).

CA storage environments demand constant monitoring and meticulous control of gas composition. This translates to a capital-intensive operation, making it suitable for high-value produce like apples, kiwifruit, and pears that benefit from long-term storage. For apples specifically, CA storage offers significant advantages over just refrigeration, mitigating certain storage disorders and diseases while potentially inducing others (Navaro, 2010).

The success of CA storage with apples spurred research on its application to a wider range of commodities. Today, CA storage recommendations exist for various fruits, vegetables, fresh-cut produce, and even ornamental flowers. Additionally, CA treatments find specific applications in insect control and disinfection (Cao Y et. al, 2019).

It's important to distinguish CA storage from CA packaging. While the former involves manipulating the atmosphere within a dedicated storage room, CA packaging remains elusive for commercial use (Bodbodak & Moshfeghifar, 2016). However, modified atmosphere packaging that utilizes oxygen and ethylene absorbers along with CO_2 releasers during the initial storage stages can be considered a rudimentary form of CA packaging.

While the core principle lies in manipulating the gasses surrounding the produce, successful implementation relies on meticulous control of several other operational parameters. This subject is hereby delved into via the key parameters influencing CA storage effectiveness: temperature, humidity, and gas control.

Controlled-atmosphere storage relies on precise temperature, humidity, and gas control to extend the shelf life of fruits and vegetables. Refrigeration units utilizing a cycle of compression, condensation, and expansion maintain cool temperatures. Humidity control is crucial, as condensation can occur if the air temperature is too high relative to the refrigerant temperature. Various methods, including spinning discs and jacketed stores, are employed to maintain high humidity without compromising cooling efficiency.

Maintaining the desired gas composition within the storage room is equally important. Oxygen (O_2) and carbon dioxide (CO_2) levels are independently controlled. Modern facilities utilize automated systems with continuous monitoring and adjustments, while smaller operations rely on manual measurements. Precise O_2 measurement is vital, with paramagnetic sensors and electrochemical cells offering the most reliable options. Infrared CO_2 sensors provide real-time monitoring of carbon dioxide concentration. Ethylene (C_2H_4), a ripening agent, is not routinely measured due to its low levels, but some facilities utilize disposable tubes or advanced analyzers to monitor its presence. By meticulously controlling these parameters, CA storage creates an optimal environment for produce, minimizing spoilage and waste.

3.2.2. Characteristics of fruits and vegetables industry for the application of CA technology

It has always been a conundrum for those who participate in the supply chain of daily and perishable goods to maintain the quality as new while transporting around the globe. This statement is especially correct for fresh fruits and vegetables, since every consumer often has high expectations for this kind of product displayed in the markets.

According to the Food and Agriculture Organization of the United Nations, 14% of all food is lost during the supply chain from harvest to wholesale market. This is because fruit and vegetables are easily decayed and highly sensitive to the change in their surrounding atmosphere. A successful fruit and vegetables supply chain must include a utilized storage method in order to meet demands with several characteristics of the fruit and vegetables, including:

a) Respiration rate

Even after being harvested, fruits and vegetables continue to respire, absorbing oxygen and emitting heat, carbon dioxide, and ethylene gas. Produce varieties differ in their respiration rates. Lower respiration rates in fruits and vegetables usually translate into longer shelf life.

b) Ethylene production and sensitivity

A naturally occurring plant hormone, ethylene speeds up the ripening process. Higher ethylene production from some fruits and vegetables can encourage ripening and senescence in other products. Controlling ethylene exposure and avoiding early ripening can be achieved by appropriate storage conditions.

c) Water content

Fruits and vegetables' ability to be stored depends on how much water they contain. Produce with higher water-content is more prone to spoiling and is more perishable. Controlling the humidity during storage aids in avoiding moisture accumulation or excessive water loss.

d) Microbial development

Microbial growth is a crucial factor to take into account while storing fruits and vegetables. Produce can develop microorganisms including bacteria, yeasts, and molds that can cause spoilage and cause health issues if ingested.

e) Shelf life

The natural duration of fruits and vegetables' shelf life differs greatly. While many produce items need to be used right away or saved for a short while, others can be kept in storage for longer periods of time provided the right circumstances are met.

3.2.3. Generally operational process of CA warehouse storage for fruits and vegetables

a) Pretreatment of fruits and vegetables for CA storage

Pre-storage treatments offer a versatile and effective approach to extending the shelf life of fruits and vegetables. By understanding the natural processes of these produce items, researchers and growers can develop targeted treatments that manipulate these processes to promote firmness, disease resistance, and overall quality.

One set of principles leverages the fruit's inherent defense mechanisms. Root crops like potatoes possess a protective cork layer that can be damaged during harvest. Exposing them to high humidity and warm temperatures after loading into storage can induce a "curing" effect. This stimulates the deposition of suberin, a waxy substance that strengthens the cork layer, effectively repairing the damaged tissue and ultimately reducing storage rot. Citrus fruits benefit from a similar curing process that promotes wound healing and disease resistance.

Another approach manipulates the fruit's own ripening physiology. Hot water or high-temperature treatments can achieve this. For apples, a pre-storage heat treatment at 46°C for 12 hours can improve firmness, reduce superficial scald, and enhance sweetness by impacting enzymatic activity and fruit metabolism. Hot water immersion or brushing can also target microorganisms on fruit surfaces, extending shelf life by reducing decay. This technique is particularly applicable to stone fruits like peaches and cherries.

Ethylene (C_2H_4), a key ripening hormone, is another target for pretreatment. Pre-storage exposure to low oxygen levels can inhibit superficial scald development in apples by influencing ethylene biosynthesis. Furthermore, 1-MCP, a commercially available C_2H_4 inhibitor, can be applied as a fumigant or through slow-release mechanisms. 1-MCP treatment has been shown to preserve fruit quality and reduce storage losses in various fruits, including apples, bananas, and litchis, by blocking ethylene receptor sites. Interestingly, while often seen as an alternative to CA storage, 1-MCP can also be used synergistically. Combining 1-MCP with CA storage has been shown to have particularly beneficial effects on apples, likely due to a combined effect on multiple ripening pathways.

Beyond these core principles, several unique pretreatment techniques have been explored. Cooling kiwi fruit to 0.5°C immediately after harvest effectively controls Botrytis cinerea rot development, further extending shelf life during CA storage. Similarly, a pre-storage heat treatment can prevent "telescoping" (excessive shoot growth) in cut green onions. Hypobaric ventilation, a technique involving storage under reduced pressure, has been shown to prevent scald development in apples by removing scald-related volatiles accumulating on the fruit surface.

