



**EFFECT OF ACTIVE MODIFIED ATMOSPHERE PACKAGING  
ON MAINTAINING THE QUALITIES OF TOMATOES DURING  
COLD STORAGE**

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**MASTER OF SCIENCE  
IN  
POSTHARVEST TECHNOLOGY AND INNOVATION**

**SCHOOL OF AGRO-INDUSTRY  
MAE FAH LUANG UNIVERSITY**

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**THIS THESIS IS A PARTIAL FULFILLMENT OF  
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**Thesis Title:** Effect of Active Modified Atmosphere Packaging on Maintaining the Qualities of Tomatoes During Cold Storage


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Matshidiso Masopa



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## ABSTRACT

During ripening, the respiration and ethylene production of tomato (*Lycopersicon esculentum* Mill.) increase, expediting postharvest quality deterioration. This study examined the integration of active packaging with modified atmosphere packaging (MAP) to extend the shelf life of tomatoes at both small and large scales during cold storage. In the first experiment, the impact of a CO<sub>2</sub>-emitting pad within a low-density polyethylene (LDPE) bag, in comparison to ethylene (C<sub>2</sub>H<sub>4</sub>) scavengers and nitrogen (N<sub>2</sub>) flushing, on the quality deterioration of breaker-turning tomatoes during cold storage was investigated in small-size packaging (400g/bag). Tomatoes were packed in LDPE bags for 21 days with 11 treatments: T1= Control (without an active agent) stored at a room temperature (25°C), T2= LDPE bag (passive MAP), T3= with CO<sub>2</sub>-emitter at a concentration of 0.5g (0.278 g NaHCO<sub>3</sub> + 0.222 g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>), T4= flushing with mixed gas (5% CO<sub>2</sub> + 5% O<sub>2</sub> + 90% N<sub>2</sub>) T5= flushing with 99.5% N<sub>2</sub> only and T6= with ethylene scavenger, held at a temperature of 6±1°C. The alternative batch was also stored in small-size packaging (400g/bag) at a storage temperature of 12±2 °C as detailed: T7=LDPE bag (passive MAP), T8= with CO<sub>2</sub>-emitter, T9= flushing with mixed gas (5% CO<sub>2</sub>+5% O<sub>2</sub>+90% N<sub>2</sub>), T10= flushing with 99.5% N<sub>2</sub> gas only, and T11= with ethylene scavenger.

The results indicated that in Active MAP, particularly with CO<sub>2</sub>-emitter, ethylene scavenger and passive MAP, there was a significant increase in CO<sub>2</sub> levels and a decrease in O<sub>2</sub> levels, along with postponed color changes and a slower decay rate of tomatoes, notably at 6±1 °C storage conditions. At the conclusion of storage, the MAP paired with a CO<sub>2</sub> emitter at a low temperature of 6±1°C effectively delayed tomato ripening, as seen by the postponement of color changes and reduced damage compared to all other treatments, particularly the control group.

Following these findings, a subsequent experiment was performed on modified atmosphere packaging (MAP) combined with CO<sub>2</sub> emitter (CO<sub>2</sub>-pad) at different concentrations to identify the best concentration to be applied with MAP in experiment 2. This involved testing various concentrations of a CO<sub>2</sub> emitter in packed turning-pink tomatoes, stored at a temperature of 6±1°C for a duration of 28 days. Treatments included T1 as the control (tomatoes in LDPE bag without active agent) known as passive MAP and other treatments utilizing a CO<sub>2</sub>-emitting pad in varying ratios: T2 with a single ratio 0.25g (0.139 g NaHCO<sub>3</sub> + 0.111 g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>), T3 with a double ratio 5g (0.278 g NaHCO<sub>3</sub> + 0.222 g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>), and T4 with a quadruple ratio 1g (0.556 g NaHCO<sub>3</sub> + 0.444 g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>), with samples stored at 6±1 °C. The findings indicated that CO<sub>2</sub>-pad (T4) effectively preserved color values and reduced the decay rate of tomatoes more efficiently up to 20 days than alternative treatments when stored at 6±1°C. There were no significant differences in firmness, total soluble solids, titratable acidity and ascorbic acid across all treatments during the storage periods. Adverse effects were observed in tomatoes stored under Active MAP (T4), exhibiting increased softening and water-soaked patches after 16 days of cold storage, attributed to chilling injury. The findings indicated that an Active MAP, specifically the T4 treatment at a low temperature of 6±1°C, effectively extended the shelf life of tomatoes from 8 days to 16 days. However, specific issues require consideration, particularly the potential for chilling injury which might have been caused by low storage temperature. Next study is essential to investigate the optimal temperature and concentration of CO<sub>2</sub> to mitigate these disorders. Furthermore, after identifying the CO<sub>2</sub> emitter concentration which

performed better in the second experiment the third experiment was then conducted by comparing the treatments of Active MAP with CO<sub>2</sub> emitter and flushing of mixed gas (5%CO<sub>2</sub>+5% O<sub>2</sub>+90% N<sub>2</sub>) on mature green tomatoes in a larger scale (bulk-size of 1000g/bag) during a storage temperature of 12±2°C for a duration of 30 days. The quadruple concentration from experiment 2 in T4 which was 1g (0.556 g NaHCO<sub>3</sub> + 0.444 g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>) was then multiplied 3 times making a total of 3g (1.668 g NaHCO<sub>3</sub> + 1.332 g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>). The concentration was increased since this time tomatoes were packaged in bulk-sizing. Three treatments were assessed: C = control (tomatoes in LDPE bag without active agent) known as passive MAP, T1 = CO<sub>2</sub> emitter pad at 3g (1.668 g NaHCO<sub>3</sub> + 1.332 g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>), and T2 = mixed gas (5% CO<sub>2</sub> + 5% O<sub>2</sub> + 90% N<sub>2</sub>). The results demonstrated significant differences in treatments with increased CO<sub>2</sub> and reduced O<sub>2</sub>, as evidenced by delayed weight loss, hardness, color changes, lycopene accumulation, decay rate, and diminished ethylene production and respiration rate of tomatoes during storage. The findings indicate that utilizing Active MAP with CO<sub>2</sub> emitters at a storage temperature of 12±2°C can maintain the quality and prolong the shelf life of ripe green tomatoes for up to 30 days.

**Keywords:** Active Modified Atmosphere Packaging, Carbon Dioxide Emitter, Physiological Disorders, Tomato Qualities

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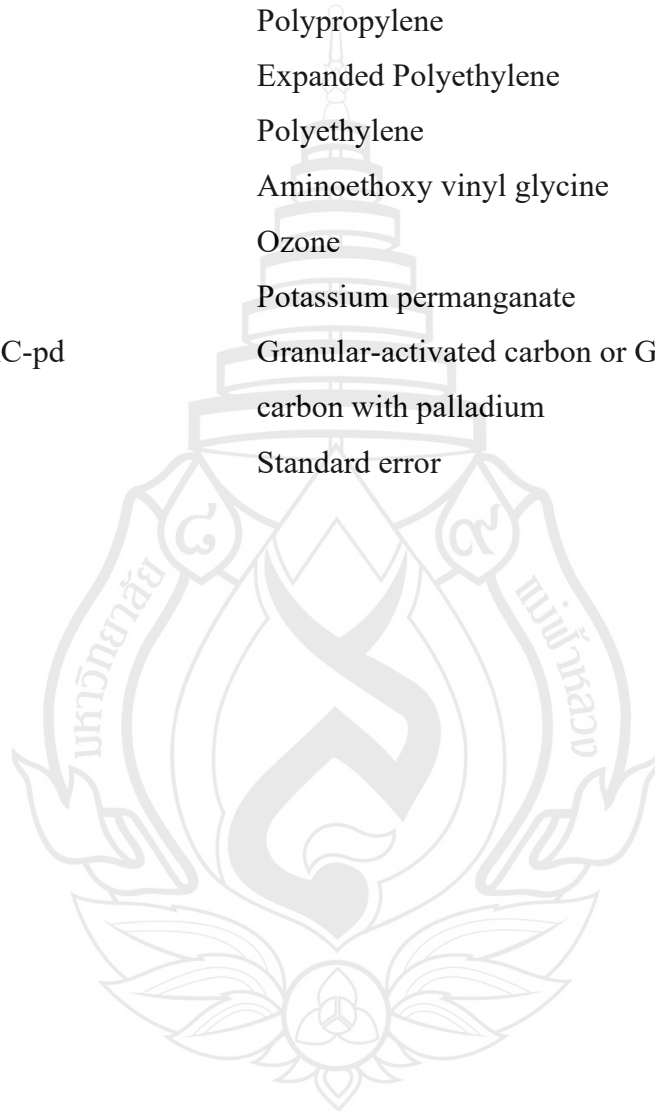


## ABBREVIATIONS AND SYMBOLS

MAP	Modified Atmosphere Packaging
MA	Modified Atmosphere
CO <sub>2</sub>	Carbon dioxide
O <sub>2</sub>	Oxygen
DI	Damage incidence
DS	Disease severity
LDPE	Low density polyethylene
NaHCO <sub>3</sub>	Sodium bicarbonate
C <sub>6</sub> H <sub>8</sub> O <sub>7</sub>	Citric acid
SBC	Sodium bicarbonate
FAO	Food Agriculture Organization
ACC	1-aminocyclopropane -1- carboxylic acid
ACS	1-aminocyclopropane -1- carboxylic acid synthase
ACO	1-aminocyclopropane -1- carboxylic acid oxidase
DP	Decay percentage
H <sub>2</sub> O	Water
C <sub>2</sub> H <sub>4</sub>	Ethylene
pH	Potential of hydrogen
RH	Relative Humidity
1-MCP	1-methylcyclopropene
CaCl <sub>2</sub>	Calcium chloride
N <sub>2</sub>	Nitrogen
H <sub>2</sub> CO <sub>3</sub>	Carbonic acid
Active MAP	Active Modified Atmosphere Packaging
PET	Polyethylene terephthalate
LDP	Low-density polyethylene
HDP	High-density polyethylene

## ABBREVIATIONS AND SYMBOLS (continued)

PVC	Polyvinyl chloride
PP	Polypropylene
EPE	Expanded Polyethylene
PE	Polyethylene
AVG	Aminoethoxy vinyl glycine
O <sub>3</sub>	Ozone
KMnO <sub>4</sub>	Potassium permanganate
GAC or GAC-pd	Granular-activated carbon or Granular-activated carbon with palladium
SE	Standard error



# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Tomato (*Lycopersicon esculentum* Mill.) is a widely produced vegetable around the world and consumed as fresh or processed products (Fagundes et al., 2015). The global production of fresh tomatoes was approximately 189.134 million metric tons in 2021 on a land of 5.1 million hectares (Food Agriculture Organization, 2021). Because of its nutritious and antioxidative properties in the diet, tomatoes have grown in popularity and demand in recent years as consumer knowledge of healthy eating has increased (Tilahun et al., 2021). Tomato is beneficial to human health as it contains compounds such as Vitamin C, flavonoids, and carotenoids. It contains high lycopene (71.6%), as well as beta-carotene (17.2%), pro-vitamin A carotenoids (14.6%), vitamin C (12.0%), and vitamin E (6.0%) (Fagundes et al., 2015). Tomato is among the vegetables which are in high demand, and its products have a significant economic value across the world. Tomato is significant due to its highly valued sensory qualities, its ability to be incorporated into a variety of food preparations, whether cooked or raw, and its nutritional value as a significant source of bioactive compounds with antioxidant activity, with lycopene being one of the more intriguing ones. Fresh tomato and its processed products are the major sources of lycopene in the diet (Camara et al., 2013). Tomato, in its different forms, is widely consumed and can supply various secondary metabolites which are responsible for free radical scavenging effects. Different types of cancers have been found to be prevented by consuming fresh tomatoes or tomato products on a regular and sufficient intake. However, post-harvest quality degradation of tomatoes has long been a challenge in food processing, as loss of specific phytochemicals may interfere with

this vegetable's pharmacological potential. With better living standards and a focus on health, the demand for high-quality fruits and vegetables has increased dramatically (Quinet et al., 2019).

The tomato is classified as a climacteric fruit, meaning that its maturation is accompanied by an increase in respiration and ethylene production. This process accelerates the degradation of quality, including softening, color changes, and aroma development (Fagundes et al., 2015). The metabolic processes of the majority of tomato cultivars are accelerated by a climacteric change in respiration. Some studies have suggested a positive correlation between ethylene levels in harvested produce and respiration rate. Any increase in respiration caused by ethylene would result in increased storage losses and a reduction in postharvest quality (Guo et al., 2014).

Preservation techniques such as Active MAP can be used to control these transformations and degradations related to increased respiration and ethylene production rates. MAP is the process of regulating the concentrations of CO<sub>2</sub> and O<sub>2</sub> in food containers by altering the atmosphere through respiration (passive MAP) or the addition and removal of gases (active MAP) (Fagundes et al., 2015). The technology entails packaging horticultural produce in permeable films delaying senescence and deterioration. A modified atmosphere with higher CO<sub>2</sub> and lower O<sub>2</sub> levels than the normal air is generated inside the package when the product respiration, package permeability, and storage temperature interact. An appropriate packing material should be considered when using passive MAP for postharvest preservation. Different headspace conditions may be achieved within the container as a result of the interaction between the rate of product respiration and the diffusion of gas through the polymeric matrix. It is critical to match commodity qualities to film permeability to create an acceptable atmosphere inside the package. As a result, the choice of plastic film is a crucial aspect in optimizing the atmosphere inside the package, allowing for the extension of product shelf life. The permeability properties of most polymeric films typically used in MAP have limitations such as high barriers to water vapor, anaerobiosis production, development of off-flavor and a higher permeability to CO<sub>2</sub> than O<sub>2</sub> (Paulsen et al., 2019).

Reduction of O<sub>2</sub> and elevation of CO<sub>2</sub> can reduce the respiration rate, which in turn delays ripening, reduces ethylene production, delays softening, and slows down the compositional changes associated with ripening. Consequently, the quality of tomatoes is maintained, and the shelf life is extended (Fagundes et al., 2015). Furthermore, anaerobic metabolism can occur when the O<sub>2</sub> and CO<sub>2</sub> levels are excessively low and high, respectively. This can result in off-flavors, physiological and microbiological decay, browning and softening. MAP can reduce ethylene synthesis and its effect on horticultural produce. However, MAP has to be combined with low. By lowering oxygen levels and increasing carbon dioxide levels, MAP helps preserve fruit quality during air storage. There are several instances, nevertheless, in which the modified atmosphere's oxygen and carbon dioxide levels are either too high or too low. Active packaging in these circumstances may raise overall quality by modifying the physiology of harvested fruits and vegetables in a preferable way (Bodbodak & Moshfeghifar, 2016).

Active packaging is a novel idea of food packaging that aims to enhance the quality and safety of fresh products due to changes in current consumption and market patterns (García-García et al., 2013). This type of packaging can be widely categorized into two different types: non-migratory active packaging, which primarily comprises of scavengers intended to eliminate undesired elements inside packaging without the intention for migration, and active releasing packaging, which consists of emitters that facilitate the controlled migration of desired compounds into the packaging atmosphere thereby benefiting the food product (Dainelli et al., 2008). Absorbing (scavenging) systems remove undesired compounds such as oxygen, carbon dioxide, ethylene, excessive water, taints, and other specific compounds. Releasing systems actively add or release substances such as carbon dioxide, antioxidants, and preservatives to the headspace of the container or the packaged food (Bodbodak & Rafiee, 2016). Delaying the ripening of climacteric fruits by using active packaging to regulate their environment has the potential to provide good yield at a relatively low cost. The shelf life of perishable products can be extended while economic losses associated with deterioration are reduced through the use of MAP and cold storage. This allows for extended transport distances while simultaneously decreasing moisture loss during

stowage. The shelf life of fresh vegetables can be extended by reducing the rate of respiration through the use of MAP. Nevertheless, the establishment of the appropriate modified atmosphere within the container is contingent upon the respiration rate of the vegetable, the permeability of the packaging film, and the emission of CO<sub>2</sub> gas and vapor. This is the reason why the use of macro-perforated films or a combination of micro-perforations and suitable permeability qualities in the films used to envelop the vegetable may be necessary to achieve the appropriate steady-state gas composition for vegetables. The majority of MAP for fresh produce employs a packing film that obstructs the diffusion of gases (ethylene, CO<sub>2</sub>, O<sub>2</sub>, and vapor) through its wall. To achieve the appropriate equilibrium gas composition, the package design process involves selecting the material, surface area, and thickness of the packaging film. (García-García et al., 2013). This is accomplished when the rate of carbon dioxide and oxygen transmission through the package is equivalent to the rate of respiration of the product (Batu & Thompson, 1998).

Types of plastic films which are commonly used are poly (vinyl chloride), oriented polypropylene, and low-density polyethylene (LDPE). However, even after selecting the most appropriate film characteristics, it is very difficult to achieve the modified atmosphere because of the difficulty of managing all the parameters impacting the gas composition in the package, which also continues to vary throughout the commercial life of the packed product. This is a problem with using either active or passive MAP to increase the storage life of pre-packaged fresh produce. By using active packaging, fresh fruits and vegetables may meet the modified atmosphere throughout their commercial life, leading to improved quality, higher safety, and a longer shelf life (García-García et al., 2013). The type of packaging has a significant impact on the shelf life of food products. A good packaging system should preserve food from contamination and conditions that shorten its shelf life. A packaging system must be inert, inhibit microorganisms, non-toxic, stable, and protect food from factors that deteriorate food quality during travel and handling. By managing physiological activity and increasing food shelf life, active packaging systems have the potential to provide major benefits in reducing quality loss. It has been observed that ethylene production speeds up ripening and senescence, hence incorporation of ethylene scrubbers within

the packaging material can be an alternative. Different active packaging systems can be used to reduce spoilage of fresh produce such as ethylene and oxygen scavengers, CO<sub>2</sub> emitters, desiccants, and antimicrobial compounds (Bhardwaj et al., 2019). Controlling ethylene levels in the environment around fresh produce throughout transportation, storage, and handling after harvesting is critical to enhance their quality and extend shelf-life. Active packaging with ethylene-scavenging properties can reduce the negative effects of ethylene.