Another unique approach involves exposing fruits like apples, pears, and avocados to a high CO_2 shock treatment prior to CA storage. This treatment improves green color retention and firmness in apples, while reducing physiological disorders in pears and avocados. The mechanism likely involves a temporary stress response that alters cellular metabolism and enzymatic activity.

b) Operational principle of CA warehouse storage

❖ ***Components of a CA storage***

Figure 1 demonstrates a standard CA storage, which consists of airtight and thermally insulated rooms or enclosures, machinery, refrigeration systems, equipment for creating and maintaining the desired gas concentrations in a specific environment, and systems for measurement and control of storage factors. These components mainly serve the purpose of controlling the amount of each gas in the storage: O_2, CO_2, C_2H_4 and N_2. Other factors like heat and humidity also need to be taken into consideration.

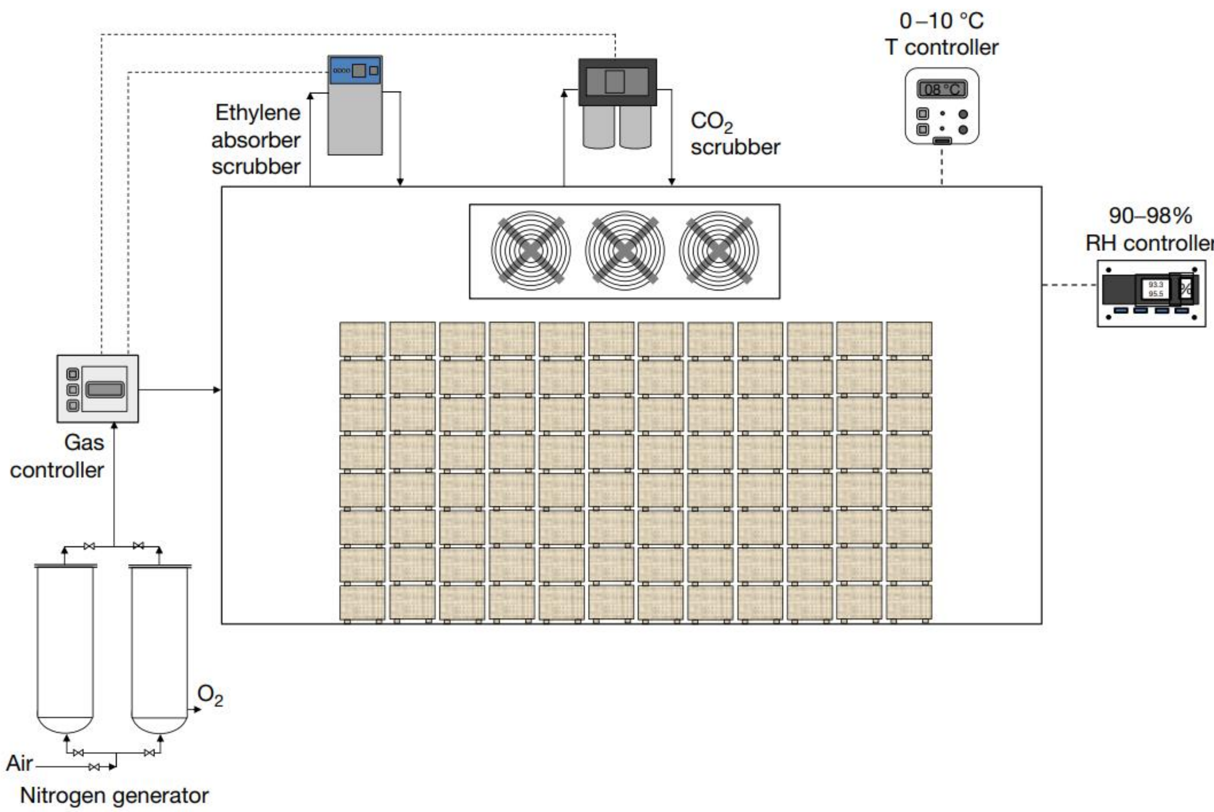

Figure 1: Standard CA storage room

Source: A Valdez Fragoso and H Mu´jica-Paz, 2016

❖ ***Control of operational parameters***

CA technique manages three major variables including temperature, humidity and gas composition.

- Temperature control

Fruits and vegetables are best preserved by refrigeration, which is the primary and most efficient method for doing so. Moreover, CA storage works best when used at colder temperatures. As a result, refrigerated units are essential parts of CA retailers. The evaporator, compressor, condenser, expansion valve, and refrigerant that flows inside these components are the major components of a basic refrigeration unit. Common refrigerants include ammonia and specific chlorofluorocarbons (CFCs). However, due to environmental concerns, new generation refrigerants with lower ozone depletion potential, such as R410A, are becoming increasingly common (Bodbodak & Moshfeghifar, 2016).

The refrigeration process can be described as the following steps:

○ The evaporator is a part of the system placed inside the store. It has pipes through which a cold liquid refrigerant flows.

○ The refrigerant absorbs heat from the store air as it circulates through the pipes, making the air cooler.

○ A fan blows the store air over the pipes to cool it quickly and distribute the cool air evenly throughout the store.

○ The refrigerant, now in a vapor state, moves to the compressor through pipes. The compressor squeezes it, making it hot and high-pressure.

○ The high-pressure vapor then goes to the condenser, where it is cooled down and turned back into a high-pressure liquid.

○ The liquid refrigerant passes through an expansion valve, which controls its flow and reduces its pressure. As the pressure drops, the refrigerant vaporizes and its temperature decreases.

○ Finally, the cooled mixture of vapor and liquid refrigerant goes back to the evaporator, and the cycle starts again.

- Humidity control

To keep fruits and vegetables fresh in a store, it's important to have a high level of relative humidity (RH). It is recommended to have the humidity close to saturation to prevent moisture from forming on the produce. If the air in the store is warmer than the refrigerant used, water will condense on the cooling system, and if the refrigerant temperature is below the freezing point, moisture will freeze on the cooling coils, making the cooling less effective. The stored crops lose moisture through the air, so it's important to balance the refrigerant temperature with the removal of heat from the crops, heat generated by fans, and temperature leakage from the store. This helps prevent the crops from drying out.

Stored produce loses moisture through vapor transpiration, further reducing humidity within the storage room. To compensate for this loss and prevent excessive desiccation, various humidifying devices are employed. Spinning-disc humidifiers are a common solution. Alternatively, secondary cooling techniques can be implemented to maintain high humidity without directly exposing the produce to cold surfaces. In jacketed stores, for instance, cooling coils are positioned between the inner and outer walls of the storage room, allowing the entire wall surface to act as a cooling element. Ice-bank cooling systems utilize tanks of chilled water or a fine water mist to cool and humidify the storage air.

- Gas generation and control

Controlling O_2 is most important in CA storage. Using chemical analyzers such as the Fyrite analyzer or Orsat analyzer, which are based on the reaction of O_2 with pyrogallol and of CO_2 with alkaline solutions, can measure the amount of O_2. Concentrations of O_2 and CO_2 are determined by measuring volume changes of a gas sample taken from the storage room.

Although the O_2 analyzers can be applied to CO_2 determination, an infrared CO_2 sensor is exclusively used for measurement of CO_2 to limit the drawbacks and maximize the correction of measurement.

Measuring C_2H_4 is difficult and not as common, but considering the significant effects it has on the products, it is still necessary to control C_2H_4 level. Gas chromatography, a method which determines C_2H_4 level by detecting the change in color, is by far the most accurate measurement for the gas. However, it is an expensive method and requires trained personnel.

Depending on the kind of produce, one or few methods of generation can be applied out of these following techniques:

○ Oxygen (O_2) removal: there are several ways such as produce's natural respiration, O_2 pulldown, but O_2 rapid reduction by flushing N_2 using nitrogen generator is the most popular method.

○ Carbon Dioxide (CO_2) removal: While the normal amount of CO_2 in the atmosphere is 0.03%, fruit and vegetables storage requires it to be around 2.5% to 3%. In an airtight environment, the ideal condition can be easily achieved via respiration. However, when CO_2 concentration is excessive, CO_2 needs to be removed in order to maintain the acceptable amount. A common method for controlling and removing CO_2 is using carbon dioxide scrubbing technology. Some storages also use methods such as N_2 flushing and using diffusion units with semipermeable membranes.

○ Ethylene (C_2H_4) removal: Also using scrubbers, commonly there are two main types: catalytic oxidation of C_2H_4 to water and CO_2 and using C_2H_4 absorbing beads. Some CO_2 scrubbers, for example flushing the N_2 can also reduce the concentration of C_2H_4.

Based on the purpose of storage, different CA methods are applied with different gas compositions, which require different amount of gas generation and control:

Table 1: Requirements for gas composition levels of different CA methods

CA methods	Description	O_2 (kPa)	CO_2 (kPa)	N_2 (kPa)
Controlled ventilation	The most basic method. CA created through accumulating CO_2 from produce's respiration in an airtight room.	6 - 18	3 - 15	79

CA methods	Description	O_2 (kPa)	CO_2 (kPa)	N_2 (kPa)
Conventional CA	Monitoring and adjusting CO_2 and O_2 levels from excessive CO_2 release of produce respiration.	2 - 5	2 - 5	90 - 92
LO (Low oxygen)	Maintaining O_2 level at 1.5 - 2 kPa	1.5 - 2	1 - 3	95 - 97.5
ULO (Ultra-low oxygen)	Maintaining O_2 level at 0.8 - 1.2 kPa	0.8–1.2	0.5–2	96.8–98.7
DCA or DCS (Dynamic controlled atmosphere)	The DCA storage consists of different stages: monitoring the levels of gasses according to the physiology of the fruit or vegetable, processing data in the control system, and then adjusting the atmosphere in the store	< 0.8	< 1.5	> 98

Source: Bodbodak, S., & Moshfeghifar, M., 2016

3.2.4. The importance of CA technology on quality of fruits and vegetables stored in warehouse

a) Effects on respiration

Controlled-atmosphere (CA) storage, with its manipulation of oxygen (O_2) and carbon dioxide (CO_2) levels, has a profound effect on fruit respiration. This passage explores this effect, highlighting the interplay between O_2 availability, CO_2 concentration, and fruit type.

Lowering O_2 levels in the storage atmosphere is a double-edged sword for respiration. At moderate reductions (around 3%), respiration slows down in many fruits and vegetables (Figure 1). This is likely due to a decrease in the activity of oxidases, enzymes crucial for respiration, rather than a direct impact on cytochrome oxidase. However, excessively low O_2 levels trigger anaerobic respiration, a less efficient process leading to off-flavor development and tissue breakdown. The optimal O_2 concentration for CA storage typically falls within a narrow range of 2-5%, depending on the produce and storage duration.

The effect of high CO_2 on respiration varies considerably depending on the fruit or vegetable. It can suppress respiration in some (apples, tomatoes), while stimulating it in others (potatoes, carrots). This inconsistency suggests that CO_2 might not directly target the core respiratory pathway but rather influence it indirectly, possibly through its effect on ethylene production.

High CO_2 can significantly reduce ethylene production in climacteric fruits (fruits with a ripening surge) like bananas and avocados. This delay in the ethylene burst translates to a delayed rise in respiration, characteristic of the climacteric peak. Conversely, some non-climacteric fruits and vegetables show increased ethylene production under high CO_2, possibly due to an early stress response.

b) Effects on ripening

CA storage affects ripening in several ways, primarily by slowing down the rate of respiration and ethylene production, the key factors influencing fruit ripening.

- Reduced respiration rate: Lowers the rate of sugar breakdown and energy production, delaying ripening.
- Decrease ethylene production: Inhibits the production of ethylene, a ripening hormone.

These effects are achieved through the manipulation of atmospheric conditions. Controlled-atmosphere storage creates an environment with lower oxygen (O_2) and higher carbon dioxide (CO_2) levels than ambient air. This disrupts the fruit's natural respiratory process, where it breaks down sugars for energy. The reduced O_2 levels and increased CO_2 levels act as a signal to the fruit to slow down respiration. Consequently, ethylene production is also inhibited, as ethylene biosynthesis is closely linked to respiration. Ethylene plays a critical role in promoting ripening, so its reduced production delays the onset of ripening and other senescence processes.

It is important to note that the effectiveness of CA storage on ripening varies depending on the fruit type and the specific CA conditions. Some fruits, like climacteric fruits, are more sensitive to CA storage than others. Climacteric fruits undergo a natural burst in respiration and ethylene production before ripening. CA storage is particularly effective in delaying the ripening of these fruits.

c) Effects on sensory quality

Controlled-atmosphere storage presents a double-edged sword for fruit and vegetable sensory quality. While it excels at preserving freshness and delaying ripening, it can also lead to the development of off-flavors and color changes.

CA storage can significantly influence the volatile compounds responsible for a fruit's unique aroma and flavor. In some cases, it excels at maintaining these qualities. Fruits like kiwi, pears, and tomatoes stored in CA retain their characteristic flavor profiles for longer compared to air-stored counterparts. Golden Delicious apples even show superior flavor retention under CA conditions. However, this is not a universal benefit. Limes and apricots, for example, experience a decline in flavor quality when stored in CA.

The impact of CA on volatile compound production is complex. Studies have shown that low O_2 levels can suppress their production in some apple varieties. Interestingly, even after removal from CA storage, these fruits may not recover their normal volatile compound production. Conversely, Granny Smith apples exhibited the highest volatile emissions after CA storage, particularly under low and ultra-low oxygen atmospheres. These findings highlight the importance of optimizing CA conditions for each fruit type.