Active packaging contains additives with a variety of active functions, such as absorbing/scavenging qualities (e.g., oxygen, carbon dioxide, moisture, ethylene, flavors); (ethanol, carbon dioxide, antioxidants, preservatives, sulfur dioxide, and flavors). Scavengers used in film packaging, either in conjunction with a solid incorporated into the plastic or as a surface on the package, are known to be an excellent option for packet-related packaging. Maximizing preservation necessitates a combination of ethylene scavenging and antibacterial improvement, both of which can extend the shelf life of fresh fruit (Vilela et al., 2018).

Carbon dioxide has releasing/emitting qualities that can help preserve quality and extend shelf life. Citric acid, sodium bicarbonate, and ferrous carbonate are a few examples of compounds that emit CO<sub>2</sub> (Vilela et al., 2018). Sodium bicarbonate (NaHCO<sub>3</sub>) and an organic acid, are often used as active substances for releasing CO<sub>2</sub>. Mostly, citric acid is the preferred acid in these systems (Yildirim et al., 2018). Nitrogen (N<sub>2</sub>) gas is also one of the main gases that can be applied with MAP to maintain the quality of fresh produce (Alden et al., 2019). Nitrogen (N<sub>2</sub>) gas packing is a prominent antioxidation technology in the food industries and beverage sectors. This approach might be used to improve the shelf life of fresh-cut vegetables (Koseki & Itoh, 2002). N<sub>2</sub> is used to substitute O<sub>2</sub> in packaging to retard oxidative rancidity and hinder the growth of aerobic microorganisms. The amount of oxygen used in MAP is often kept as low as possible in order to prevent the formation of aerobic spoilage microorganisms (Sivertsvik et al., 2002).

The challenge with tomato is that it is a climacteric fruit in which its ripening is associated with increased respiration and ethylene production which accelerates quality loss such as softening, color changes, and aroma development (Fagundes et al., 2015).

Hence, applying preservation techniques such as Active MAP can be used to control these quality changes. To our knowledge, there has been limited information on the application of Active MAP to maintain quality and extend the shelf life of tomatoes during cold storage especially with MAP and CO<sub>2</sub> emitters.

## **1.2 Objectives**

1.2.1 To investigate the different types of active MAP to prolong the shelf life of tomatoes in small and bigger scales during cold storage at  $6\pm 1^{\circ}\text{C}$ ,  $12\pm 2^{\circ}\text{C}$  and  $25^{\circ}\text{C}$

1.2.2 To investigate different concentrations of CO<sub>2</sub> emitter in small scale during cold storage at  $6\pm 1^{\circ}\text{C}$

## **1.3 Scope of Research**

1.3.1 CO<sub>2</sub> emitter pads were prepared and tested

1.3.2 Different active agents (CO<sub>2</sub> emitter, ethylene scavenger), mixed gas (CO<sub>2</sub>, O<sub>2</sub> and N<sub>2</sub>) and N<sub>2</sub> gas flushing alone were incorporated in LDPE plastic films and used on tomatoes during cold storage at  $6\pm 1^{\circ}\text{C}$ ,  $12\pm 2^{\circ}\text{C}$  and  $25^{\circ}\text{C}$  of tomatoes in small-size packaging (400g/bag).

1.3.3 Different concentrations of CO<sub>2</sub> emitters were incorporated in LDPE plastic films and used on tomatoes during cold storage at  $6\pm 1^{\circ}\text{C}$  in small-size packaging (400g/bag).

1.3.4 Tomato qualities in the bulk-size packaging (1000g/bag) during cold storage at  $12\pm 2^{\circ}\text{C}$  were determined to investigate the effect of MAP combined with CO<sub>2</sub> emitter, CO<sub>2</sub>, O<sub>2</sub> and N<sub>2</sub> gas flushing on tomatoes.

## **1.4 Expected Benefits**

### **1.4.1 Research Outcomes**

1.4.1.1 Extension of shelf life of tomato or reduction of quality loss during

cold storage by using MAP.

1.4.1.2 The user-friendly technique can be used to maintain the quality of tomatoes along the supply chain.

1.4.1.3 Contribute in reducing postharvest losses of tomato

#### **1.4.2 Research Outputs**

1.4.2.1 Alternative preservation technique for extending tomato shelf life

1.4.2.2 Conference proceedings or publication of the research results



## CHAPTER 2

### LITERATURE REVIEW

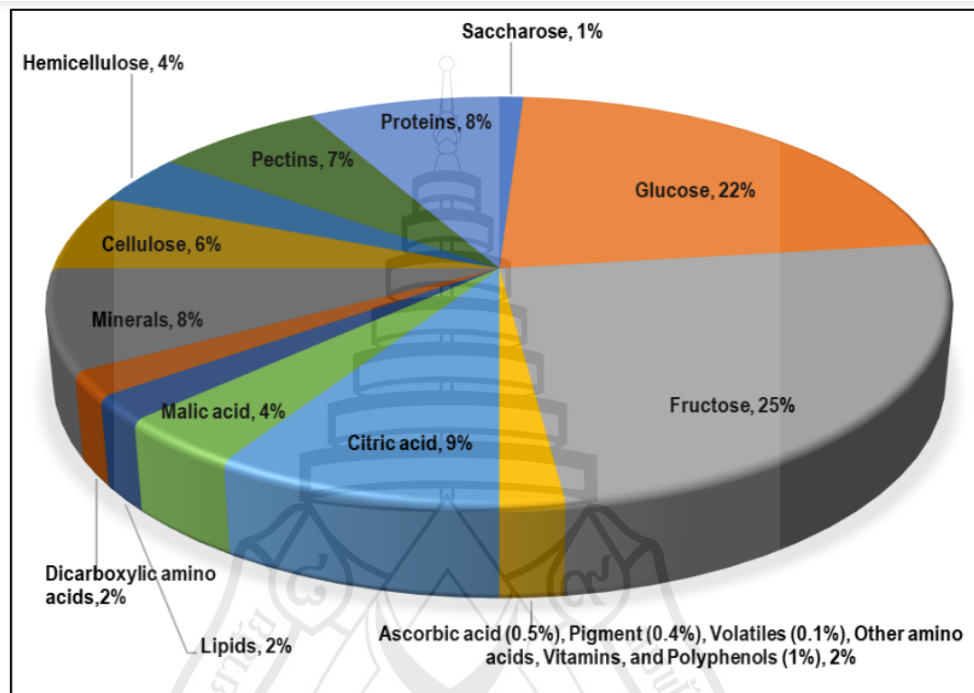
#### 2.1 Tomato

Tomato fruit (*Lycopersicon esculentum* Mill.) is widely grown and consumed in different ways such as fresh or processed products around the world (Domínguez et al., 2016). It is considered a sensitive warm-season crop; however, it is a perennial plant that is grown annually. Tomato is frost sensitive with optimal growing conditions of 70-85 degrees F during the day and 65-70 degrees F at night. Harvesting is done after tomato fruits have reached the mature-green stage. If harvested earlier, the fruit will not mature properly (Kelley et al., 2010). The diverse health benefits of tomato fruit underscore the necessity and significance of tomatoes in our daily diet. The shift in eating practices in both developed and developing nations can be attributed to these health benefits, which have increased the demand for high-quality, fresh, nutrient-rich fruits. This necessitates the use of suitable storage techniques to preserve the freshness of fruits and minimize their quantitative and qualitative losses (Vijay et al., 2011). According to data from the Food and Agriculture Organization Corporate Statistical Database in 2021, the global production of tomatoes was 189.134 million metric tons. China had the highest production of tomatoes with 38.714 million metric tons making 20.5% of the world's production. The top ten countries for global production were China, the United States of America, India, Turkey, Egypt, Italy, Iran, Spain, Brazil and Mexico respectively (FAO, 2021).

Tomatoes are used in many basic staple recipes. They may be eaten fresh in salads or cooked in sauces, soups, meats, or fish. Tomato paste and ketchup are also commonly used to flavor a variety of foods. Fruits may be stored by drying or preserving in cans to ensure their availability year-round. Tomatoes include a variety of nutrients that are useful to consumer health and well-being. Tomatoes are rich in

carbohydrates, proteins, fatty acids, minerals, vitamins, amino acids, and phenolic compounds (Figure 2.1). The fruits are cholesterol-free, lipids (0.3%) and protein (1.1%) contents are found in trace levels. Vitamins present in tomatoes include A, C, K, B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6, and B9 (folate). Several investigations have discovered 23 different types of minerals. They account for 8% of dry matter and include both main elements (magnesium, phosphorus, calcium, potassium, sodium, sulfur, chlorine) and minor elements (iron, iodine, zinc, fluorine, cobalt, manganese, and so on). Carbohydrates, primarily fructose (25%) and glucose (22%), account for more than 50% of the dry matter's sugar content. Organic acids, which play a key role in fruit acidity, account for 10% of dry matter and are mostly composed of citric acid (60%) and malic acid (4%). Amino acids also represent 2–2.5% of the tomato's dry matter, which has a significant impact on its flavors. Tomatoes are rich in antioxidants mainly from lycopene,  $\beta$ -carotene, ascorbic acid, phenolic acids, anthocyanins, and flavonoids. These compounds are essential to consumers' nutrition. Consuming 100 g of tomato gives up to 20 calories, which is around 1% of daily needs. Tomatoes also have several health benefits, including lowering the risk of cardiovascular disease, cancer, and diabetes. These good benefits result from antioxidant and micronutrient functions such as lycopene, minerals, fibers, and vitamins, which are vital for the body's functioning and resistance to diseases. Tomatoes are a good source of vitamins that may be used therapeutically in cases of deficiency or in relation to other diseases, including cancer. Tomatoes are high in vitamins C and E, which help the body maintain its acid-base balance, develop important organs, transmit nerve signals, and control blood pressure. Tomatoes contain a pigment called lycopene, which can help prevent diabetes, colon, prostate, and breast cancer. The consumption of dietary lycopene is part of the strategies for managing patients with diabetes. Studies have shown that lycopene stimulates an increase in insulin levels, a decrease in glucose levels, and an improvement in lipid profiles in diabetic mice. It also improves kidney function and antioxidant activities. Therefore, tomato is a very nutritious food that can prevent many diseases. Consumption of dietary lycopene is one of the diabetes management techniques. Some studies have indicated that lycopene can increase insulin levels, lower glucose levels, and improve lipid

profiles in diabetic mice. It also enhances kidney function and antioxidant activity. As a result, tomato is a very healthy diet that can prevent various physiological conditions (Ouattara & Konate, 2024).



Source Ouattara and Konate (2024)

**Figure 2.1** Percentages of the Various Components that Makeup the Tomato's Dry Matter

## 2.2 Socio-economic Importance

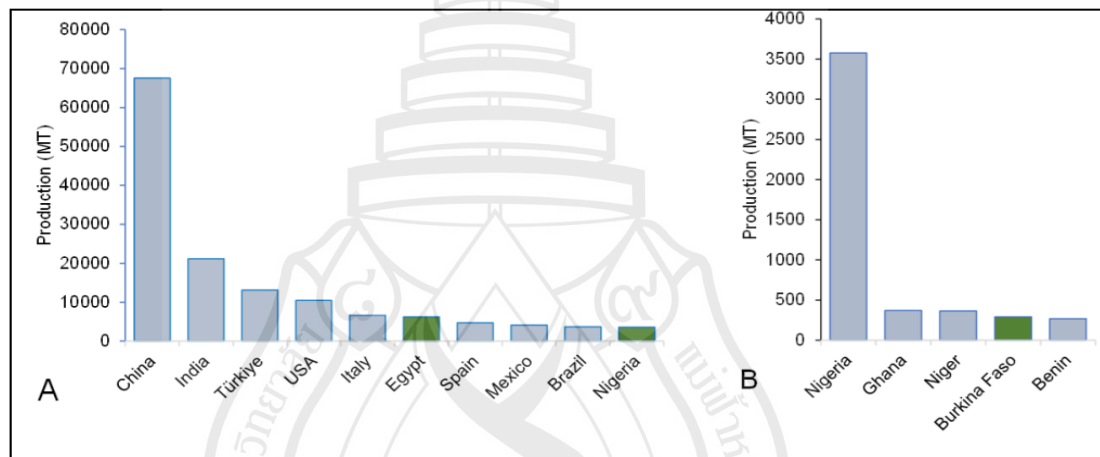
In addition to their health benefits, tomatoes are grown for their economic value; they provide income for farmers, agro-dealers, and traders along the tomato value chain. The business in production of tomatoes appears to be more profitable from small scale farmers, processing and marketing. The production of this vegetable yields higher income for producers and also creates employment during the seasonal period in rural

areas. Produce from tomatoes with cereals provides farmers with extra income to improve farmers' lives, hence significantly contributing to the resilience of populations by reducing poverty and food insecurity. Tomato production also provides jobs in relation to transport, processing and commercialization where women are working in high numbers (90%). Although the tomato value chain requires additional coordination, the production of this fruit-vegetable currently provides major socioeconomic benefits. The tomato sector has great potential, provides women and young farmers with economic opportunities, and can help reduce poverty and ensure food security (Ouattara & Konate, 2024).

Tomato farming has changed dramatically over the past years, responding to different environmental and socioeconomic conditions. Tomatoes were traditionally grown on small farms in small areas, mostly for local markets and domestic use. However, with the Green Revolution in the 1960s and the development of high-yielding hybrid cultivars, tomato production has increased significantly. Improved fertilizers, irrigation systems, and seeds from the Green Revolution were key components in raising tomato yields and extending tomato farming into new regions. In recent decades, the world's largest producer of tomatoes is China, followed by India. India's diversified agro climatic conditions have allowed for year-round production, with many cropping seasons in different regions. Recently, tomatoes are grown in open fields and enclosed facilities, such as greenhouses and playhouses, to provide year-round availability and reduce production risks. While small-scale farmers continue to contribute significantly to overall production, large-scale commercial farming has increasingly gained significance, driven by increased demand in domestic and export markets (Ali et al., 2023).

Tomatoes are currently produced in over 170 nations across the world. In 2021, it was the most produced vegetable crop in terms of quantity, with an expected global production of approximately 189 million tons, above onion (106 million tons), watermelon (101 million tons), and cabbage (71 million tons). Figure 2.2 shows the top ten tomato-producing countries in the world (A) and the top five countries in West Africa (B). Tomato production increased by almost 500% between 1970 and 2021. This remarkable increase was mostly driven by Asian production, which accounts for 63%

of global production. America and Europe each account for approximately 13% of global overall production. European countries, particularly the Netherlands, Belgium, and Sweden, produce high yields. Africa ranks fourth among continents, accounting for 11% of global production. Its production has increased, from 3 million tons in 1970 to 21 million tons in 2021. In contrast to the potential and population demands of the continent, tomato production in Africa is still low. Tomato production in Oceania is quite low when compared to other continents, accounting for less than 1% of global production, most likely due to the area size (Ouattara & Konate, 2024).



Source Ouattara and Konate (2024)

**Figure 2.2** Top Ten Tomato-producing Countries in the World (A) and Top Five Countries in West Africa (B)

### 2.3 Postharvest Handling of Tomato

One of the most serious concerns facing postharvest of fresh produce is quality loss during storage. The primary objective of postharvest handling is to maintain the product at a low temperature in order to prevent moisture loss, slow down unwanted chemical changes, and prevent physical injury. Delays in chilling horticultural produce

can result in direct losses (water loss and deterioration) and indirect losses (reduced flavor and nutritional content). Reducing the chilling delay can prolong the storage life of a product. Shading has the potential to reduce the ambient temperature after harvest and mitigate the excessive temperature increase for fresh produce. In contrast, objects that are directly exposed to sunlight may experience temperatures that are higher (4-6 °C) than the ambient temperature. The quality of tomatoes and their processed products is considerably impacted by the postharvest handling procedure, which takes place from harvest to storage, as well as during subsequent marketing activities, such as long-term storage or transportation. It is essential to maintain the integrity of tomatoes during storage or transportation. Tomatoes are products that are highly susceptible to injury from improper handling, impact loading, and vibrations during transportation, storage, and marketing. As a result, it is imperative to maintain the most favorable environmental conditions in order to minimize the postharvest losses of tomatoes (Kabir et al., 2020).

#### **2.4 Quality Changes of Tomato during Transportation**

For any fresh produce, transportation is a crucial step in the supply chain after harvest. However, if it is not well handled, it can result in post-harvest losses that would result in significant economic losses (Al-Dairi et al., 2021). The main objective in transport is to ensure that tomatoes will reach the final market in good quality. Poor roads, non-refrigerated trucks and the atmosphere contribute to postharvest losses during transit. The roads are rough leading to mechanical injury of tomatoes hence loss of quality (Idah et al., 2007). Long transportation from one region to the other and lack of temperature management when transporting tomatoes are problems which can result in a loss in market value and an increased risk of mechanical damage (Vursavuş & Özgüven, 2004). Vibrational, abrasive, impact, compressional, and cutting forces are the primary causes of transportation-related damage (Aba et al., 2012). Moisture loss, browning, and wounding in fruits are the result of vibration bruising and abrasion damage, which ultimately leads to deterioration (Mutari & Debbie, 2011). Overloading fruit in wooden crates also increases the accumulation of field and respiration heat,

which leads to huge losses (Arah et al., 2015). One of the causes of mechanical damage to tomato fruits is rough handling during transportation which includes exposing fruit to drop heights when transferring them from containers. Suitable packaging is also very important for containing tomatoes since they provide structural support and are therefore significant agents for mitigating product damage during transportation. One of the primary causes of mechanical injury to tomatoes during transportation is the use of inappropriate packing materials (Idah et al., 2007).

## **2.5 Postharvest Losses of Tomato**

FAO (2018) reported that the biggest problem with tomatoes is postharvest losses. Immaturity, overripening, mechanical injury, and decomposition are the primary causes of losses between harvest and consumption. These losses can be attributed to inadequate harvesting practices, harsh handling, improper packaging, and poor transportation conditions. Post-harvest losses in tomatoes have a considerable impact on prices, making products scarcer and more expensive for consumers. Tomato spoilage and waste are caused by improper post-harvest handling and storage techniques, which reduces the total amount of tomatoes available for the market. Post-harvest losses of tomatoes can vary from 20% to 50% of the overall production. These losses occur at different phases of the supply chain, including harvesting and sorting to transportation and retailing. Tomatoes can get physically damaged and deteriorate during the post-harvest period if they are not handled and transported properly. The primary causes of tomato post-harvest losses are bruising, crushing, and spoilage from moisture during storage and transportation. Additionally, losses are exacerbated by physiological modifications that transpire during the postharvest period. Tomatoes are more susceptible to microbial assaults and rot as they mature, particularly if they are stored in unfavorable conditions. The prices are substantially affected by these post-harvest losses. The total amount of tomatoes available in the market declines as a result of decreased supply brought on by spoilage and waste. Due to this shortage of tomatoes, demand will increase and prices increase too especially during off-seasons when there is a supply shortage. Post-harvest losses are critical to maintain tomato pricing and

ensure food security. Improved post-harvest management practices, such as proper handling, cooling, and storage techniques, can reduce losses and increase tomato market availability. Improved supply chain coordination and investments in contemporary infrastructure for transportation and storage can help to reduce postharvest losses and maintain consistent tomato prices (Ali et al., 2023). Manasa et al. (2018) reported climacteric and perishable produce such as cherry tomatoes have a very short life span of 5-6 days. Losses of fresh fruits and vegetables are caused by improper postharvest handling, which includes broken cold chains and inappropriate packaging materials. These factors lead to increased postharvest losses because the deterioration of produce is associated with increased physiological activities and other metabolic processes.

According to Ayomide et al. (2019) the primary causes of tomato losses during storage can be classified as biological, microbiological, chemical, mechanical, physical, and physiological losses.

### **2.5.1 Biological**

This type of loss results from consumption by rodents, birds and insects. In some instances, fruit contamination by birds and rodent faeces, feathers and hair are at a high rate, making it unsuitable for human consumption. Insects reduce quantity and quality by consuming the fruit and leaving behind frass, faeces, webbings and an unpleasant odor which can affect the fruit.

### **2.5.2 Microbiological**

Fungi and bacteria are microorganisms that cause damage in storage of tomato fruits, making them unpleasant due to rot and other defects. Microorganisms easily attack and spread on fresh vegetables, spreading their tissues hence the available nutrients and moisture promote microbial development. *Aspergillus Niger* is a common fungus that affects tomato fruit, and it appears to induce degradation during an 8-day incubation period by secreting a protein containing polygalacturonase and cellulose activity. In the event of abrasion or injury, the fruit's epidermis functions as a protective layer. It can serve as an entry point for microorganisms, which can lead to losses (both qualitative and quantitative). Green or unripe tomatoes that are mature are more

resistant to microorganisms than matured tomatoes.

### **2.5.3 Chemical**

The spontaneous reaction of the chemical elements in the fruit is responsible for this, which leads to a reduction in color, flavor, texture, or nutritional value. A biochemical reaction, which is characterized by the occurrence of numerous enzyme-triggered reactions during storage, may lead to the softening of produce, discoloration, and contamination of flavors. An unblanched frozen fruit or vegetable is a prevalent illustration. The softening of tomato fruits is significantly influenced by cell wall degrading enzymes.

### **2.5.4 Mechanical**

Mechanical activity, including cutting, bruising, excessive tugging, or trimming, results in this loss by altering the fruit's appearance and increasing its susceptibility to microbial infection

### **2.5.5 Physical and Physiological**

An average of 36.5% of the damage in a 10 kg basket of tomatoes of diverse species is attributed to physical and physiological losses. The life cycle of a fresh tomato fruit persists, albeit in a distinct manner, after it is harvested. It is entirely dependent on its accumulated reserves; no additional water or fruit material is added. Upon depletion, a natural aging process takes place, leading to deterioration and disintegration. The fruit becomes unpalatable due to natural decay. Fruit quality is also diminished as a consequence of inadequate physical conditions. Excessive or insufficient heat or weather are among these circumstances.

## **2.6 Ripening of Tomato**

The content of sugars, organic acids, lycopene, phenolic compounds, and other phytochemicals undergoes a substantial transformation as tomatoes mature from green to red during the maturation process. Additionally, the accumulation of sugars, organic acids, and other fruit components in tomatoes is contingent upon environmental factors

during the maturation process from the mature green stage. The intensity of tomato flavor is directly influenced by the interaction between soluble sugars and organic acids in tomato fruits, which is a noteworthy quality characteristic. This interaction is characterized by variations in sweetness and sourness. Antioxidant activity is a critical component of tomato produce quality. Conditions throughout the ripening process affect this antioxidant activity, and as tomatoes ripen, different antioxidant components gradually increase along with a proportional rise in antioxidant activity. Temperature is one of the most critical environmental factors that affect the maturation of tomatoes. The number of days required for tomato fruits to mature from green to the breaker stage during maturation decreases as the temperature approaches the optimal level. The accumulation of lycopene in tomatoes is significantly influenced by temperature during the maturation process. Another significant environmental factor that affects the coloration of tomato fruit during the ripening process is ambient light. The phytochrome that is present in fruits is essential for the regulation of a variety of aspects of tomato fruit maturation, including the accumulation of carotenoids like lycopene. Like all living organisms, horticultural crops rely on photosynthesis to generate their own energy. As a result, light is a critical environmental factor in their development, similar to temperature. Light not only influences plant photosynthesis but also plays a critical role in signaling metabolic activities. The metabolism of ethylene, a hormone associated with the growth and senescence of plants, is influenced by light conditions. Additionally, the quality of tomato fruit has been demonstrated to be influenced by light, which affects the levels of soluble sugars, lycopene content, antioxidant activity, and organic acid content during the maturation cycle. These results underscore the significance of light in the postharvest management of horticultural commodities by demonstrating the diverse effects of light on the ripening process (Choi & Park, 2023).

## 2.7 Factors Affecting Fruit Ripening

### 2.7.1 Ethylene and Its Biosynthesis

The ripening of fruit is controlled by ethylene. Several biochemical processes are induced throughout the growth of plant tissue by modulating ethylene production and signaling. Both positive and negative feedback regulation affect ethylene biosynthesis. The enzymes 1-aminocyclopropane-1-carboxylic acid (ACC) synthase (ACS) and ACC oxidase (ACO) have been identified as the rate-limiting step in ethylene production. The crucial stage in regulating ethylene synthesis is ACS activity, while ACO activity is constitutive (Mubarok et al., 2023). Ethylene removal is one of the most important factors in the regulation of the conservation atmosphere in the post-harvest preservation of fruit and vegetables. Ethylene is a phytohormone that climacteric fruit naturally produces and that accelerates the ripening process. Although beneficial at the beginning of fruit development, these ripening mechanisms ultimately result in product losses and quality deterioration. The removal of ethylene from the postharvest conservation environment has the potential to maintain quality parameters, including pH, acidity, ascorbic acid content, and antioxidant activity. Ethylene elimination is achieved through an oxidation-reduction process that utilizes an oxidizing agent to either hinder ethylene signaling or production or dissociate it into CO<sub>2</sub> and H<sub>2</sub>O (Alonso-Salinas et al., 2022). Ethylene accelerates respiration, which is induced by wounding and contributes to wound-induced respiration in postharvest plant products (Fugate et al., 2010). Respiration is a metabolic mechanism that provides energy for the biochemical activities of plants. The process involves the oxidative degradation of organic compounds, resulting in the release of energy and the formation of simpler molecules such as water and O<sub>2</sub>. These changes commence during the fruit's growth on the plant and accelerate after extraction, resulting in the fruit becoming overripe within a brief period (Majidi et al., 2014). Firmness is one of the parameters that determines tomato maturity and has a significant impact on marketability. The texture of tomatoes changes with storage time. The fruits' softening is a result of the breakdown of carbohydrates in the cell wall structure and an increase in soluble pectin compounds. This process results in the weakening of the cell walls and a reduction in

the cohesive forces that bind cells together (Oliveira-Bouzas et al., 2021). The synthesis of ethylene in tomato fruits is regulated by various gene families that express 1-aminocyclopropane-1-carboxylate (ACC) synthase (ACS) and ACC oxidase (ACO). The suppression of ACO and ACS expression led to a greater reduction in ethylene synthesis, as indicated by certain studies. On the other hand, the application of ethylene to mature climacteric fruit stimulates ethylene synthesis, which in turn accelerates ethylene production and respiration, including alternate pathway respiration, and enhances fruit maturation. These results suggest that the resistance to ripening of harvested fruit may be influenced by diminished respiration rates and ethylene production (Guo et al., 2014). Reduced ethylene production and respiration rate could be beneficial in preserving the quality of fresh tomatoes for a prolonged storage period (Tilahun et al., 2021). The presence of ethylene in postharvest horticultural products has become a major concern. To maintain the postharvest quality of horticultural products, such as tomatoes, it is necessary to employ several techniques to manage the negative effects of ethylene (Mubarok et al., 2023).

### **2.7.2 Respiration**

Factors that affect respiration include temperature, atmospheric composition, physical stress, and stages of development. Increased temperatures cause a peak in respiration, however, if temperatures are too low can cause physiological injury. Atmospheric composition particularly  $O_2$  and  $CO_2$  levels also affect respiration. Reducing metabolic activity and  $O_2$  availability slows respiration. Reduced  $O_2$  decreases respiration,  $C_2H_4$  production, and  $C_2H_4$  sensitivity. Low  $O_2$  levels reduce respiration rate by decreasing the activities of other oxidases such as polyphenol, ascorbic acid, and glycolic acid whose affinity is too low. Aerobic respiration requires enough  $O_2$ . However, if the oxygen level within the package drops too low it may cause anaerobiosis accompanied by tissue breakdown, odor, and off-flavor production. Elevating  $CO_2$  levels around some commodities reduces respiration,  $C_2H_4$  sensitivity and production, delays maturation and senescence, inhibits bacterial and fungal development and lowers pH. Even moderate physical stress can result in a significant increase in respiration, which is frequently accompanied by an increase in  $C_2H_4$  evolution. The signal generated by physical stress migrates away from the site of injury

and induces a variety of physiological changes in adjacent, non-injured tissues, including increased respiration,  $C_2H_4$  production, phenolic metabolism, and wound healing. Respiration rates differ within commodities even in different varieties of the same product. Climacteric fruits display an increase in respiration rate in early development and then decrease until an increase that corresponds with ripening or senescence (Mangaraj & Goswami, 2009). According to Ayomide et al. (2019), a high rate of respiration causes the fruit to produce a higher amount of ethylene. Thus, it is evident that both respiration rate and storage system temperature would be an appropriate method for reducing ethylene production.

### **2.7.3 Temperature and Relative Humidity**

The storage temperature for tomatoes has a significant role in determining their shelf life. Low storage temperature prolongs the shelf life of fruits. The optimum storage temperature of fruits should be kept at a temperature that is above their recommended chilling temperature. Chilling injury in tomatoes occurs at temperatures below 12.5, 12.7, or 11°C for a certain period (Batu & Thompson, 1998). Temperature impacts metabolic processes, including respiration and maturation rates. For each 10°C increase in temperature, the rate of biological reactions typically increases by two to three times. Consequently, the efficacy of a MAP system is contingent upon temperature management. The permeability of the film increases as the temperature rises, with  $CO_2$  permeability responding more strongly than  $O_2$  permeability. Desiccation, increased respiration, and, ultimately, an unsellable product can result from low RH, which can exacerbate transpiration damage. One significant issue associated with excessive in-package humidity is the condensation on the film, which is a result of temperature fluctuations (Sandhya, 2010). Horticultural products that have been harvested can be gravely damaged by fluctuations in temperature and humidity. Tomatoes are unable to endure temperatures below 10 °C, while elevated temperatures can accelerate their respiration rate. Preserving the quality of fruits and vegetables necessitates the regulation of temperature between harvest and consumption. Tomatoes that are stored at low relative humidity (below 85% to 90%) may shrivel, while those that are stored at 100% relative humidity may promote the growth of mildew and fungi (Kabir et al., 2020). The storage of tomatoes is contingent upon the rate of respiration,

the rate of ethylene production, the relative humidity, and the storage temperature. The quality and shelf life of tomatoes are significantly influenced by temperature, which is associated with other factors that contribute to produce deterioration (Ayomide et al., 2019). The optimal storage temperature for matured green tomatoes ranges between 12.5-15°C, whereas the optimal storage temperature for light red ranges from 10-12.5°C and ripe tomatoes range between 7 and 10°C. Storage temperature below 10 °C can cause chilling injury, and even at 10 °C may cause failure of ripening in mature green tomatoes (Tilahun et al., 2021). Relative humidity also plays a big role in maintaining tomato quality. A low relative humidity results in fruit wilting, softening, and weight loss, while a high relative humidity preserves the nutritional qualities, weight, appearance, and flavor. For firmer mature tomatoes, the optimal relative humidity range is 90-95%, while for green tomatoes, it is 85-95%. The shelf life of tomatoes is also influenced by the production of ethylene and the rate of respiration. The rate of respiration and the production of ethylene are significantly increased in response to an increase in temperature, thereby expediting the process of deterioration. The fruit's respiration rate is also directly correlated with ethylene production. The fruit produces a greater quantity of ethylene when its respiration rate is elevated. Therefore, it is clear that the reduction of ethylene production would be achieved through the implementation of both respiration rate and storage system temperature (Ayomide et al., 2019).

In addition, the respiration rate is typically taken into account when designing fresh produce packaging in order to estimate the targeted O<sub>2</sub> and CO<sub>2</sub> barrier characteristics needed to reach the intended equilibrium O<sub>2</sub> and CO<sub>2</sub> levels for a particular product. But transpiration and respiration also contribute to the increase of water vapor, which primarily influences the humidity level inside the package. Condensation within fresh produce packages occurs when water molecules evaporate from the product surface and do not pass through the package film and condense within the package and on the product surface. The temperature where condensation occurs is known as the dew point temperature and condensate forms on any surface that is below or equal to the surrounding air's dew point. There is a correlation between water vapour in the air and temperature. Air can store less moisture at lower temperatures, so when

moist air is cooled, the decrease in temperature leads to an increase in relative humidity (RH).

Hence, controlling humidity in fresh product packing requires proper temperature management. In contrast to the transpiration rates of fresh produce, most of the polymeric materials used in MAP have low water vapor permeability. The water vapor pressure in the package micro-environment is therefore increased since the majority of the water molecules that evaporate off the produce do not pass through the film and stay inside the package. Even a small temperature change in these near-saturation conditions can cause condensation inside the packaging, which can result in sliminess, accelerated microbiological development, deterioration, and a shorter shelf life (Mahajan & Lee, 2023).

#### **2.7.4 Maturity**

Harvesting of tomatoes can be done at various stages of maturity, from the green mature stage to the fully ripe stage. It is very important to harvest before the climacteric rise as this can be the best technique for extending shelf-life and reducing spoiling rate. Tomatoes at mature green or breaker stages can be harvested and allowed to ripen in transport or at the destination, as fully matured tomatoes are prone to damage. However, tomato fruits can still be harvested at a fully ripe red stage for immediate consumption, but their shelf-life is too short due to texture loss and susceptibility to fungi (Tilahun et al., 2019).

#### **2.7.5 Postharvest Diseases**

During the processing and storage of postharvest products, postharvest diseases are frequently encountered. In general, crops that are preserved in any condition are susceptible to the development of diseases. Before and after harvest, tomatoes are susceptible to fungi and bacteria. The major postharvest diseases which affect tomatoes are Rhizopus rot (*Rhizopus stolonifera*), grey mold (*Botrytis cinerea*), anthracnose (*Colletotricum coccoides*, *C. gloeosporoides*, *C. dematium*), bacterial soft rot (*Erwinia carotovora* pv, *caratovora*), early blight (*Alternaria solani*), southern blight (*Sclerotium rolfsii*), phoma rot (*Phoma destructiva*) and Fusarium rot (*Fusarium oxysporum* f. sp. *Lycopersici* races 1-3) (Devappa et al., 2021).