An unfavorable balance of O_2 and CO_2 in CA storage can trigger the development of off-flavors and unpleasant tastes. This shift from aerobic to anaerobic respiration is often the culprit. For instance, lettuce exposed to high CO_2 levels develops off-flavors associated with the production of ethanol and acetaldehyde. Similarly, broccoli and cauliflower develop undesirable odors when stored under CO_2 concentrations exceeding 15%. Several fruits, including Granny Smith apples and peaches, also exhibit a tendency to develop alcoholic off-flavors under ultra-low oxygen conditions. Even sweet potatoes stored in low O_2 show a reduction in their characteristic sweet flavor. These examples underscore the need for careful monitoring and adjustments of O_2 and CO_2 levels to prevent such drawbacks.

CA storage can also impact the levels of ascorbic acid (vitamin C), an essential nutrient. Tomatoes stored in high CO_2 atmospheres experience an accelerated loss of ascorbic acid. Similar trends are observed in strawberries and blackberries. However, the effect of CA on ascorbic acid is not always negative. For example, pineapples stored under low O_2 conditions retain higher ascorbic acid content, highlighting the importance of tailoring CA conditions to specific produce.

Organic acids, particularly malic acid in apples, can be better preserved under optimal CA conditions. However, excessively high CO_2 levels (around 3%) can sometimes lead to a loss of acidity in these fruits. Tomatoes also exhibit a complex response, with titratable acidity initially increasing during CA storage and then decreasing with extended storage duration. Vegetables like lettuce and spinach generally retain higher levels of titratable acidity when stored in air compared to CA.

By delaying ripening, CA storage can maintain desirable textures in various fruits, including apples, pears, peaches, and tomatoes. Retention of firmness is a significant advantage for commercially stored apples. Both high CO_2 and low O_2 contribute to firmness, with high CO_2 playing a more prominent role. Conversely, some fruits, like kiwi, see this positive effect negated by even trace amounts of ethylene gas. The impact of CA on the texture of most vegetables is minimal. However, positive effects include a delay in softening of strawberries, reduced splitting in bitter gourd, and retention of firmness and color in vegetables like asparagus and green beans.

CA storage can also play a role in color preservation. The reduced breakdown of chlorophyll under CA conditions helps maintain the green color of vegetables like spinach and asparagus. High CO_2 concentrations are particularly effective in preserving chlorophyll content. Winter white cabbages stored under CA retain their green color and crisp texture better than those stored in air. Tomatoes also exhibit suppressed degradation of chlorophyll and synthesis of pigments like lycopene under CA storage.

In conclusion, CA storage presents a multifaceted approach to maintaining fruit sensory quality. While it offers advantages like delayed ripening and color preservation, careful consideration of O_2 and CO_2 levels is crucial to avoid the development of off-flavors and nutrient loss. By understanding the complex interplay between these factors and fruit physiology, we can optimize CA storage conditions to deliver high-quality produce to consumers.

4. Application of CA method in the warehouse storage of fruits and vegetables in Vietnam

4.1. The situation of current storage methods of fruits and vegetables in Vietnam

4.1.1. Current situation of fruits and vegetables market in Vietnam

Vietnam is a tropical country with favorable soil and climate conditions for producing a variety of fruits and vegetables. From 2017 to 2021, the fruit cultivation area in Vietnam increased by an average of 6.2% per year. The main types of fruit in Vietnam are bananas, dragon fruit, pomelo, mango, longan, durian, and jackfruit, all of which have seen steady growth over the years, with bananas having the highest proportion. In addition, the area of vegetables and beans in Vietnam increased by an average of 0.7% during the same period, and the output increased by an average of 3.3% (VietnamCredit, 2021). This shows that the potential for development and expansion of the fruit and vegetable production industry in Vietnam is not small.

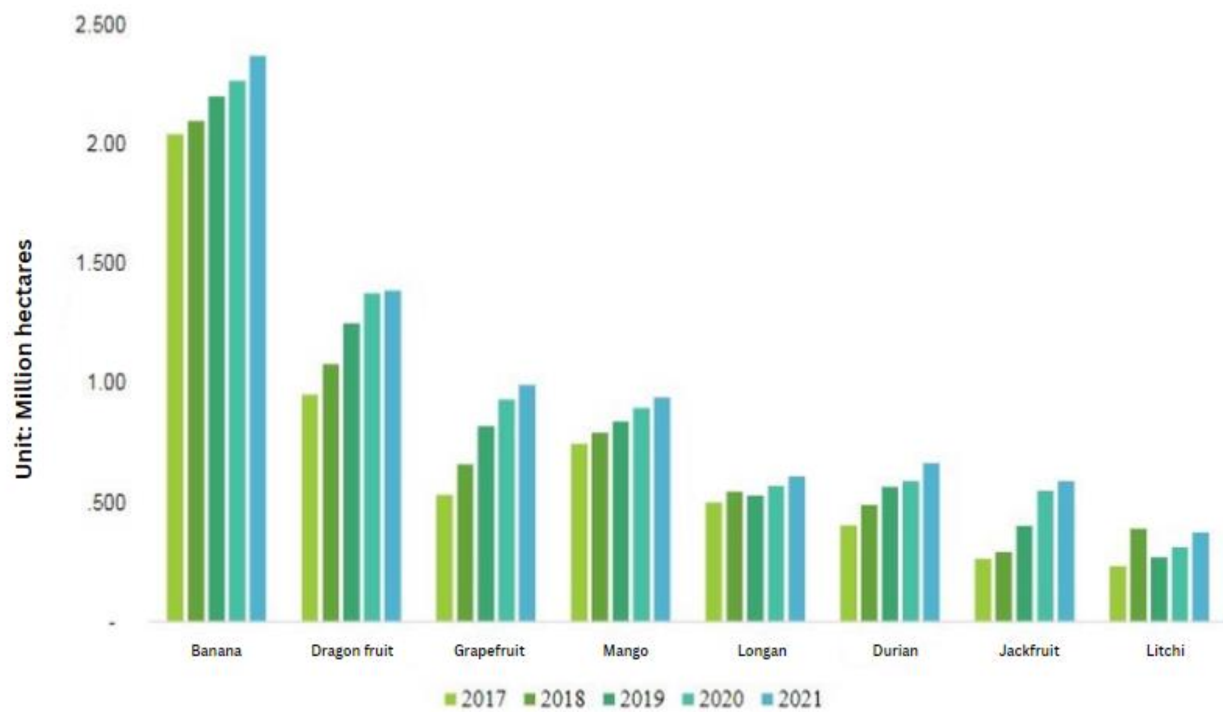

Figure 2. Yield of some fruit trees in Vietnam from 2017 to 2021

Source: Ministry of Agriculture and Rural Development, 2022

The Vietnamese Fruits and Vegetables market size is estimated at USD 18.10 billion in 2024, and is expected to reach USD 23.57 billion by 2029, growing at a CAGR of 5.42% during the forecast period from 2024 to 2029 (Mordor Intelligence, 2023).