## 2.8 Physiological and Biochemical Changes of Tomato

Tomato fruits mature from green to mature green stage by a climacteric process that begins with low ethylene production and gradually increases until ripening. Ripening is the final stage of fruit development where biochemical and physiological changes affect flavor, color, aroma, and texture. The process is controlled by ethylene, a gaseous plant hormone (Bayoumi et al., 2023). The transformation of a tomato fruit from mature green to fully ripened involves significant changes in color, composition, aroma, flavor, and texture. Ripening is dependent on a variety of different synthetic and degradative reactions. The modifications occur in the fruit's cells and affect every subcellular compartment. Plant hormones appear to coordinate and regulate the many aspects of ripening. However, genetic and environmental factors may influence this. The red color of ripe fruit results from the breakdown of chlorophyll and accumulation of carotenoids, specifically  $\beta$ - and lycopene-carotene, when the chloroplasts change into chromoplasts. Normal growth and vision depend on carotenoids, secondary metabolites which are involved in animal vision, and vitamin A (retinol), which is synthesized in vivo from  $\beta$ -carotene. These compounds, together with protein-carotenoid complexes, contribute to the coloring of various fruits and flowers. Lycopene as one of the main carotenoids (red tomatoes) might be the cause of tomato fruits' health benefits because of their potent antioxidant properties (Abdul-Hammed et al., 2009).

## 2.9 Postharvest Treatments of Tomato

After harvesting, the postharvest quality of the fruit can no longer be improved by postharvest technologies, the only option is to preserve the quality with the following treatment methods (Arah et al., 2016).

### 2.9.1 Refrigeration Storage

The texture, nutrition, aroma, and flavor of certain harvested fruits can be safeguarded through low-temperature storage. Nevertheless, certain fruits and

vegetables are extremely susceptible to frost injury when stored at low temperatures. The optimal temperature for tomato storage is approximately 10–15° C, with a relative humidity of 85–95%.

### **2.9.2 Heat Treatment**

Postharvest heat remedies, which involve the use of heated water and hot air, can mitigate chilling injuries in tomatoes. Ripening can be slowed and pathogen resistance can be increased during storage by maintaining temperatures between 37–42° C prior to cold storage. Combine refrigeration storage with postharvest heat treatment to extend the retail life of harvested tomatoes.

### **2.9.3 1-Methylcyclopropene (1-MCP)**

The maturation process can be expedited by the use of 1-methylcyclopropene (1-MCP), which can suppress the activity of ethylene in a variety of fruits and vegetables. 1-MCP has been shown to significantly delay the ripening process, which encompasses color change, cell wall disintegration, and respiration rates. The rate of ethylene production in the harvested climacteric fruit is a measure of the metabolic activity that occurs within the fruit, such as tomatoes. The fruit's store life is diminished as its metabolic activity increases (Arah et al., 2016)

### **2.9.4 Calcium Chloride (CaCl<sub>2</sub>) Application**

In numerous fruits and vegetables, the application of calcium chloride (CaCl<sub>2</sub>) after harvest can reduce respiration rate, increase shelf life, preserve firmness, and reduce physiological issues, as well as delay ripening and senescence. Calcium chloride treatment can maintain tomato quality by delaying ripening, increasing firmness, and extending shelf life. Tomatoes exposed to CaCl<sub>2</sub> treatment had their shelf lives increased by 92% due to a delay in fruit development and ethylene production. CaCl<sub>2</sub> treatment of fruit also reduces physiological weight loss and maintains firmness during storage (Arah et al., 2016).

### **2.9.5 MAP**

CO<sub>2</sub>, O<sub>2</sub>, and N<sub>2</sub> are the three most frequently employed gases in modified atmosphere packaging. The selection of gas is significantly influenced by the culinary

product that is being packaged. These gases are frequently employed to achieve a balance between the desirable organoleptic qualities of food and the safe extension of its shelf life, either individually or in combination (Sandhya, 2010).

#### 2.9.5.1 Carbon dioxide

Carbon dioxide is a colorless gas that emits a moderate, unpleasant odor at elevated concentrations. Asphyxiation and mild corrosion may result when it is exposed to moisture. CO<sub>2</sub> is readily dissolved in water (1.57 g/kg at 100 kPa, 20°C) and generates carbonic acid (H<sub>2</sub>CO<sub>3</sub>), which results in a decrease in pH and an increase in acidity. This substantially influences the MAP of foods. The high solubility of CO<sub>2</sub> can result in pack collapse and a decrease in headspace volume (Sandhya, 2010). According to Manasa et al. (2018), the most critical gas in the MAP is carbon dioxide, which is characterized by its bacteriostatic and fungistatic properties. It also decreases the rate of enzyme activity, which in turn preserves the integrity of the produce and extends its shelf life.

#### 2.9.5.2 Oxygen

Oxygen is a very reactive gas that is colorless and inert, and it is a catalyst for combustion. At a pressure of 100 kPa and a temperature of 20 degrees Celsius, it has a water solubility of 0.040 g/kg. Oxygen produces food deterioration, including pigment oxidization, browning, and lipid oxidation. Oxygen is necessary for the proliferation of the majority of spoilage bacteria and fungi. Pack atmospheres should have minimal residual oxygen levels to extend the shelf life of foods (Sandhya, 2010).

#### 2.9.5.3 Nitrogen

Nitrogen is a gas that is relatively non-reactive, colorless, and inert. It is non-flammable, less dense than air, and has a low solubility in water (0.018 g/kg at 100 kPa, 20 C) and other food substances. Nitrogen prevents spoilage by suppressing the development of aerobic microbes; however, it does not impede the growth of anaerobic bacteria. To prevent pack collapse, enough N<sub>2</sub> should be included in the gas mixture to compensate for the reduction of the volume caused by CO<sub>2</sub> entering the solution, as nitrogen is not easily soluble in foods. Pack collapse can occur due to reduced headspace volume (Sandhya, 2010).

The quantities of O<sub>2</sub> and CO<sub>2</sub> in the modified environment can be adjusted using

MAP. By decreasing respiration and ethylene production rates, the combination of MAP and low storage temperatures has the potential to postpone changes associated with maturation and senescence. The modified atmosphere may be generated as a consequence of the addition or elimination of gases from food packaging or product respiration. A combination of gases is introduced into the packaging by active MAP, and its composition changes over time (Majidi et al., 2014). The atmospheres of 3-5 kPa O<sub>2</sub> and 2-3 kPa CO<sub>2</sub> under MAP have been recommended for fresh tomatoes to extend their shelf life (Robertson, 2016). The equilibrium concentrations of O<sub>2</sub> and CO<sub>2</sub> in passive MAP are contingent upon the weight of the product and its respiration rate, which is determined by the temperature, surface area, perforations, thickness, and gas permeability of packaging materials.

Although active MAP entails the introduction of the desired atmosphere into the package headspace prior to thermal sealing, the final atmosphere will continue to be influenced by the same factors as passive MAP. Consequently, the shelf life of produce can be extended by delaying respiration and senescence, as well as slowing down the rate of deterioration, in a proper equilibrium atmosphere. In recent years, Active MAP has also integrated technologies that can adsorb molecules such as O<sub>2</sub>, ethylene, moisture, CO<sub>2</sub>, flavors/odors, and release substances such as antibacterial agents, CO<sub>2</sub>, antioxidants, and flavors. At present, the product's respiration rate is the sole critical parameter for determining the target gas barrier qualities that are required to establish an equilibrium-modified environment. Nevertheless, it is also crucial to evaluate the humidity level within the package in order to reduce condensation and/or the development of mold and bacteria in MAP systems. The water vapor permeability of the packaging material and the respiration and transpiration of the fresh produce are generally assumed to influence the in-package humidity. The water vapor permeability of the majority of plastic films (polyethylene, polypropylene, or polyvinyl chloride) utilized in MAP is lower than the product's transpiration rates. Consequently, the water vapor pressure in the package microenvironment is elevated as a result of the fact that the majority of water molecules that evaporate from the produce are unable to exit through the film and remain within the package to become slimy and accelerates the growth of microorganisms and the decay of the produce (Mahajan et al., 2014).

According to (Bailén et al., 2006), high CO<sub>2</sub> and low O<sub>2</sub> concentrations in MAP are frequently achieved to decrease the rates of ethylene generation and respiration. Anaerobic metabolism, which results in the production of off-flavors, physiological and microbial decomposition, browning, and softening, can be caused by excessively low levels of O<sub>2</sub> and excessively high levels of CO<sub>2</sub>. Consequently, the implementation of high O<sub>2</sub> atmospheres has been recommended as an effective approach to prevent anoxic fermentation and impede microbial growth (Odriozola-Serrano et al., 2009). MAP is a packaging method that involves the use of packaging materials, including polyethylene terephthalate (PET), polyvinyl chloride (PVC), polypropylene (PP), and polystyrene, to package products in an atmosphere of carbon dioxide (CO<sub>2</sub>) and oxygen (O<sub>2</sub>). (Arah et al., 2016). The objective of MAP is to rapidly accomplish the equilibrium concentration of O<sub>2</sub> and CO<sub>2</sub> within the package as a result of the interaction between the produce, the package, and the external atmospheric. The respiration and metabolic process rates should be maintained at the lowest possible rate during the storage period to ensure the freshness and extend the shelf life of stored commodities. Consequently, the equilibrium concentration of O<sub>2</sub> and CO<sub>2</sub> within the package should remain constant (Mahajan et al., 2007).

The efficacy of MAP in plant products is contingent upon the temperature, maturation stage, storage duration, and variety. In order to achieve substantial outcomes, it is imperative to implement optimal temperature, humidity, and atmosphere composition conditions. Common gases utilized in MAP include O<sub>2</sub>, CO<sub>2</sub>, and N<sub>2</sub>. O<sub>2</sub> is consumed and CO<sub>2</sub> is produced during the storage of produce as a result of product respiration. Nitrogen is an inert gas that is employed in MAP as a "filler" gas to mitigate the volume loss resulting from CO<sub>2</sub> absorption and to prevent package collapse (Sandhya, 2010). It is commonly used to replace oxygen in MAP. Nitrogen can also indirectly inhibit the growth of aerobic spoilage organisms in perishable foods (Parry, 2012). CO<sub>2</sub> has a direct and significant antimicrobial effect among the primary gases employed in MAP. The lag phase, maximum growth rate, and maximum population densities attained are all influenced by the inhibition of microbial growth by dissolving CO<sub>2</sub> (Devlieghere & Debevere, 2000).

Although MAP effectively prolongs the shelf life of fresh produce while maintaining its quality, it is applied using plastic materials in the form of bags, pouches, trays, and containers. Due to growing societal concerns about plastic waste, the produce business is searching for sustainable packaging options. Simply removing plastics from fresh fruit packaging is neither practical nor useful; instead, a coordinated and systematic strategy is necessary to establish a sustainable and successful solution. In addition to optimizing produce packaging design, choices for food and package waste disposal must be explored in terms of food security and environmental effects (Mahajan & Lee, 2023).

## **2.10 Active Packaging**

Active packaging is a form of packaging that utilizes active agents or technologies to enhance the quality of products and extend their shelf life (Figure 2.3). In the context of fruit preservation, active packaging is essential for the preservation of freshness, the prevention of deterioration, and the enhancement of safety (Vilela et al., 2018). Active packaging technologies have garnered considerable attention over the past decade. Currently, the global market price for active packaging films is \$50 million, and it is expected to experience a significant increase. Fresh produce has been the primary focus of active packaging. Active packaging has expanded the possibilities for the preservation of fresh food and the extension of its expiration life, while passive packaging was employed to restrict microbial growth and deterioration in fresh fruits and vegetables. It is challenging to obtain the optimal concentrations of oxygen, carbon dioxide, and water vapor in packaging using only passive plastic films. Nevertheless, using active packaging techniques can help ensure that food containers have the requisite gas atmospheres and moisture levels to ensure the longest possible shelf life. The majority of active packaging technologies in use today are mostly on sachet technology. Sachets are not well-accepted by customers because of concerns about ingestion by children and consuming the contents of the container accidentally (Ozdemir & Floros, 2004). There are some researchers studied on application of active

packaging with fruits and vegetables (Table 2.10). Here are some examples of active packaging techniques used for fruit preservation:

**Oxygen Absorbers:** Oxygen is a primary factor that accelerates fruit deterioration. Oxygen absorbers are packets containing iron powder, which reacts with oxygen to create iron oxide while removing oxygen from the packaging. By reducing the oxygen level inside the package, the rate of fruit ripening and spoilage can be significantly slowed down.

**Ethylene Scavengers:** Ethylene is a naturally occurring gas released by fruits as they ripen, and it can accelerate the ripening process and lead to spoilage. Ethylene scavengers are designed to remove ethylene gas from the package, effectively slowing down the ripening of fruits and extending their shelf life.

**Moisture Control:** Excess moisture can promote the growth of microorganisms and result in fruit decay. Active packaging solutions with moisture-absorbing properties help maintain an optimal moisture level by reducing humidity inside the package, thus preventing microbial growth and extending the shelf life of fruits.

**Antimicrobial Packaging:** Some active packaging materials are infused with antimicrobial agents or coatings. These agents inhibit the growth of bacteria, fungi, and other microorganisms that cause spoilage. Antimicrobial packaging can help preserve the quality and safety of fruits by minimizing microbial contamination.

**Temperature Control:** Active packaging systems can incorporate cooling or heating elements to maintain the desired temperature range for fruits. This is particularly useful for perishable fruits that require specific temperature conditions to slow down enzymatic activity and microbial growth. It is worth noting that active packaging for fruit preservation is an area of ongoing research and development. Various innovative technologies and materials are being explored to enhance fruit quality, safety, and shelf life (Vilela et al., 2018).



Source Vilela et al. (2018)

Figure 2.3 Active Agents for Active Food Packaging

### 2.10.1 Carbon Dioxide Emitters

Carbon dioxide ( $\text{CO}_2$ ) is a gas molecule that is soluble in the aqueous and lipid phases of food. It produces carbonic acid, which causes the food product to become acidic (Yildirim et al., 2018). The rate of respiration in fresh produce is typically slowed by elevated levels of carbon dioxide. The majority of the carbon dioxide contained within the container often penetrates through the film, as many plastic films used for food packaging are more permeable than oxygen. A carbon dioxide emitting system may be necessary to reduce the rate of respiration and inhibit microbial growth in situations where the plastic film has a high carbon dioxide permeability. In cases where the container has a high carbon dioxide permeability, it may be necessary to use a carbon dioxide releasing device to prevent microbial growth and limit the rate of respiration (Ozdemir & Floros, 2004). Carbon dioxide acts as a competitive inhibitor of ethylene activity. In addition to inhibiting respiration, high concentrations of  $\text{CO}_2$  reduce ethylene evolution in fruits including tomatoes, pears, and apples. The optimal conditions for storing fruits and vegetables in modified atmosphere packaging (MAP) are 3 - 8%  $\text{CO}_2$  and 2 - 5%  $\text{O}_2$ . (Taye et al., 2017). Carbon dioxide ( $\text{CO}_2$ ) may affect

ethylene production in a variety of ways, although the precise method of action is uncertain. The enzymes 1- aminocyclopropane-1-carboxylate (ACC) synthase and ACC oxidase catalyze the reactions from S adenosylmethionine to ACC and from ACC to ethylene, respectively. ACC oxidase necessitates CO<sub>2</sub> as a cofactor. The autocatalytic ethylene generation in intact pear fruits was impeded by CO<sub>2</sub> at 5 kPa and above. It has been proposed that CO<sub>2</sub> inhibition is the result of the ethylene binding protein (EBP) competing with ethylene at the ethylene receptor site. Nevertheless, numerous studies indicate that CO<sub>2</sub> also suppresses activity at an alternative location. Both ethylene-dependent and ethylene-independent ripening-associated gene expression in pre-climacteric tomato fruits was inhibited by CO<sub>2</sub>. It was determined that the inhibitory effect of CO<sub>2</sub> on ethylene synthesis could not be accounted for solely by ethylene perception. Despite the fact that CO<sub>2</sub> is a critical cofactor for ACC oxidase, it is impossible to exclude the possibility that this enzyme also contributes to the suppression of ethylene synthesis by CO<sub>2</sub>. It has been demonstrated that the concentration of ACC in intact fruit remains unaffected by the increase in CO<sub>2</sub>. This inhibits the synthesis of ethylene. According to one study, ethylene production was inhibited by CO<sub>2</sub> when ACC content was low (the amount seen in fruits), but it increased when ACC concentration was high. As a result, it is likely that CO<sub>2</sub> is (at least partly) inhibiting the formation of ethylene at the level of ACC oxidase (de Wild et al., 2003).

**Table 2.1** Absorbers Used in Active MAP for Extending Shelf-life

Packaging system	Example of working principle/ mechanism/ reagent	Purpose
Oxygen absorbers (sachet, abels, films, corks)	Ferro-compound (iron powders), ascorbic acid, metal salt, glucose oxidase, alcohol oxidase	Reducing/preventing respiration rate, mold, yeast and aerobic bacteria growth; prevention of oxidation of fats, oils, vitamins, colors; prevention of damage by worms, insects and insect eggs

Table 2.1 (continued)

Packaging system	Example of working principle/ mechanism/ reagent	Purpose
Carbon dioxide absorbers (sachet)	Calcium hydroxide and sodium hydroxide or potassium hydroxide, calcium oxide, magnesium oxide, activated charcoal and silica gel	Removing excess carbon oxide formed during storage to prevent fruit damage and bursting of package
Ethylene absorbers (sachets, films)	Aluminum oxide and potassium permanganate (sachets), activated hydrocarbon (squalane, apiezon) + metal catalyst (sachets), builder-clay powders (films), zeolite (films), Japanese oya stone (films) and other compounds like silicones (phenyl-methyl silicone)	Prevention of too fast ripening and softening
Humidity absorbers (drip absorbent sheets, films, sachets)	Polyacrylates (sheet), polypropylene glycol (film), silica gel (sachet), clays (sachet)	Control of excess moisture in packed produce, reduction of water activity on surface of food in order to prevent growth of molds, yeast and spoilage bacteria
Absorbers of off-flavors, amines and aldehydes (films, sachets)	Cellulose acetate film containing narinaginase enzyme, ferrous salt and citric or ascorbic acid (sachet), specially treated polymer	Reduction of bitterness in fruit, improving flavor, and oil-containing foods
UV-light absorbers	Polyolefins like polyethylene and propylene doped in the material with a UV-absorbent agent; modification of nylon 6	Restricting light induction oxidation
Reagents	Ferrous carbonate: $4\text{FeCO}_3 + \text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4\text{Fe}(\text{OH})_3 + 4\text{CO}_2$	For quickly developing an MA within a package. The reaction quickly builds up the CO <sub>2</sub> content of the package while reducing the O <sub>2</sub> content somewhat
Preservative films	Slowly diffuse preservatives such as nisin, sorbate, glycol, antioxidants, antibiotics, ethanol or ethylene into the package	Control microbial growth; suppress unwanted biochemical reactions

Source Goswami and Mangaraj (2011)

In addition to its antibacterial properties, CO<sub>2</sub> can also be employed to prevent food from oxidizing. Nitrogen (N<sub>2</sub>) is frequently employed to inhibit oxidation, while CO<sub>2</sub> is frequently combined with N<sub>2</sub> to create antioxidative food packaging. The pressure or volume of a container may be reduced by the addition of CO<sub>2</sub> to its atmosphere, as it is highly soluble in food matrices. This may also be advantageous for the marketing of MAP food products in low temperature and pressure environments, as it may help to regulate the pressures between the package's internal headspace and its external environment. Nevertheless, excessive CO<sub>2</sub> levels can be detrimental, resulting in package collapse and unfavorable product quality, including flavor and texture, at elevated CO<sub>2</sub> concentrations. Consequently, it is imperative to implement CO<sub>2</sub>-based MAP with due diligence, considering the food's characteristics and the environment in which it is implemented. An optimal level of elevated CO<sub>2</sub> concentration is also advantageous for the preservation of fresh produce by delaying physiological processes such as respiration and ethylene synthesis. The success of a fresh-produce MAP system is contingent upon the preservation of an appropriate O<sub>2</sub> concentration and a correct CO<sub>2</sub> concentration within the container. It is crucial to maintain an appropriate equilibrium between the CO<sub>2</sub> released by the product's respiration and the CO<sub>2</sub> released from the packaging. The O<sub>2</sub> supply must be balanced with the O<sub>2</sub> consumption of the packaged fresh produce in order to maintain an optimal O<sub>2</sub> concentration that is compatible with the CO<sub>2</sub> concentration. A physiological impairment to the product is caused when the tolerance limit is surpassed by CO<sub>2</sub> levels. In order to package fresh products with the optimal CO<sub>2</sub> concentration and beneficial O<sub>2</sub> concentration, packaging films with high gas permeability capabilities that are in balance with the product's respiration activity are frequently employed (Lee, 2016).

The respiration of fresh fruits and vegetables generates carbon dioxide. If this gas is not eliminated and accumulates to an excessive level within the container, it may induce physiological stress in the produce. Consequently, the integrity of the product can be preserved through the implementation of regulated CO<sub>2</sub> removal. Various commercial sachets and label devices are employed to either scavenge or discharge carbon dioxide (Bodbodak & Rafiee, 2016). Citric acid, sodium bicarbonate, and ferrous carbonate are a few examples of substances that release carbon dioxide (Vilela

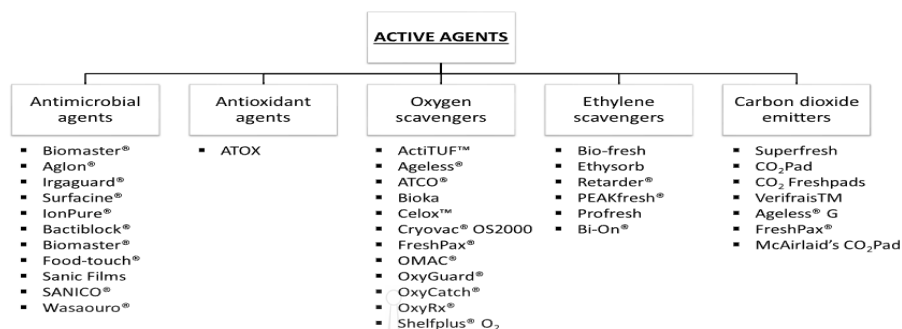
et al., 2018). A prevalent method for the release of CO<sub>2</sub> involves the use of two active substances: an organic acid and sodium bicarbonate (NaHCO<sub>3</sub>). Citric acid is the acid of preference in these systems the majority of the time (Yildirim et al., 2018). Superfresh™ CO<sub>2</sub> Pad and CO<sub>2</sub> Freshpad™ (Figure 2.2) are all types of emitters that use sodium bicarbonate and citric acid. When the active ingredients are dissolved by the liquid from the food product, the reaction commences. Due to the acid's reduction of the system's pH, Le Chatelier's principle predicts that un-dissociated carbonic acid and carbon dioxide will occur when the sodium bicarbonate buffering system shifts its direction of creation. This implies that the pH will decrease and carbon dioxide generation will begin when liquid is added to the system. Enclosing dry powdered sodium bicarbonate and citric acid in a liquid absorber pad in specific ratios and amounts is a commonly applied concept. The pad is positioned beneath the food product and functions as both a liquid absorber and a CO<sub>2</sub> emitter, making it easy to use in production and frequently eliminating the need for additional phases in industrial packaging lines (Hansen et al., 2016). Other non-chemical alternatives, such as thermal treatments and biological control, are more costly and time-consuming than carbonic salts, such as sodium bicarbonate (SBC, NaHCO<sub>3</sub>), which are readily available and can be used without causing significant fruit damage. SBC is generally recognized as safe to use (GRAS) by the US Food and Drug Administration, has a broad spectrum of antifungal properties, and is free of residue on agricultural commodities (Vilaplana et al., 2018). Acidic and alkaline sources, such as citric acid or tartrate acid and sodium bicarbonate, are combined to generate active substances (Lingga, 2019). When this product is added to water, citric acid and sodium bicarbonate react chemically, creating CO<sub>2</sub> and sodium salt from the acid. The reaction happens relatively quickly, generally taking a minute or less. Citric acid, malic acid, and fumaric acid are commonly used acid sources, whereas sodium bicarbonate is a commonly used alkaline source.

Microbial activity is frequently inhibited by carbon dioxide. Microbial proliferation on surfaces is inhibited by elevated CO<sub>2</sub> levels (60 to 80%), which results in a longer shelf life. The desired concentration within the plastic films must be maintained by perpetually producing CO<sub>2</sub>, as its permeability is 3 to 5 times greater than that of O<sub>2</sub> in the majority of plastic films. While carbon dioxide frequently has a

microbiological inhibitory effect in modified atmosphere packaging, an excessive amount of carbon dioxide can have a detrimental impact on the product or compromise the inhibitory effect (Mane, 2016).

### **2.10.2 Ethylene Scavengers**

Ethylene is a growth-stimulating hormone that diminishes the shelf life of climacteric fruits and vegetables by increasing the respiration rate, thereby accelerating maturation and senescence (Ozdemir & Floros, 2004). Furthermore, ethylene also contributes to tomato fruit softening and chlorophyll degradation (Akbulak et al., 2007). It is imperative to regulate the levels of ethylene in the environment surrounding fresh food products during transportation, storage, and handling after harvesting in order to improve their quality and extend their shelf life (Vilela et al., 2018). Ripening is influenced by two types of ethylene: endogenous ethylene, which is biologically produced by the plant, and external ethylene, which is produced by neighboring crops, tobacco, polymers, and automobile emissions. The adverse effects of ethylene are mitigated through the utilization of active packaging that possesses ethylene-scavenging capabilities. The shelf life of fresh foods is prolonged through the use of ethylene scavenging methods. Ethylene scavengers can be incorporated into film packaging as either a surface on the packaging or in conjunction with a solid integrated into plastic. This solution is likely already well-known and is an excellent solution to packet-related packaging. A combination of antibacterial enhancement and ethylene scavenging is necessary to optimize preservation, which can be achieved by extending the shelf life of perishable foods such as fruits and vegetables. Included in this category are chitosan film, sachets, polymeric films (Polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC), and Polyethylene terephthalate (PET), and gelatine-TiO<sub>2</sub>-coated Expanded Polyethylene (EPE) Foam nets.



Source Vilela et al. (2018)

**Figure 2.4** Examples of Commercial Active Agents for Active Food Packaging

Available ethylene scavengers include inhibitors such as aminoethoxy vinyl glycine (AVG), silver thiosulfate and 1-methylcyclopropene (1-MCP), Ethylene Catalytic Oxidants, ozone (O<sub>3</sub>) and titanium dioxide and potassium Permanganate (KMnO<sub>4</sub>) (Mariah et al., 2022). Potassium permanganate (KMnO<sub>4</sub>) is an oxidant which is often used. The efficacy of KMnO<sub>4</sub> is contingent upon its adsorption onto a large-surface-area inert carrier (such as zeolite, vermiculite, silica gel, alumina granules, or activated carbon) that contains approximately 4-6% KMnO<sub>4</sub>. The oxidation of ethylene by KMnO<sub>4</sub> occurs in two stages. In order to oxidize ethylene to carbon dioxide and water, acetaldehyde must be oxidized to acetic acid, which in turn must be oxidized to acetaldehyde. Nevertheless, the adsorbent materials containing KMnO<sub>4</sub> are not suitable for fruit contact packaging and are exclusively distributed in sachets due to their toxicity and purple appearance (Bodbodak & Rafiee, 2016). Potassium permanganate (KMnO<sub>4</sub>) is the most recommended technique for eliminating ethylene in terms of cost-effectiveness. At the saturation point, the color of this molecule changes from violet to dark brown, indicating that ethylene is being eliminated during the reaction (Alonso-Salinas et al., 2022). Potassium permanganate (KMnO<sub>4</sub>), as one of the most utilized ethylene scavengers can be able to break down the C<sub>2</sub>H<sub>4</sub> double bond, releasing carbon dioxide and water (Álvarez-Hernández et al., 2021).

However, C<sub>2</sub>H<sub>4</sub> scavengers are not yet very effective, most likely due to

insufficient absorption capacity (Vermeiren et al., 1999). Consumers may perceive these active components as harmful and refuse to take them, which appears to be the primary concern of the food industry with respect to their introduction into packaging (Mikkola et al., 1997). (Mariah et al., 2022), cited that unexpected safety concerns include, but are not limited to, the transfer of active substances from packaging to food items, the accidental release of active materials from a sachet into food, and the ingestion of active materials by humans. Knowledge transfer, regulatory safety standards, environmental concerns, customer acceptability, and the scaling of manufacturing processes are additional substantial obstacles (Vilela et al., 2018). Currently, the majority of active packaging technologies consist of sachet technologies. The development and utilization of thin-film active packaging systems are anticipated to increase over the next decade. New opportunities for active packaging have arisen as the food industry has come to recognize the advantages of these technologies, as economically feasible active packaging solutions have been developed, and as consumer acceptance has increased. Because of this, active packaging is a dynamic field that welcomes new ideas and future developments. Continuous innovations in active packaging are anticipated to result in enhanced food quality, safety, and stability. (Ozdemir & Floros, 2004).

### **2.10.3 Application of MAP and Active Agents for Tomatoes**

Packaging contributes to the value chain of vegetable production by offering ease, protection, containment, marketing opportunities, and traceability. Plastics are increasingly being used in food packaging all over the world due to their wide availability at reasonable prices. Additionally, plastic's useful properties such as its strong optical qualities, good tensile and tear strength, good permeability to oxygen and fragrance chemicals and its capacity for heat sealing—favor its continued usage. However, as plastics are non-biodegradable, their continued usage presents issues for the environment and public health. Packaging makes it easier to handle, distribute, and transport produce to customers. Tomatoes are protected by packaging against physical, chemical, and biological damage that may be caused by several factors. However, utilizing inappropriate packaging often leads to fruit deterioration, which results in losses across the food chain.

Different packing materials are used commercially for the retail and wholesale selling of fresh food. Fresh produce's quality and shelf life are often impacted by the kind and quality of packaging used during storage and transportation. Most farmers in developing countries still handle tomatoes in traditional woven baskets made of bamboo and palm fronds. However, using traditional baskets resulted in post-harvest losses ranging from 30% to 50% for both small and big-scale farmers in local markets. Losses occur as a result of excessive pressure to the fruits in the bottom part. Farmers minimize the physical damage to the fruit by smooth-lining the inside of the basket and quickly laying up a layer of dry grass as a cushion. Other common packing and transportation methods used by farmers in developing countries include wooden and plastic crates because they are easy to make and can be constructed with readily accessible materials. Tomatoes, however, are often damaged as a result of the size, interior rough surface, and difficulties in handling crates. Packing liners are used as shock/impact absorbers in packing crates to serve as shock/impact absorbers during handling and shipping. Polyethylene (PE) and polypropylene (PP) are the most used plastic films for packaging tomatoes due to their low water permeability characteristics. MAP process employs plastic films. The primary function of MAP packaging materials is to serve as a permeation barrier for the gases until a stable equilibrium is achieved between the external gases and those within the container. The passage of moisture, carbon dioxide, oxygen, and ethylene is facilitated by edible films and coatings, which act as a diffusion barrier. Although the two terms are frequently used interchangeably, a coating is typically applied in a liquid form by immersing the product in a consumable material solution, whereas the film is pre-manufactured before application (Mibulo et al., 2020).

MAP systems that have been designed poorly might not be effective or can even reduce a commodity's storage life. The package will not be useful if the required atmosphere is not generated quickly, if O<sub>2</sub> and/or CO<sub>2</sub> levels are not within the specified range, the product may undergo substantial changes, reducing its storage life. MAP's effects are frequently observed in the slowdown of plant respiration in a low O<sub>2</sub> atmosphere. When the O<sub>2</sub> concentration inside the package drops below 10-12%, respiration begins to reduce. This inhibition of respiration continues until O<sub>2</sub> levels for

most products reach between 2-5%. If O<sub>2</sub> levels drop below 2-5% (depending on product and temperature), fermentative metabolism takes over, resulting in off-flavors, off-odors, and unpleasant volatiles. Same as this, as CO<sub>2</sub> concentrations rise above the atmospheric level, some commodities experience a reduction in respiration rate, ethylene (C<sub>2</sub>H<sub>4</sub>) production and sensitivity to ethylene, as well as a reduction in microorganism and fungal/bacterial growth. Reduced O<sub>2</sub> and elevated CO<sub>2</sub> concentrations combined can slow down the rate of respiration more than either alone. The respiration activity of the product generates a modified atmosphere (MA) when oxygen (O<sub>2</sub>) is consumed and carbon dioxide (CO<sub>2</sub>) is released within a sealed plastic packaging. To guarantee the best possible balance of these gases during storage and transportation, specialized film packaging with the appropriate permeability to CO<sub>2</sub> and O<sub>2</sub> is utilized. The purpose of MAP is to establish a steady-state condition or equilibrium package atmosphere where the CO<sub>2</sub>% and O<sub>2</sub>% are at levels that are beneficial and non-harmful to the product. The steady-state level is determined by the rate of product respiration, the weight of the produce, and the package permeability. In developing countries, MAP has a significant benefit because it can be done economically by hand, saving the high cost of new machinery. Furthermore, a scarcity of refrigerated storage makes such a technique much more necessary. However, MAP requires additional costs in equipment and labor in the packaging process. There is also a risk of spoilage caused by improper packing and temperature misuse (Goswami & Mangaraj, 2011).