Figure 3. Vietnamese fruits and vegetables market size

Source: Mordor Intelligence, 2023

Vietnam has a favorable climate and fertile land, which provides favorable conditions for agricultural export production. This is a strong point for the country with significant potential and high demand. Over the short term, the growing demand for Vietnamese fruits and vegetables among countries such as China and Korea and an increase in the number of free trade agreements to boost regional fruits and vegetable exports are some of the factors driving the market growth. According to ITC trade data, fruit export from Vietnam increased by almost 8% from 2020 and reached USD 5,504.5 million in 2021. The major importers of fruit from Vietnam are China, the United States, the Netherlands, Thailand, and Germany.

Of that, China is the major importer, with a value amounting to USD 2,080.1 million in 2021, which is almost 38% of the total fruit import value of the country. In the case of vegetables, the exports increased by 17.6% from 2020 and reached USD 486.3 million in 2021. Most of the vegetable exports from Vietnam are to the Asia-Pacific region, including China, Korea, Japan, and Singapore. The export of fruits and vegetables to Korea increased by 10.1% and to Japan by 20.1% in 2021. The major exports from the country to Korea include coconuts, bananas, mangoes, and dragon fruits.

In recent years, Vietnam has had the advantage of exporting vegetables and fruits in the EU market because Vietnam is the only country in the Asia Pacific region that has a free trade agreement with the EU. As a result, the tax rate on some Vietnamese vegetables and fruits exported to the EU market has been reduced to 0%, creating a significant competitive advantage compared to other countries in the region.

Therefore, with the increasing quantity and improving quality of vegetables and fruits in Vietnam, coupled with export and import opportunities to countries around the world, the market for vegetable and fruit production in Vietnam is a thriving one. This growth has led to the development of the entire supply chain, from preservation, processing, packaging, to transportation for export.

4.1.2. Current status and limitations of fruit and vegetable warehouse storage in Vietnam

a) Current status

In the past few years, the number of enterprises investing in the field of fruit processing and preservation has increased 3 times with 7,500 establishments processing and preserving fruits and vegetables, and about 156 processing factories with modern technology and production lines (VietnamCredit, 2021).

However, the processing industry can only use 8-10% of the annual output of vegetables and fruits. So far, 76.2% of exported fruits and vegetables have not been processed. Consumption is still in the form of fresh or preliminary preservation, and post-harvest losses are still too high, at about over 20% (VietnamCredit, 2021). Therefore, the biggest challenge of the Vietnamese fruit and vegetable industry is in the processing and preservation stages. The tropical fruits in Vietnam have the characteristic of spoiling quickly, and it takes a long time to reach distant consumer markets. As a result, Vietnamese businesses have not been able to fully exploit their advantages, thus limiting the export of agricultural products to neighboring countries in Asia such as Japan, South Korea, and China.

The losses after harvesting for fruits are about 25% and for vegetables are about 30%. Preserving fruits and vegetables is an important technology to reduce economic losses for farmers. However, the preservation technology in Vietnam is unable to meet the needs of vegetable farms. This is one of the reasons leading to fragmented and underdeveloped production, making it difficult to gather and preserve with consistent quality. Additionally, the harvesting techniques of our farms are generally still weak. Here are some post-harvest preservation methods currently used in our country:

- Irradiation, or sterilization using ionizing agents such as X-rays and gamma rays, is a method used to preserve food. Some types of irradiation include using infrared rays to kill fungi and using ultraviolet rays to kill harmful microorganisms. This method is costly and requires high technical expertise, so it is rarely used by farms in Vietnam.

- Using antioxidants, sulfur dioxide – preservation with anhydrous sulfur dioxide: There are two types, gas and wet sulfur dioxide, mainly used for hydroponic vegetables. Sulfur dioxide is injected into a container and directly sprayed onto the fruits and vegetables to be preserved. This method is labor-intensive and requires many containers, making it quite costly. Additionally, the sulfur dioxide preservation process is difficult to control the concentration and may cause environmental pollution and health hazards for workers.

- Cold storage is the most common method for preserving fruits and vegetables after harvesting. The cold storage industry in Vietnam is developing well and is expected to reach $295 million by 2025 with an annual growth rate of 12% (Cushman & Wakefield, 2024). As of May 2021, there are approximately 48 cold storage locations in the country, with a capacity of 700,000 pallets and a total capacity of about 2 million tons of products. Among these, about 66.7% are for export manufacturers and 8.2% are for domestic manufacturers. Cold storage in Vietnam is mainly used to preserve seafood and is not widely used in the agricultural product industry (Briefing, 2022).

b) Limitations of existing warehouse storage techniques

Cold storage is currently the most modern and safest preservation method in Vietnam, after harvest. However, freezing vegetables, roots, and fruits can affect the nutritional content of some types of vegetables and other nutrients. The temperature for cold storage depends on the type of agricultural product and the storage time. The typical storage temperature ranges from -2°C to 5°C.

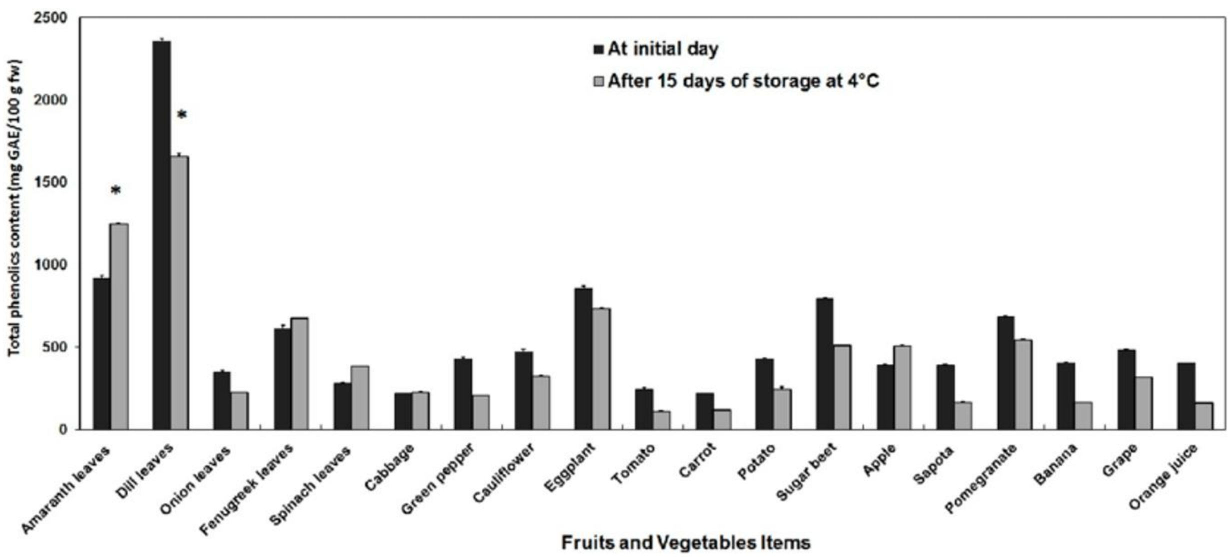

Figure 4. Changes in total phenolic content of fruits and vegetables before and after 15 days of storage at 4 °C