**Table 2.2** Summary of Modified Atmosphere Packaging on Tomato Fruits

Study topic	Results	References
1. Effect of MAP on Postharvest Quality of Pink tomatoes	Tomatoes sealed with PE50 and PP films had the lowest weight loss and the highest soluble solids after 60 days of storage	Batu and Thompson (1998)
2. Effect of Active MAP and cold storage on the Postharvest Quality of Cherry tomatoes	Combination of MAP and low temperature-maintained quality and extended Postharvest life of cherry tomatoes up to 25 days	Fagundes et al. (2015)

**Table 2.2 (continued)**

Study topic	Results	References
3. Influence of MA and Ethylene levels on quality attributes of fresh tomatoes ( <i>Lycopersicon esculentum</i> Mill.)	Ethylene removal in combination with MAP led to a higher content in total phenols and ascorbic acid in the short life cultivar.	Domínguez et al. (2016)
4. Ready to eat Cherry tomatoes: Passive MAP conditions for shelf-life extension	Considering sensory quality, ready-to-eat cherry tomatoes packaged in PE exhibited a shelf life of 21 days	Paulsen et al. (2019)
5. Extension of Shelf Life of Tomato Using KMnO <sub>4</sub> as Ethylene Absorbent	For increasing concentrations of KMnO <sub>4</sub> , the rate of change of TSS, acidity, ascorbic acid, lycopene, firmness and color slowed down, which was minimum in case of 2500 ppm KMnO <sub>4</sub> treated tomatoes.	Nath et al., 2015
6. Evaluation of MAP system in pallets to extend shelf life of the stored tomato at cooling temperature	MAP delayed color evolution, reduced the firmness loss, biosynthesis of lycopene, and decay rate of tomato	Olveira-Bouzas et a. (2021)
7. Active packaging for Postharvest storage of Cherry tomatoes: Different strategies for application of microencapsulated essential oil	The strategy can enhance quality preservation during post-harvest storage of fresh fruit	Locali-Pereira et al. (2021)
8. Role of KMnO <sub>4</sub> on physicochemical properties, during storage of five different tomato cultivars	KMnO <sub>4</sub> ethylene absorber sachets preserved ascorbic and antioxidant capacity of tomatoes	Köstekli M et al., 2016

## 2.11 Nitrogen Application

The technique helps to prolong the shelf life of fresh produce. N<sub>2</sub> packaging offers several practical benefits since it is a simple approach that requires only N<sub>2</sub> gas. In order to establish an appropriate gas composition, the gas permeability of plastic is used to facilitate the permeation of air gases following N<sub>2</sub> packaging and the respiration

of fresh-cut vegetables. Nitrogen packaging technology may enhance the shelf life of vegetables in terms of their appearance. However, it is important to be aware of the risk of bacterial growth. Regardless of the storage technique used, vegetables may pose a risk to public health if pathogenic microbes are present. When fresh vegetables are kept for longer periods, the risk of foodborne disease increases significantly. This is because bacteria can spread to larger populations during this time. Because the growth of microorganisms is not inhibited by the N<sub>2</sub> packaging technique, it is not appropriate to use it alone to extend the shelf life of cut vegetables (Koseki & Itoh, 2002). Some research has indicated that applying N<sub>2</sub> before storage will delay fruit ripening, minimize chilling injury, and prolong the shelf life of avocados (Polenta et al., 2006).

Following the above literature, an experiment was then conducted to investigate different types of active MAP such as CO<sub>2</sub> emitter (CO<sub>2</sub> pad), ethylene scavenger, mixed gas (5%CO<sub>2</sub>, 5%O<sub>2</sub>, 90%N<sub>2</sub>), 99.5% N<sub>2</sub> flushing only and passive MAP on the quality of tomatoes stored at different storage temperatures of 6±1 and 12±2 and 25°C for 21 days. The main purpose for the first experiment was for screening to establish the best treatment and temperature to apply with MAP to maintain and extend the shelf of tomatoes during cold storage. The entire study wanted to work with mature green tomatoes, the challenge was that tomatoes at the market were stored in open places exposed to high temperatures hence leading to ripening faster in a short period of time. Therefore, the research had to be conducted with available tomatoes at the market such as breaker, turning, pink and mature green stages.

## CHAPTER 3

### METHODOLOGY

#### **3.1 Experiment 1: Application of Active MAP such as CO<sub>2</sub> Emitter (CO<sub>2</sub> Pad), Ethylene Scavenger, Mixed Gas (5%CO<sub>2</sub>, 5%O<sub>2</sub>, 90%N<sub>2</sub>), 99.5% N<sub>2</sub> Flushing Only and Passive MAP) on the Quality of Tomatoes Stored at Different Storage Temperatures of 6±1, 12±2 and 25°C**

The objective of the first experiment was to investigate the different types of active MAP to prolong the shelf life of tomatoes in small scales during cold storage at 6±1°C, 12±2°C and 25 °C for 21 days.

##### **3.1.1 Tomato Preparation**

Fresh tomatoes (*Lycopersicon esculentum* Mill.) were purchased at Lan Muang market in Chiang Rai and selected according to uniformity such as color (breaker / turning stages), size and without any defects (Guo et al., 2014). Calyx was removed before washing. All tomatoes were washed in running tap water and dipped in Sodium hypochlorite (200 ppm) for 1 minute to reduce microbial load. They were allowed to dry for 10-15 minutes (Zakriya et al., 2023). All the treatments were packaged in Low-density polyethylene (LDPE) plastic bags and sealed. Chemicals and instruments in this experiment are shown in Table 3.1.

**Table 3.1** Chemicals and Equipment Used in Experiment 1

Chemicals	Equipment
-Sodium hypochlorite	-Cold room ( $6\pm 1$ , $12\pm 2$ and room temperature $25\text{ }^{\circ}\text{C}$ )
-Sodium bicarbonate	
- Citric acid	-Hygrometer
-Ethylene scavenger (Green keeper™)	-Gas analyzer
-CO <sub>2</sub> , O <sub>2</sub> and N <sub>2</sub>	-LDPE plastic bags
	-Digital scale
	-Heat sealer
	-Desiccator
	-Absorbent pads
	-Septum
	-Baskets
	-Air pump

### 3.1.2 Preparation of CO<sub>2</sub>-Emitting Pads

CO<sub>2</sub>-pads in one ratio of 0.5g (0.304g NaHCO<sub>3</sub> and 0.237g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>) was weighed, mixed, packed in the absorbent pad sachets, and kept in the Low-density polyethylene (LDPE) plastic bags (8x12 inches) and sealed using the method of Hansen et al. (2016).

### 3.1.3 Application of MAP in Small Packaging of Tomatoes

In this study, tomatoes were weighed (averagely 400g/bag) and packed in Low-density polyethylene (LDPE) plastic bags (8 x 12 inches) with and without an active agent, e.g., CO<sub>2</sub>-emitting pads, ethylene scavenger, mixed gas (5%CO<sub>2</sub>+5% O<sub>2</sub>+90% N<sub>2</sub>), 99.5% N<sub>2</sub> flushing alone and passive MAP. All the bags were sealed and placed in cold storage. Table 3.2 illustrates treatments with or without active agents in MAP stored at different temperatures of  $6\pm 1$  and  $12\pm 2^{\circ}\text{C}$ , RH of 85-90% and also at  $25^{\circ}\text{C}$  (room temperature) for 21 days. There were 11 treatments with 5 replications for each sampling day.

**Table 3.2** Eleven Treatments with or without Active Agents in MAP stored at Different Temperatures of  $6\pm 1$ ,  $12\pm 2^\circ\text{C}$ , and  $25^\circ\text{C}$

No.	Treatment	Description	Temperature ( $^\circ\text{C}$ )
1	Control	Tomatoes in LDPE bag without an active agent (passive MAP)	25
2	LDPE bag	Tomatoes in LDPE bag without an active agent (passive MAP)	$6\pm 1$
3	CO <sub>2</sub> emitter	Tomatoes in LDPE bag with CO <sub>2</sub> -emitting pad	$6\pm 1$
4	5%CO <sub>2</sub> +5% O <sub>2</sub> +90% N <sub>2</sub>	Tomatoes in LDPE bag with mixed gas	$6\pm 1$
5	99.5% N <sub>2</sub> gas	Tomatoes in LDPE bag with 99.5% N <sub>2</sub> flushing (alone)	$6\pm 1$
6	Ethylene scavenger	Tomatoes in LDPE bag with ethylene scavenger (Green keeper™)	$6\pm 1$
7	LDPE bag	Tomatoes in LDPE bag without an active agent (passive MAP)	$12\pm 2$
8	CO <sub>2</sub> emitter	Tomatoes in LDPE bag with CO <sub>2</sub> -emitting pad at 0.5g (0.278 g NaHCO <sub>3</sub> + 0.222 g C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> )	$12\pm 2$
9	5%CO <sub>2</sub> +5% O <sub>2</sub> +90% N <sub>2</sub>	Tomatoes in LDPE bag with mixed gas	$12\pm 2$
10	99.5% N <sub>2</sub> gas	Tomatoes in LDPE bag with 99.5% N <sub>2</sub> flushing (alone)	$12\pm 2$
11	Ethylene scavenger	Tomatoes in LDPE bag with ethylene scavenger (Green keeper™)	$12\pm 2$

### 3.1.4 Physicochemical Analysis

#### 3.1.4.1 Gas composition

The gas composition for CO<sub>2</sub> and O<sub>2</sub> analysis was conducted with a gas analyzer (CheckMate 3 O<sub>2</sub> (Zr) CO<sub>2</sub>- 100, Dansensor, Denman) from day 0, 3, 6, 9, 12, 15, 18, and 21 of the storage periods. A rubber septum was attached to the package.

Gas composition was checked from the package by piercing the package (septum attached to the plastic film) with a fine needle syringe. On each sampling date, three packages from each storage condition were tested (Fagundes et al., 2015).

#### 3.1.4.2 Score of maturity (Color)

Color changes of tomatoes were analyzed by visual observation using maturity scores from a scale of 1-6, following the method of Garcia et al. (2019) in Figure 3.1.



Source Garcia et al. (2019)

**Figure 3.1** Maturity and Ripening Stages of Tomatoes

#### 3.1.4.3 Disease incidence

Disease incidence was determined by calculating the number of tomatoes infected in each bag for each treatment on each sample date following the method of (Tilahun et al., 2021) as follows:

$$DI (\%) = \frac{\text{No. of Infected Fruits}}{\text{Total No. of Fruits}} \times 100$$

### 3.2 Experiment 2: Application of Different CO<sub>2</sub> Emitter Concentrations under a MAP in Small Packaging of Tomatoes Stored at 6±1°C

The objective of the second experiment was to investigate different concentrations of CO<sub>2</sub> emitter (CO<sub>2</sub> pad) in small scale on turning/pink tomatoes during cold storage at 6±1°C. Fresh tomatoes were purchased and prepared with the same procedure conducted in the previous experiment. The chemicals and instruments used in this experiment are shown in Table 3.3.

**Table 3.3** Chemicals and Equipment Used in Experiment 2

Chemicals		Equipment	
-Sodium hypochlorite	-Syringe (5ml, 10ml)	-Cutting board	-Cold room (6±1°C)
-Sodium bicarbonate	-Glass beakers (50ml)	-Knife	-Hygrometer
-Citric acid	-Gas chromatograph	-Funnels	-Gas analyzer
-Metaphosphoric acid	-Glass rod	-Blender	-Colorimeter
-Acetic acid	-Magnetic bar	-Pipette (2ml and 5 ml)	-Spatula stainless
-Ascorbic acid	-Air pump	-Amber bottle (250ml)	-Pipette bulb
-2,6 dichloroindophenol sodium salt	-White cloths	-Amber burette (50ml)	-Septum
-CO <sub>2</sub> , O <sub>2</sub> and N <sub>2</sub>	-Heat sealer	-Hand-held refractometer	-LDPE bags
	-Texture analyzer	-Filter paper No. 1	-Distilled water
	-Digital scale	-Jars (1.8 litres)	bottle
	-Baskets	-Absorbent pads	-Volumetric flasks
	-Desiccator	-Conical flask (50ml and 100ml)	(50ml and 100ml)

#### 3.2.1 Preparation of CO<sub>2</sub>-Emitting Pads

CO<sub>2</sub>-pads in different ratios were prepared in the same way as in experiment 1 and kept in the Low-density polyethylene (LDPE) plastic bags as follows: T2 = single ratio (0.139g NaHCO<sub>3</sub> + 0.111g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>), T3 = double ratio (0.278g NaHCO<sub>3</sub> + 0.222g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>), and T4 = quadruple ratio (0.556g NaHCO<sub>3</sub> + 0.444g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>)

### 3.2.2 Application of MAP in Small Packaging of Tomatoes

In this study, tomatoes were weighed (averagely 400g/bag) and packed in Low-density polyethylene (LDPE) plastic bags (8 x 12 inches) with and without active agents (CO<sub>2</sub>-emitting pads). All the bags were sealed and placed in cold storage.

Table 3.4 illustrates treatments with or without CO<sub>2</sub>-emitter in MAP stored at different temperatures of 6±1°C, 85-90% RH for 28 days. There were 4 treatments with 3 replications for each sampling day.

**Table 3.4** Four Treatments with or without CO<sub>2</sub>-Emitter in MAP Stored at 6±1°C

No.	Treatment	Description	Amount of concentration	Temperature (°C)
1	Control	Tomatoes in LDPE bag without CO <sub>2</sub> -emitting pad (passive MAP)	None	6±1
2	Single	Tomatoes in LDPE bag with CO <sub>2</sub> -emitting pad	0.25g(0.139 g NaHCO <sub>3</sub> + 0.111 g C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> )	6±1
3	Double	Tomatoes in LDPE bag with CO <sub>2</sub> -emitting pad	0.5g(0.278 g NaHCO <sub>3</sub> + 0.222 g C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> )	6±1
4	Quadruple	Tomatoes in LDPE bag with CO <sub>2</sub> -emitting pad	1g (0.556 g NaHCO <sub>3</sub> + 0.444 g C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> )	6±1

### 3.2.3 Physicochemical Analysis

#### 3.2.3.1 Gas composition

The gas composition for CO<sub>2</sub> and O<sub>2</sub> analysis was analyzed in the same way as in experiment 1 but differs with day intervals. Analysis was conducted from day 0, 4, 8, 12, 16 and 20 of the storage periods.

#### 3.2.3.2 Weight loss

The weight was measured by deducting the sample weight from its previous weight (initial) and results were expressed as the percentage (%) of weight loss compared to its initial weight (Tilahun et al., 2017a).

#### 3.2.3.3 Color

The measurement of color on tomatoes was done on 2 sides of the fruit to

make an average on parameters such as L\*, a\*, b\*, chroma (C), and hue angle (h) using Colorimeter Hunter Lab Miniscan instrument (United States of America). The colorimeter was calibrated using a standard white reflector plate (Paulsen et al., 2019).

#### 3.2.3.4 Firmness

Compression force was determined by using a digital texture (TA.XT. Plus Texture Analyzer (Stable Micro Systems, Surrey, UK). Results were expressed in Newtons (N) (Oliveira-Bouzas et al., 2021).

#### 3.2.3.5 Total soluble solids and Titratable acidity

Tomatoes were cut and blended. The juice from tomatoes represented each treatment and was measured by an automatic hand-held refractometer (Atago Pocket refractometer Co.Ld., Japan). The machine was standardized using distilled water before each measurement and the results were expressed as °Brix' (%). The titratable acidity was analyzed using 1 mL of the juice and diluted with 49 mL of distilled water. The acid percentage of the diluted solution was then accessed using a digital titratable acid kit (Antago acidity meter, Japan) (Adhikari et al., 2020).

#### 3.2.3.6 Damage incidence and severity

Damage Incidence was conducted using the same formula in experiment 1, whereas damage severity (DS) was also analyzed per replicate using the following formula:

$$DS (\%) = \frac{((\text{Severity rating} \times \text{Number of tomato fruit clusters in the rating}))}{(\text{Total number of tomato fruit clusters assessed}) \times \text{Highest DS score (4)} \times 100}$$

(Tilahun et al., 2021).

### 3.2.4 Antioxidant Analysis

#### Ascorbic acid

Ascorbic acid concentration of triplicate tomato fruit samples was analyzed using the burette to measure the amount of dye used during titration following the method of (Nielsen, 2024).

### 3.3 Experiment 3: Application of CO<sub>2</sub> Pad Compared to Flushing with Mixed Gas (5% CO<sub>2</sub>, 5% O<sub>2</sub>, and 90% N<sub>2</sub>) in Bulk-Size Packaging of Tomatoes Stored at 12±2°C

The objective of the third experiment was to investigate two types of active MAP such as CO<sub>2</sub> emitter (CO<sub>2</sub> Pad) and mixed gas (5% CO<sub>2</sub>, 5% O<sub>2</sub>, 90% N<sub>2</sub>) to prolong the shelf life of tomatoes in bigger scales (bulk- size packaging) during cold storage at 12±2°C. Fresh tomatoes (turning/pink) were purchased and prepared with the same procedure conducted in the first experiment. The chemicals and instruments used in this experiment are shown in Table 3.5.

**Table 3.5** Chemicals and Equipment Used in Experiment 3

Chemicals		Equipment	
-Sodium hypochlorite	-Syringe (5ml, 10ml)	-Digital scale	-Cold room (12±2 °C)
-Sodium bicarbonate	-Knife	-Amber bottle (500ml)	-Gas analyzer
-Citric acid	-Funnels	-Spectrophotometer	-Gas chromatograph
-Hexane	-Blender	-Desiccator	-Colorimeter
-Acetone	-Spatula stainless	-Hygrometer	-Centrifuge
-Ethanol	-Cutting board	-Baskets	-Texture analyzer
	-Absorbent pads	-Test tubes (50ml)	-Septum
	-Centrifuge tube rack	-Heat sealer	-LDPE bags
	-Cuvette glass		-Jars (1.8 litres)

#### 3.3.1 Preparation of CO<sub>2</sub>-Emitting Pads

CO<sub>2</sub>-pads in one ratio of 3g (1.668g NaHCO<sub>3</sub> + 1.332g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>) were weighed, mixed, packed in absorbent pad sachets and kept in the Low-density polyethylene (LDPE) plastic bags using the method in experiment 1.

#### 3.3.2 Application of MAP in Bulk Packaging of Tomatoes

Tomatoes were weighed (averagely 1000g/bag) and packed in Low-density

polyethylene (LDPE) plastic bags (12 x 18 inches) with and without active agents (CO<sub>2</sub>-emitting pads) and also mixed gas flushing. All the bags were sealed and placed in cold storage. Table 3.5 illustrates treatments with or without CO<sub>2</sub>-emitter and gas flushing in MAP stored at 12±2°C, 85-90% RH for 30 days. There were 3 treatments with 3 replications for each sampling day.

**Table 3.6** Three Treatments with or without CO<sub>2</sub>-emitter and mixed gas Flushing in MAP stored at 12±2°C

No.	Treatment	Description	Amount of concentration	Temperature (°C)
1	Control	Tomatoes in LDPE bag without CO <sub>2</sub> -emitting pad (passive MAP)	None	12±2
2	T1(CO <sub>2</sub> -pad)	Tomatoes in LDPE bag with a CO <sub>2</sub> -emitting pad at 3g (1.668 g NaHCO <sub>3</sub> + 1.332 g C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> )	3g (NaHCO <sub>3</sub> + C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> )	12±2
3	T2 (5%CO <sub>2</sub> +5% O <sub>2</sub> +90% N <sub>2</sub> )	Tomatoes in LDPE bag with mixed gas application	5% CO <sub>2</sub> , 5% O <sub>2</sub> , and 90% N <sub>2</sub>	12±2

### 3.3.3 Physicochemical Analysis

#### 3.3.3.1 Gas composition

The gas composition for CO<sub>2</sub> and O<sub>2</sub> analysis was conducted in the same way as in experiment 1 but on different date intervals as day 0, 6, 12, 16, 21, 26 and 30 (Fagundes et al., 2015).

#### 3.3.3.2 Ethylene production and respiration rate

Samples of 12 fruits (around 600 g) per replicate were placed in a 1.8 L jar sealed with a silicon septum and kept at 25 °C for 1 h. Gas of the headspace was sampled after 1 hour incubation in an acclimatized chamber at 20°C, using the same method as Mansourbahmani et al. (2018).

#### 3.3.3.3 Quality Determination

Other qualities of tomatoes such as weight loss, color, firmness, ascorbic acid and decay percentage were also analyzed using the same method in experiment 2.

### 3.3.4 Antioxidant Analysis

#### Lycopene

Lycopene content was measured in 3 replications for each treatment by homogenizing 1g of tomato sample. 5 ml of ethanol, 5 ml of acetone and 10 ml of hexane were mixed in a test tube and centrifuged at 5,871xg for 15 min. 3ml of distilled water was then added in all the test tubes and shaken again for another 5 minutes. Afterwards, all the test tubes were stored at room temperature to allow for separation of hexane layer for 5 minutes. A spectrophotometer was used to measure the absorbance of the upper layer (hexane) at 503 nm versus a blank of hexane solution. The results were then expressed as  $\text{mg/kg}^{-1}$  of fresh weight (Tilahun et al., 2017a).

### 3.4 Statistical Analysis

The experimental design was a Completely Randomized Design (CRD) in all experiments. In the first experiment, there were 5 replications/treatment with each replication having 6 fruits/400g/bag), whereas the second and third experiments had 3 replications/treatment and each replication had 6 fruits and 20 fruits/1000g/bag. Data was analyzed using a significance test of the mean  $\pm$ SE.

## CHAPTER 4

### RESULTS AND DISCUSSION

#### **4.1 Experiment 1: Application of Active MAP (CO<sub>2</sub> Emitter, Ethylene Scavenger, 5%CO<sub>2</sub>, 5%O<sub>2</sub>, 90%N<sub>2</sub> Gas Flushing, 99.5%N<sub>2</sub> Gas Flushing, LDPE Bags-Passive MAP) on the Quality of Tomatoes Stored at Different Storage Temperatures of 6±1, 12±2 and 25°C**

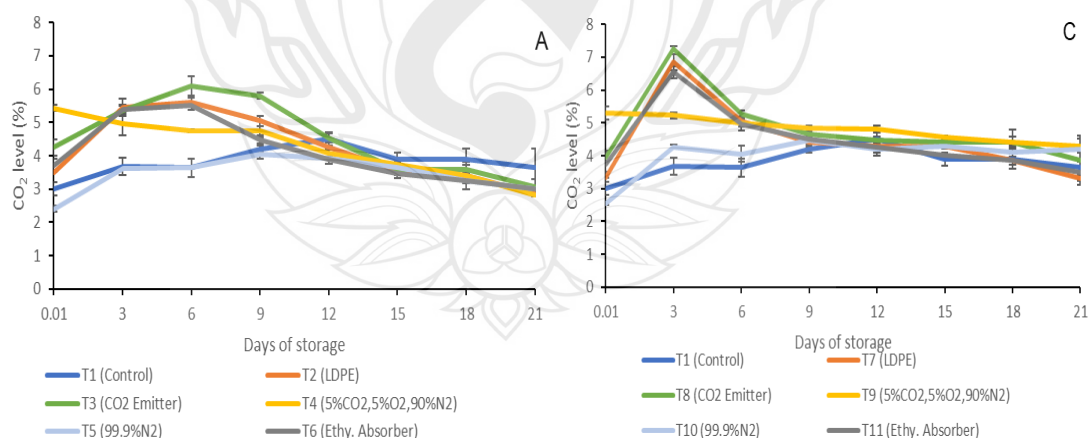
A comparative analysis was conducted on the effects of CO<sub>2</sub>-emitting pads, ethylene remover (Green keeper™), mixed gas flushing (5% CO<sub>2</sub> + 5% O<sub>2</sub> + 90% N<sub>2</sub>), and 99.5% N<sub>2</sub> gas flushing only on the quality of tomatoes held at temperatures of 6±1°C and 12±2°C, with 85-90% relative humidity, over a duration of 21 days.

##### **4.1.1 Gas Composition**

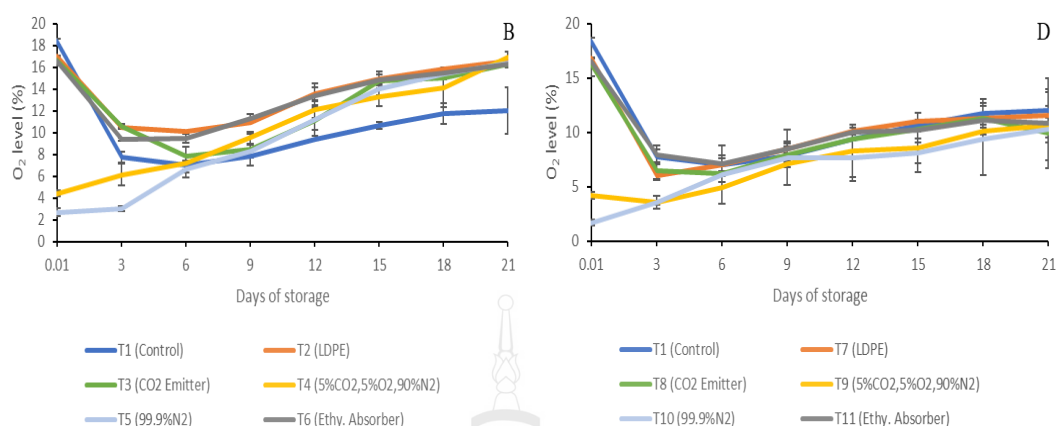
CO<sub>2</sub> and O<sub>2</sub> concentrations are shown at different temperature levels in Figure 4.1. As usual, CO<sub>2</sub> concentration increased (Figure 4.1A and C), and O<sub>2</sub> concentration decreased (Figure 4.1B and D) in all treatments during the first days of storage due to product respiration in both storage temperatures (Domínguez et al., 2016). Sun et al. (2024) also reported a similar pattern stating that O<sub>2</sub> levels significantly decreased and CO<sub>2</sub> levels increased during the first storage period. The authors continued to explain that this decrease and increase was caused by the aerobic respiration of “Kyoho” grapes in different packing groups, which resulted in a considerable increase in CO<sub>2</sub> production and O<sub>2</sub> consumption. The authors added that O<sub>2</sub> reduced from 11.3% to 6.1% whereas CO<sub>2</sub> increased from 9.2% to 12.2% between the 5th and 15th days of storage. The O<sub>2</sub> and CO<sub>2</sub> levels in the packaging groups remained steady over the later storage phase, from days 15 to 35. Before the storage (10 minutes after sealing packages), CO<sub>2</sub> concentration was more pronounced in T4 (5% CO<sub>2</sub> flushing), followed by T3 (CO<sub>2</sub>

emitter), T2 (passive MAP) and T6 (ethylene absorber). Control (T1) and T5 (99.5% N<sub>2</sub> flushing) recorded the lowest significant rates during this time. Similar trends are shown in tomatoes at 12±2°C, T9 (5% CO<sub>2</sub> flushing) showed a great level of CO<sub>2</sub> concentration recording the highest significant difference among all other treatments. T4 and T9 showed the highest CO<sub>2</sub> at the beginning because the gas was flushed directly in the plastic bag before sealing. The CO<sub>2</sub> level in the bag with the CO<sub>2</sub> emitter of T3 and T8 reached its peak at 6% and 7% on day 6 and day 3, respectively. Nonetheless, the CO<sub>2</sub> concentration for each treatment decreased on day 12 (6 °C) and 9 (12 °C) due to the gas permeability of the LDPE bag and reached an equilibrium level until the end of storage.

The level of O<sub>2</sub> inside the packages exhibited a trend opposite to that of CO<sub>2</sub>. At warmer temperatures, CO<sub>2</sub> levels increased while O<sub>2</sub> levels decreased compared to lower storage temperatures, indicating enhanced respiration rates in tomatoes at higher temperatures. The results of our findings are similar to those of Manasa et al. (2018) who reported that treatment with flushing of mixed gas (3% O<sub>2</sub>+ 5% CO<sub>2</sub>+ 92% N<sub>2</sub>) effectively delayed the physicochemical changes and extended the shelf life of cherry tomatoes up to 33 days (60%), followed by flushing with 5 % O<sub>2</sub>+ 5 % CO<sub>2</sub>+ 90% N<sub>2</sub> which extended the shelf life up to 32.33 days.



**Figure 4.1** CO<sub>2</sub> and O<sub>2</sub> Concentrations of Tomatoes in LDPE plastic Films with Different Treatments Stored at 6±1 (A, B) and 12±2°C (C, D) (Means Showing Significance Difference Using Test of the Mean ±SE)

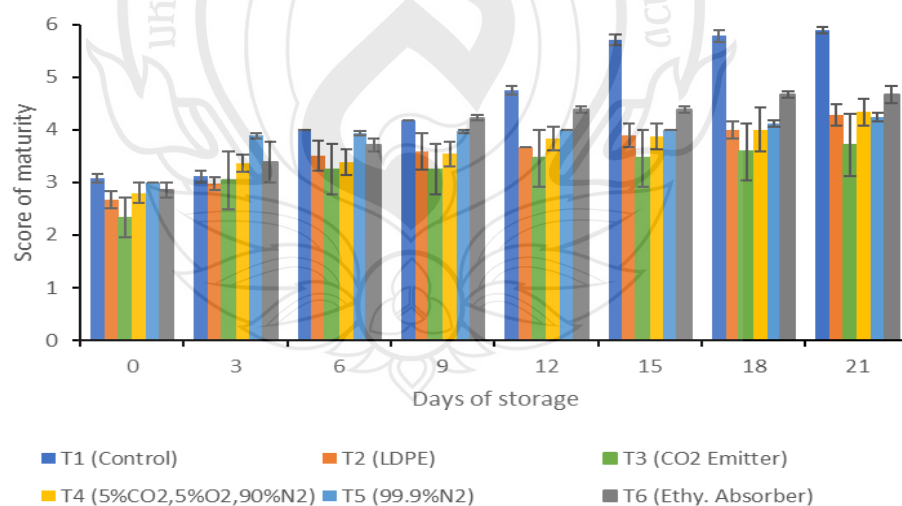


**Figure 4.1 (continued)**

#### 4.1.2 Score of Maturity (Color)

The maturity of tomatoes was determined by observing the change in color, and the change in the score from one to six following the level of maturity stage that occurred to the tomatoes during the storage process, as depicted in Figure 4.2 and 4.3. Color changes were noted in the control on days 12, 15, 18, and 21, corresponding to maturity scores of 4.75, 5.71, 5.78, and 5.89, respectively, at  $6\pm 1^\circ\text{C}$ . On the same dates, T3 exhibited the lowest external color, with maturity indices recorded at 3.46. Tomatoes in treatments with active packaging showed slow color changes until the end of storage. No significant differences were observed among all treatments with active agents and passive MAP at the conclusion of storage. T3 with the CO<sub>2</sub> emitter exhibited superior performance compared to all other treatments, as indicated by lower maturity scores although it was not significantly different from others except the control. The control exhibited the highest scores of 5.71, 5.78, and 5.89 on days 15, 18, and 21, respectively, at a temperature of  $12\pm 2^\circ\text{C}$ , which were marginally greater than those of other treatments. At higher temperature maturity score was higher than at the lowest temperature. Tomatoes with active packaging showed the slow color changes until the end of the storage at  $6\pm 1^\circ\text{C}$ , especially with a treatment incorporated with CO<sub>2</sub>-pad. Tomatoes at  $6\pm 1^\circ\text{C}$  were greener than at  $12\pm 2^\circ\text{C}$  (Figure 4.3).

The most visible change that occurs during fruit storage is the external color of tomato peels changing from green to yellow and then to red. This causes an increase in starch and aroma development. Peel color changes are caused by chlorophyll breakdown or qualitative and quantitative changes from green pigments into other colors (Hossain & Rashid, 2021). Giuliano et al. (1993) also stated that during tomato ripening, chlorophyll degrades from green to colorless compounds, while carotenoids are synthesized from phytoene to produce carotene (pale yellow), lycopene (red),  $\beta$ -carotene (orange), xanthophylls, and hydroxylated carotenoids (yellow). Murmu and Mishra (2018) also reported 32 days shelf life of guava when using ethylene (potassium permanganate) and moisture scavengers under MAP conditions. In their study chilling injury was very low in guava stored at 4 °C with 3 g ethylene scavenger and 46 g Moisture Scavenger. This was shown by brighter color, lower firmness and the highest number of acceptable (95.33%) guava compared to other treatments. They continued to report that active MAP with 3 g ethylene Scavenger and 46 g moisture Scavenger can be substituted with fungicide treatments to extend shelf-life of guava up to 32 days. Buescher (1979) also reported that color changes were delayed in tomatoes when exposed to all levels of CO<sub>2</sub>.



**Figure 4.2** Score of Maturity of Tomatoes in LDPE plastic Films with Different Treatments Stored at 6±1(A) and 12±2°C(B) for 21 Days (Means Showing Significance Difference Using Test of the Mean ±SE)

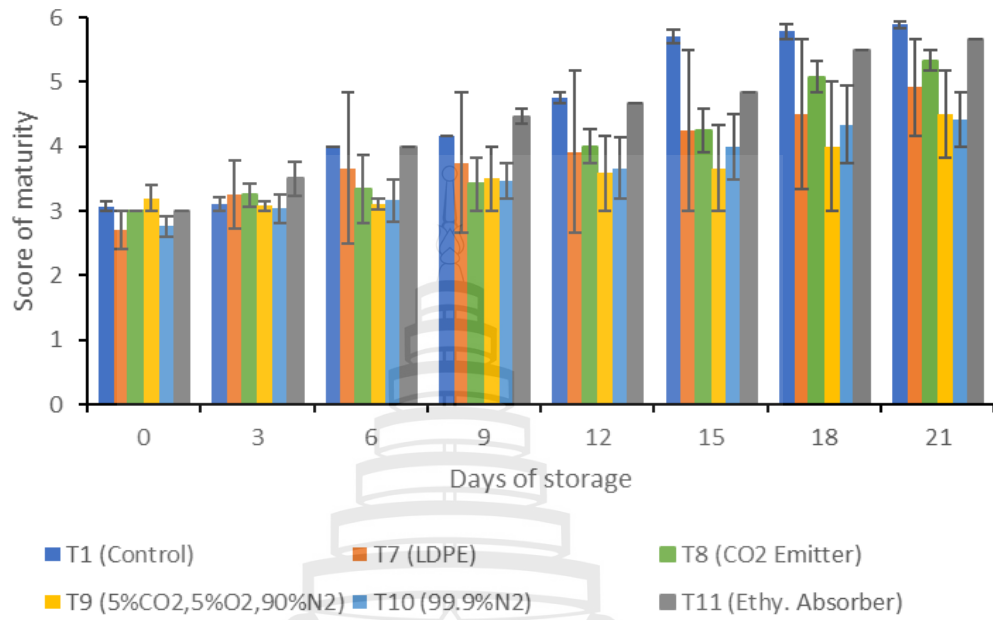


























Figure 4.2 (continued)

Treatment	6±1°C		12±2°C	
	Day 0	Day 21	Day 0	Day 21
Control (LDPE bag) (T1) At 25°C				
In sealed LDPE bag (T2, T7)				
In bag with CO <sub>2</sub> emitter (T3, T8)				
In bag with 5%CO <sub>2</sub> +5% O <sub>2</sub> +90% N <sub>2</sub> (T4, T9)				
In bag with 99.5% N <sub>2</sub> gas (T5, T10)				
In bag with Ethylene scavenger (T6, T11)				