Source: Joseph Hubert, 2017

Total phenolics were extracted in methanol and measured by the Folin-Ciocalteu colorimetric method (Hubert, J., 2017). The phenolic compounds are secondary metabolites of plants such as flavonoids, alkaloids, and terpenoids. They not only have physiological functions but also have positive effects on human health due to their antioxidant properties (Rapisarda et al., 2018). Submitted study report has been published in a journal article, where it has been mentioned that anthocyanins, flavanones and hydroxycinnamic acids present in oranges and the antioxidant property of oranges are increased by storing at 6°C for 65 days but the vitamin C content becomes less. Researchers also found broccoli stored at 1°C for 28 has a rapid reduction of total antioxidant activity, ascorbic acid and total phenolic compounds contents (MenuSano, 2018).

4.2. Evaluation of the warehouse storage of fruits and vegetables in Vietnam

4.2.1. Potentials of Vietnam in the application of CA technology

Surging exports of fruits and vegetables and the limitations of traditional storage

Vietnam has great potential in the application of controlled-atmosphere (CA) technology in the fruits and vegetables market. This potential is driven by the large demand for storage due to the increasing export of agricultural products, including fruits and vegetables, to countries such as China and Korea which have been pointed out in 4.1 section.

According to the General Department of Customs, in January 2024, the export of fruits and vegetables brought in over 510 million USD, an increase of 24.9% compared to December 2023 and a significant 89% increase compared to January 2023.

In February 2024, due to the overlap with the Lunar New Year, export activities were temporarily suspended for one week. However, the estimated results of fruit and vegetable exports in February 2024 still reached 460 million USD, an increase of 56% compared to February 2023.

A gap in the market: Opportunity for controlled-atmosphere technology

Although the cold storage companies have the highest design capacity, they are classified as second-tier enterprises. The leading companies in this group include Hoang Lai, Hung Vuong, SATRA, and Phan Duy. Among them, Hung Vuong and SATRA were the first companies to implement cold storage to meet their own needs. However, these cold storage facilities are only equipped with basic and simple designs. Some of them even lack shelves for storing goods. On the other hand, foreign enterprises lead the market with 48% market share by effectively utilizing professional teams and modern equipment. However, the cost is high and only suitable for large orders. As mentioned above, although cold storage is considered the most modern technology after controlled-atmosphere, it is not yet fully optimized in terms of controlling the nutritional quality of goods and minimizing risks during preservation.

Therefore, the current Vietnamese market has potential stemming from the demand for exports and large-scale fruit and vegetable production, combined with the fact that the supply of services is not yet fully optimized, leaving many gaps for new enterprises to research and develop technologies to meet market demands.

Success stories of Vietnamese companies in applying new technological innovations

The development of agriculture applying high technology is an inevitable trend, the answer to the development of Vietnam's agriculture. According to the report, scientific and technological advances contribute over 30% of value added in agricultural production, 38% in seed production, and animal husbandry. The loss of agricultural products has decreased significantly. Therefore, the government and companies are increasingly promoting the application of science and technology, encouraging investment in companies focusing on the development of this technology. This is both a development potential and a driving force for healthy competition, bringing the best service to customers.

One of the technologies that helps preserve food after harvest is MAP (Modified Atmosphere Packaging) technology, widely used in the food industry and gradually replacing traditional food packaging methods with conventional packaging. Many Vietnamese companies are currently providing machinery and services based on MAP technology, helping to change the packaging and preservation process of agricultural products after harvest, for example: the Center for Information and Statistics of Science and Technology, SAYA PACK Trading and Technical Services Company, Sao Nam International Trading and Services Joint Stock Company (SANCOPACK), My Lan Joint Stock Company, etc.

Regarding the application only, CASS Vegetable and Fruit Preservation Company Limited was established, pioneering in providing CA storage systems, controlling temperature, humidity, and gas composition (oxygen, nitrogen, carbonic, ethylene, etc.) to inhibit agents causing damage, maintain natural living conditions, and extend the preservation time after harvest while ensuring quality. The intelligent CASS warehouse has a capacity of 4000 pallets (divided into 2 rooms) with double deep shelves, 9 floors, and a service area of up to 7000 m^2. CASS currently serves 4 trucks, 6 containers, with a daily import-export capacity of 150-200 tons. In addition, the company has a specialized humidification and ventilation system for fresh agricultural products, a nitrogen gas generation system, and automatic control to ensure the warehouse environment has an oxygen ratio from 5-10%, nitrogen from 90-95%. The warehouse is operated and managed by a precise, transparent robot and software system. Its location is 45 km from Cat Lai port, 40 km from Long An port, and 35 km from Tan Son Nhat airport. This technology helps accurately control the components of gasses, temperature, and humidity to extend the freshness of agricultural products by 2-4 times compared to current cold storage conditions, reducing high wastage rates. In addition, CASS also provides many services to reduce costs and increase the value of agricultural products: receiving, processing, preserving, distributing, and delivering. This success story serves as a model for further development and adoption of CA technology within Vietnam.

Overall, the application of high technology in agriculture is crucial for the development of Vietnam's agricultural sector, contributing to increased value, reduced losses, and healthy competition among companies, ultimately providing the best services to customers.

4.2.2. Difficulties in application of CA in Vietnam

High initial investment

The application of CA technology in Vietnam faces a significant challenge due to the high initial investment required. The cost of setting up a CA storage facility can be substantial, as it involves the purchase of specialized equipment, construction of the storage facility, and the installation of control systems to regulate temperature, humidity, and gas levels. This high upfront cost can be a barrier for many businesses, particularly small and medium-sized enterprises (SMEs) According to a report by the Food and Agriculture Organization which accounts for 97% of total (General Statistics Office of Vietnam, 2022), the cost of installing a CA storage facility can range from $3,000 to $20,000 per ton of storage capacity, depending on the complexity of the system and the local cost of materials and labor.

Poor infrastructure and facility

Efficient operation of a refrigerated warehouse hinges on one crucial factor: a reliable electricity supply. Most of the substantial coal reserves are found in the Quang Ninh region, while major gas reserves are located off the Eastern and Southwestern continental shelves. Hydropower reserves, on the other hand, are mainly situated in the Northern and Central regions. This contrasts with the demand for electricity, which is approximately 50% in the South, 40% in the North, and slightly above 10% in the Central region. These regional disparities, along with the significant differences in electricity networks between urban and rural areas, make it less likely for new cold storage facilities to be established.

Additionally, the nature of the agricultural industry necessitates the shortest possible delivery times, making road infrastructure an essential consideration. Regrettably, Vietnam's highway system is underdeveloped, particularly in the Mekong Delta and Southeast regions, which have total exploited lengths of just 117 km and 95 km, respectively.

Lack of high-quality labor and expert

Another challenge is the lack of high-quality labor and expertise in the field of CA technology. The operation of a CA storage facility requires specialized knowledge and skills, including understanding the principles of CA technology, the ability to monitor and adjust environmental conditions, and the ability to troubleshoot and maintain the equipment. However, Vietnam currently faces a shortage of skilled labor in this field. According to a study by the Vietnam Chamber of Commerce and Industry (VCCI), the lack of skilled labor is one of the top challenges faced by businesses in Vietnam, with 86% of businesses reporting difficulties in finding employees with the necessary skills.

Maintenance and control the condition of facility

The effectiveness of CA technology depends on the ability to maintain precise environmental conditions over extended periods. Any deviation from the optimal conditions can lead to a decrease in the quality of the stored produce. This requires regular monitoring and maintenance of the equipment, as well as a reliable power supply to ensure the continuous operation of the facility. However, in Vietnam, issues such as power outages and lack of access to maintenance services can pose challenges to the effective operation of CA storage facilities.

Customer mindset and priority

While CA technology can significantly improve the quality and shelf life of fruits and vegetables, it also increases the cost of storage. Customers who use the storage warehouse are producers. With exported products (require more strictly on the content of vegetables and fruit) producers are more likely to use cold storage or other methods which are safe and meet the importer's standard. However, in domestic markets, producers prioritize the cost instead of the quality of the products, so that they use chemicals to keep the vegetables fresh for a long day without much cost.

In Vietnam, many consumers prioritize price over quality when purchasing fruits and vegetables. According to a survey by the Vietnam Standards and Consumers Association (VINASTAS), 87% of consumers in Vietnam consider price to be the most important factor when buying fruits and vegetables. This preference for lower-priced produce may limit the market for fruits and vegetables stored using CA technology, thereby reducing the incentive for businesses to invest in this technology.

4.3. Recommendations for Vietnam

4.3.1. For the Vietnamese government

- Encourage financial support and incentives: The government should continue to expand funding programs such as the VND 5 trillion fund allocated by the Ministry of Agriculture and Rural Development (MARD) for the application of science and technology in agriculture. Such funding can be specifically directed towards the high initial costs of CA technology.
- Infrastructure development: The government should prioritize improving electricity supply and road infrastructure in agricultural regions. The Asian Development Bank's approved USD 1 billion package for a new expressway in the Mekong Delta region is a good start.
- Foster training and skill development: The government should continue to partner with international organizations to launch vocational training programs aimed at improving the skills of the workforce in the agricultural sector, like the initiatives launched with German Development Cooperation (GIZ).

4.3.2. For warehouse storage supplying enterprises

- Collaborate with research institutions: Enterprises should actively seek collaboration with institutions like the Postharvest Technology Institute (SOFRI) and international institutions to gain access to cutting-edge knowledge and practices.
- Explore public-private partnerships: Enterprises should consider forming partnerships with government agencies or established companies in the agricultural sector. The successful collaboration between the local government of Lam Dong province, Dalat Hasfarm Company, and the Danish government can serve as a model.
- Invest in advanced monitoring systems: Enterprises should incorporate technologies like IoT in their facilities for efficient monitoring and control of the environmental conditions. VinEco, a leading agricultural firm in Vietnam, has successfully adopted such technology.

4.3.3. For fruit and vegetable producers using warehouse storage services

- Focus on high-value commodities: Producers should prioritize the storage of high-value commodities like dragon fruit, mango, and lychee that have a high demand in export markets. This strategy will maximize the return on investment in CA storage.

- Leverage government funding: Producers should take advantage of the financial support options provided by the government to mitigate the cost of using CA storage facilities.

- Consumer education: Producers should participate in education and marketing campaigns to shift consumer preference towards quality over price. The "Vietnamese people prioritize using Vietnamese goods" campaign led by the Ministry of Industry and Trade (MOIT) is a successful example.

5. Conclusion

Controlled-atmosphere technique, which does not incur any chemical uses but only focusing on managing gas composition to maintain low O_2, high CO_2 and reduced C_2H_4 in an refrigerated yet high-retained humidity air environment, has proven its effectiveness in the warehouse storage of fruits and vegetables. Although specific figures for each parameter vary with different CA methods, a standard CA warehouse consists of airtight and thermally insulated rooms, machinery, refrigeration systems, equipment, etc to guarantee the most-desired storage environment. Before storing any kind of fruit or vegetables in warehouses, pretreatment is needed which differs based on specific types of horticultural products. CA measure can strongly help in preserving the quality of fruits and vegetables via three main effects: respiration rate, ripening process and sensory quality. Due to this importance of CA technology, itt is not only applied in many developed countries but also highly recommended for implementation in Vietnam - a nation with a large market size of fruits and vegetables along with increased demand in warehouse storage services and emerging technological absorption trend. However, it is essential to take into consideration the difficulties of the country in the application, including high initial investment, poor infrastructure, lack of high-quality labor and experts, challenges in maintaining precise environmental conditions in CA warehouses and changing customer mindset, to have suitable solutions for Vietnam to put CA into practice.

Together with the development and continuing construction of CA warehouses used for the storage of horticultural products worldwide, this report is expected to offer valuable insights about CA warehouse preservation of fruits and vegetables to enhance the understanding in the application of this method; therefore, assessing and recommending more comprehensively for the case of Vietnam to better Vietnamese fruits and vegetables storage, contributing to further research and practical applications in Vietnam. However, it is essential to acknowledge the limitations of this report. While it provides major theories about CA technology in the examined field and emphasizes key strategies to address Vietnamese current storage challenges, it may not cover every aspect of CA method in fruits and vegetables warehouse conservation as well as not proposing a radical solution for all the storage issues faced by Vietnam at present and in the future. Therefore, caution is advised for Vietnamese stakeholders and authorities when absorbing the CA knowledge and implementing any recommendation under specific situations affected by unmentioned external factors.

Lastly, our team would like to express sincere gratitude to our instructor, Dr. Nguyen Thi Yen, for her invaluable guidance and support throughout the completion of this report. Her instructions and feedback have significantly enhanced the quality of this work, aiding us in shaping the analysis to extract meaningful insights for future purposes and applications.

Reference

Anh Tuan, P. & Thanh Tinh, P.T. (2014). "Bảo quản vải thiều bằng phương pháp kiểm soát khí quyển", *cesti.gov.vn*, Available at: https://cesti.gov.vn/bai-viet/khong-gian-cong-nghe/quy-trinh-va-cong-nghe-san-xuat-con-kho-01000560-0000-0000-0000-000000000000.

Arshad, M. O. (2022). "Advancements in Controlled Atmosphere Storage Technology—A Review", *ResearchGate,* Available at: https://www.researchgate.net/publication/362033904_Advancements_in_Controlled_Atmosphere_Storage_Technology-A_Review/.

Bao Khanh, T. (2018). "Tổng quát về phương pháp bảo quản bằng khí quyển điều chỉnh CA", *luanvan.co,* Available at: https://luanvan.co/luan-van/tong-quat-ve-phuong-phap-bao-quan-bang-khi-quyen-dieu-chinh-ca-2923/.

Bodbodak, S. & Moshfeghifar, M. (2016). "Eco-Friendly Technology for Postharvest Produce Quality: Advances in controlled-atmosphere storage of fruits and vegetables", pp. 39–76.

Bodbodak, S., & Moshfeghifar, M. (2016). "Advances in controlled-atmosphere storage of fruits and vegetables", *Elsevier eBooks*, Available at: https://doi.org/10.1016/b978-0-12-804313-4.00002-5.

Butkeviciute, A., Viskelis, J., Liaudanskas, M., Viskelis, P. & Janulis, V. (2022). "Impact of Storage Controlled Atmosphere on the Apple Phenolic Acids, Flavonoids, and Anthocyanins and Antioxidant Activity In Vitro", *Plants,* Vol. 11 No. 2, p. 201.

CalCA (2016). "Case Study: Controlled Atmosphere Storage: Controlled atmosphere specialist CalCA provides energy efficient and reliable industrial refrigeration systems for produce storage", Available at: https://documents.opto22.com/casestudies/2180_Case_Study_Cal_Controlled_Atmos.pdf.

Cao, Y., Xu, K., Zhu, X., Bai, Y., Yang, W. & Li, C. (2019). "Role of Modified Atmosphere in Pest Control and Mechanism of Its Effect on Insects", *Frontiers in Physiology,* Vol. 10.

David R Dilley. (2006). "Development of controlled-atmosphere storage technologies", *Stewart Postharvest Review,* Vol. 2 No. 6, pp. 1–8.

Edinburgh Sensors (2019). “Frozen Food Storage Gas Monitoring*”, Edinburgh Sensors*, Available at: https://edinburghsensors.com/news-and-events/gas-monitoring-in-frozen-and-dried-food-storage/.

Food and Agriculture organization of the United Nations (2021). “Get Involved - International Day of Awareness of Food Loss and Waste”, Available at: https://openknowledge.fao.org/server/api/core/bitstreams/63e6ac5c-68ab-4525-aea8-83c9896f5e0f/content.

Haginuma, S. (1972). “Controlled Atmosphere Storage of Fruits in Japan”, Available at: https://www.jircas.go.jp/sites/default/files/publication/jarq/06-3-175-180_0.pdf.

Hubert, J., Patel, J., Patel, N. & Talati, J. G. (2017). “Storage of Fruits and Vegetables in Refrigerator Increases their Phenolic Acids but Decreases the Total Phenolics, Anthocyanins and Vitamin C with Subsequent Loss of their Antioxidant Capacity”, *ResearchGate*, Available at: https://www.researchgate.net/publication/318658975_Storage_of_Fruits_and_Vegetables_in_Refrigerator_Increases_their_Phenolic_Acids_but_Decreases_the_Total_Phenolics_Anthocyanins_and_Vitamin_C_with_Subsequent_Loss_of_their_Antioxidant_Capacity.

Linh, P. (2024). “Ứng dụng công nghệ kiểm soát khí quyển - CA kéo dài thời gian bảo quản nông sản”, *congnghiepcongnghecao.com.vn*, Available at: https://congnghiepcongnghecao.com.vn/tin-tuc/t24755/ung-dung-cong-nghe-kiem-soat-khi-quyen--ca-keo-dai-thoi-gian-bao-quan-nong-san.html#:~:text=Ki%E1%BB%83m%20so%C3%A1t%20kh%C3%AD%20quy%E1%BB%83n%20%E2%80%93%20CA.

Mordor Intelligence (2023). “Vietnam Fruits and Vegetable Market Size, Analysis | 2022 – 27”, *www.mordorintelligence.com*, Available at: https://www.mordorintelligence.com/industry-reports/vietnam-fruits-and-vegetables-market.

Navarro, S. (2010). “Commercial applications of oxygen depleted atmospheres for the preservation of food commodities”, *Elsevier eBooks*.

Pace, B., Cefola, M., Logrieco, A.F., Sciscio, B., Sacchetti, A., Siliberti, M., Laforgia, P., Amodio, A., Calderoni, G., Garavelli, C.A., Amodio, M.L. & Colelli, G. (2020). “Shipping container equipped with controlled atmosphere: Case study on table grape”, *Journal of Agricultural Engineering,* Vol. 51 No. 1, pp. 1–8.

Phong, N. A. (2023). “NGÀNH HÀNG RAU QUẢ VIỆT NAM”, Available at: https://psav-mard.org.vn/upload/Tài%20liệu_VN/2023/Master%20Slide%2007.12.2022_VN.pdf.

Tan, S. (2016). “Storage of fresh fruit and vegetables”, *www.agric.wa.gov.au*, Available at: https://www.agric.wa.gov.au/fruit/storage-fresh-fruit-and-vegetables?page=0%2C0#smartpaging_toc_p0_s1_h3.

Team, M. (2018). “Effects of Cold Storage on the Nutritional Value of Food”, *MenuSano*, Available at: https://www.menusano.com/effects-of-cold-storage-on-the-nutritional-value-of-supermarket-foods-and-vegetables/.

Tungmunnithum, D., Thongboonyou, A., Pholboon, A. & Yangsabai, A. (2018). “Flavonoids and Other Phenolic Compounds from Medicinal Plants for Pharmaceutical and Medical Aspects: An Overview*”, Medicines,* Vol. 5 No. 3, p. 93.

Valdez Fragoso, A. and Mújica-Paz, H. (2016). “Controlled Atmosphere Storage: Effect on Fruit and Vegetables”, *Encyclopedia of Food and Health*, pp. 308–311.

Vietnam Industry & Trade Information Center and Vietnam Fruit and Vegetables Association (2021). “Overview of Vietnam’s fruit and vegetables industry”, *VietnamCredit*, Available at: https://vietnamcredit.com.vn/news/overview-of-vietnams-fruit-and-vegetables-industry_14570.

Vy, N. H. L. (2022). “Vietnam’s Cold Storage Industry: Drivers, Challenges and Market Entry”, *Vietnam Briefing News,* Available at: https://www.vietnam-briefing.com/news/vietnams-cold-storage-industry-drivers-challenges-market-entry.html/.

www.senmatic.com. Transporting perishable commodities in CA Reefer Containers, Available at: https://www.senmatic.com/sensors/knowledge/controlled-atmosphere-reefer-containers#:~:text=Transporting%20perishable%20commodities%20in%20Controlled.