**Figure 4.3** Appearances of Tomatoes in Different Treatments Stored at 6±1°C and 12±2°C for 21 Days

### 4.1.3 Damage Incidence

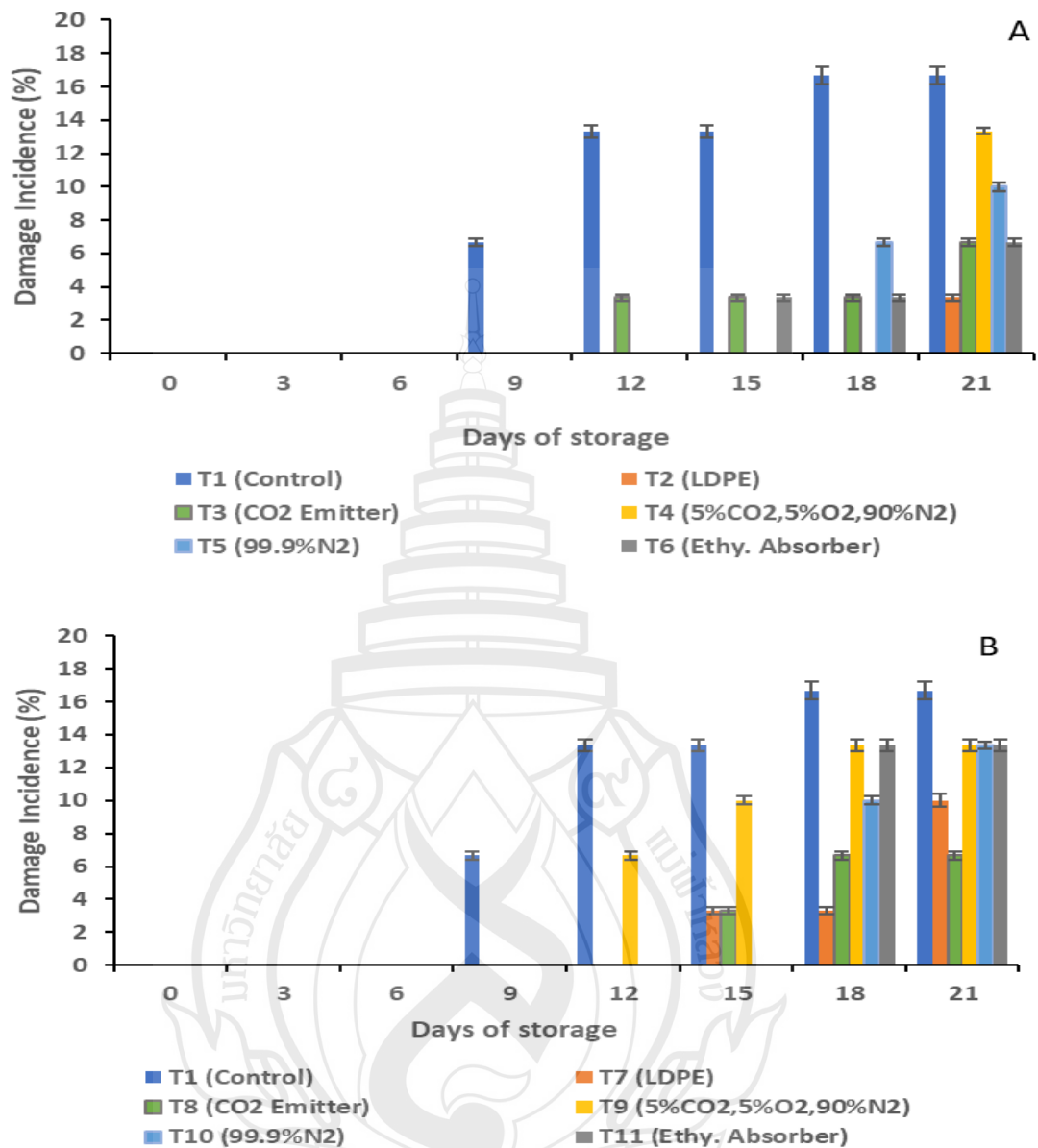
Damage incidence of all treatments of tomatoes is shown in Figure 4.4. Decay was first noticed on tomatoes on day 9 of storage at the ambient temperature (25 °C) in the control (6.67%). During the storage condition of 6±1°C, rotting was first observed in T3 (CO<sub>2</sub> emitter) on day 12, at the lowest rate of 3.33%. It continued with the same pattern until day 18 of storage. Tomatoes incorporated with ethylene scavenger (T6) started to show decay (3.33%) on day 15 and continued with the same pattern until day 18. Decay was also observed for the first time in T5 (99.5% N<sub>2</sub>) on day 18. During this storage condition, the highest decay rate was observed in the control from the beginning of storage until the end of storage. At 6±1°C, on the last day of storage, the maximum decay was recorded in the control (16.67%), while the minimum decay was recorded in T2 (LDPE) at 3.33%, followed by T3 (CO<sub>2</sub> emitter) and T6 (ethylene scavenger) at both 6.67%. CO<sub>2</sub> pad and ethylene scavenger showed the lowest rates until the end of storage. At 6±1°C, Passive MAP (T2) and mixed gas (T4) performed better than other treatments as decay started on the last day of storage. There was a significant difference between all treatments on the last day of storage. The control displayed the highest significant changes than active agents together with passive MAP (6±1°C). At 6±1°C, Passive MAP and mixed gas performed better than other treatments as decay started on the last day of storage

At the temperature of 12±2°C, T9 (5% CO<sub>2</sub>, 5% O<sub>2</sub>, 90% N<sub>2</sub>) started to show some rotting (6.67%) on day 12 and continued throughout storage. On day 15 of storage, the highest decay (13.33%) was observed in the control, while the lowest rate was recorded in T7 (LDPE) and T8 (CO<sub>2</sub> emitter) at the same rate of 3.33%. At warmer temperatures, Passive MAP (T7) and CO<sub>2</sub> emitter (T8) delayed decay rate especially from day 15 until the end of storage. All treatments showed some rotting on day 18 during this cold storage condition (12±2°C), with the highest rate (16.67%) recorded in the control while the lowest decay was recorded in T7 (LDPE), followed by T8 (CO<sub>2</sub> emitter) at 3.33% and 6.67% respectively. On the last day of storage, the maximum DI (16.67%) was recorded in the control while the minimum decay was recorded in T8 (CO<sub>2</sub> emitter), followed by T7 (LDPE) at 6.67% and 10% respectively. All treatments showed infection on the last day of storage (day 21) during a storage temperature of

$6\pm 1^{\circ}\text{C}$ , while in  $12\pm 2^{\circ}\text{C}$  rotting was observed in all treatments on day 18. At warmer temperature,  $\text{CO}_2$  emitter performed better followed by passive displaying the lowest DI from day 15 and continued with the lowest rate until the end of storage. There was a significant difference between all treatments, especially from day 18 until the end of storage. Similarly at this temperature, the control displayed the highest significant changes than active agents together with passive MAP ( $12\pm 2^{\circ}\text{C}$ ).

$\text{CO}_2$  emitter proved to be the most effective active agent in delaying decay rate of tomatoes in both cold storage conditions. Active MAP showed high efficiency in delaying the percentage of decay in tomatoes especially at the lowest temperature. Bailén et al. (2006) also reported that Active MA can be effective in slowing down the decay rate in tomatoes. A significant difference was also observed between the control and other treatments under both storage conditions. The findings demonstrated an increase in the number of rotting fruits during the storage period, regardless of modified atmosphere packaging, or their interactions. This could be linked to postharvest treatments, which contributed to the strengthening of the cell walls and skin of the fruit to prevent micro-organisms from causing decay in tomatoes (Hossain & Rashid, 2021).

According to Manasa et al. (2018), cherry tomato shelf life was prolonged to 33 days in modified atmosphere packages with a gaseous composition of 3%  $\text{O}_2$ , 5%  $\text{CO}_2$ , and 92%  $\text{N}_2$ . However, the control's shelf life was extended up to 15 days. This could be due to ripening and spoilage which occurred more quickly in the control whereas it was less in the case of low  $\text{O}_2$  treatment, which slows down the oxidation reaction and decreases transpiration and respiration rate, and high  $\text{CO}_2$  treatment, which slowed down microbes during storage. It could also be because different physicochemical changes, such as delay in color change and firmness, were delayed and quality was maintained throughout the storage period. Cherry tomato fruits packed in low-density polyethylene with different gas concentrations extended the shelf life at  $8\pm 2^{\circ}\text{C}$  and  $80\pm 5\%$  RH.



**Figure 4.4** Damage Incidence of Tomatoes in LDPE plastic Films with Different Treatments Stored at  $6\pm 1$  (A) and  $12\pm 2^\circ\text{C}$  (B) (Means Showing Significance Difference Using Test of the Mean  $\pm$ SE)

#### Summary (Experiment 1)

1. The control at ( $25^\circ\text{C}$ ) performed lower than all treatments in all the parameters

2. Tomatoes at ( $6\pm 1^\circ\text{C}$ ) were greener than those in ( $12\pm 2^\circ\text{C}$ ).

3. At  $6\pm 1^\circ\text{C}$ , Passive MAP and mixed gas performed better as they delayed 3. symptoms of decay which started to show on the last day of storage. In addition, T3 ( $\text{CO}_2$  emitter) and T6 (Ethylene absorber) also displayed the lowest DI from day 12 and 15, respectively and continued at the low rate until the end of storage period.

4. At  $12\pm 2^\circ\text{C}$ , Passive MAP and  $\text{CO}_2$  emitter performed better as they displayed less incidence throughout the storage period.

After screening to establish the best treatment and temperature in the first experiment, it was found out that Active MAP with  $\text{CO}_2$  emitters tend to slow down color changes under low temperature ( $6\pm 1^\circ\text{C}$ ), although it was not significantly different from other active agents and passive MAP. In addition, a combination of MAP with  $\text{CO}_2$  emitters also delayed damage incidence throughout the storage period. Based on these results, a  $\text{CO}_2$  emitter integrated with LDPE packaging was utilized for the storage of tomatoes in different concentrations in the second experiment. The aim was to establish the best concentration to be applied and compared with mixed gas flushing in the third experiment.

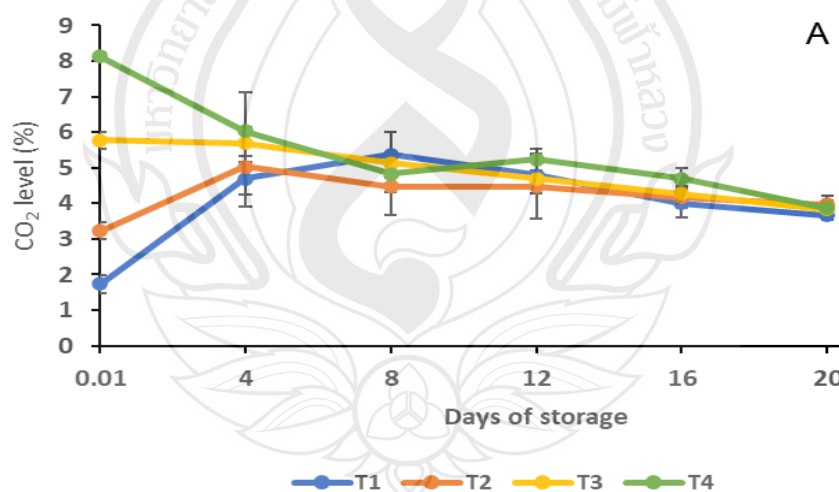
## **4.2 Experiment 2: Application of $\text{CO}_2$ Emitter Concentrations under MAP in Small Packaging of Tomatoes Stored at $6\pm 1^\circ\text{C}$**

The characteristics of tomatoes were examined, followed by an assessment of the impact of  $\text{CO}_2$  emitters on their shelf life in 28 days. However, quality parameters such as gas composition, weight loss, color, firmness, ascorbic acid, TSS and TA were assessed up to 20 days due to degradation of quality in tomatoes since there was high damage incidence and severity after 20 days. Furthermore, damage incidence and severity continued to be analyzed until day 28.

### **4.2.1 Gas Composition**

The concentration level of  $\text{CO}_2$  increased and that of  $\text{O}_2$  decreased rapidly at the beginning of storage in treatments with  $\text{CO}_2$  pads than the control (Figure 4.5). T4 (8.13%) exhibited the highest increase of  $\text{CO}_2$  than all treatments, especially the control

(1.73%). It declined on control, T2 (single ratio) and T3 (double ratio) on day 4 of storage but decreased for T4 (quadruple ratio) on the 8th day of storage. Afterwards, a decline of CO<sub>2</sub> was observed in all the treatments until the end of storage. Both treatments under MAP condition reached an equilibrium state after 7 days until the end of storage. O<sub>2</sub> declined in all the treatments as days progressed until the end of storage. Less O<sub>2</sub> was observed in T4 more especially from day 16 until the end of storage. The level of O<sub>2</sub> concentrations declined in all treatments until the end of storage. T4 (quadruple ratio) also exhibited a significant change in CO<sub>2</sub> and O<sub>2</sub> from the beginning of storage compared to other treatments. Similar results were obtained by (Fagundes et al., 2015), who reported that the CO<sub>2</sub> level increased from 5% to 5.97%, whereas the O<sub>2</sub> level showed a decline from 5% to 4.35%. This low O<sub>2</sub> and high CO<sub>2</sub> reached an equilibrium after 7 days in MAP packages. Odriozola-Serrano et al. (2008) reported a significant decline of O<sub>2</sub> level in the gas composition of the package under MAP when fresh-cut tomatoes were stored at 5°C as compared to tomatoes stored at a higher temperature.



**Figure 4.5** CO<sub>2</sub> (A) and O<sub>2</sub> (B) Concentrations Inside LDPE Packages of Tomatoes LDPE plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) Stored at 6±1°C for 20 (Means Showing Significance Difference Using Test of the Mean ±SE)

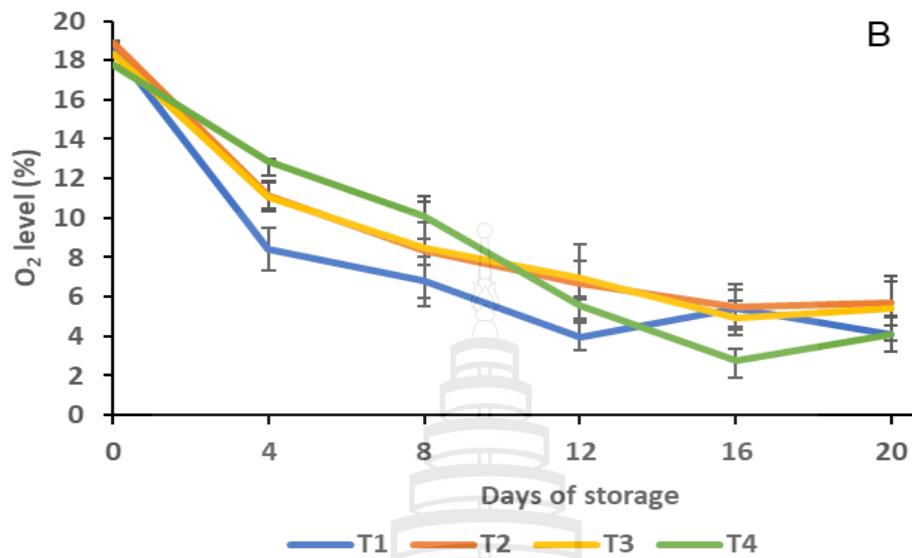
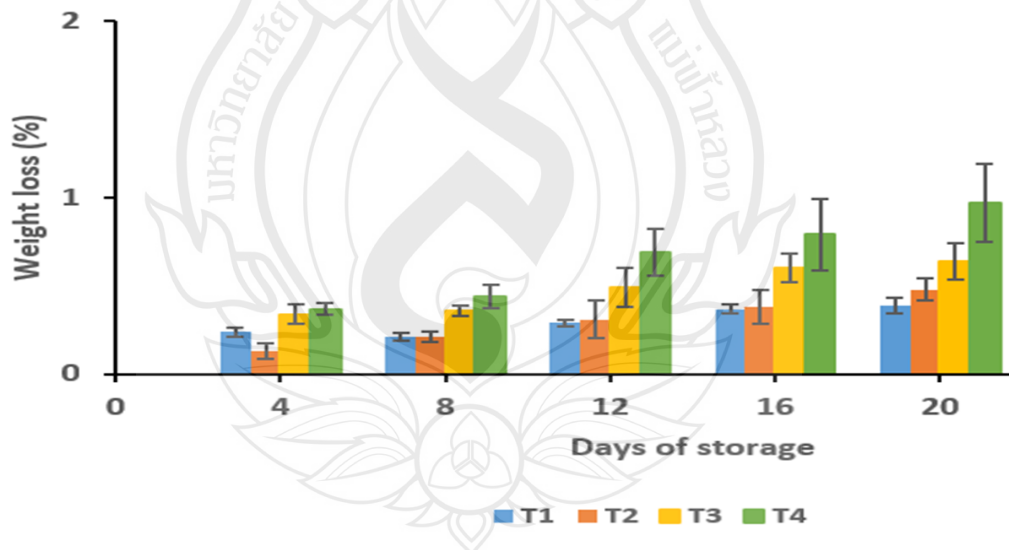


Figure 4.5 (continued)



**Figure 4.6** Weight loss of Tomatoes during Storage in LDPE plastic films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days

#### 4.2.2 Weight Loss

All treatments showed the lowest weight loss throughout the storage period (Figure 4.6). Although T4 showed the highest weight loss above all treatments it was too low at less than 1%. Álvarez-Hernández et al. (2021) reported a similar trend in which weight loss was reported to be low (less than 1%) as expected for horticultural produce stored at high RH due to packaging. T1 (Passive MAP) and T2 (Single Ratio) displayed the lowest significant values than other treatments from days 4-8 of storage.

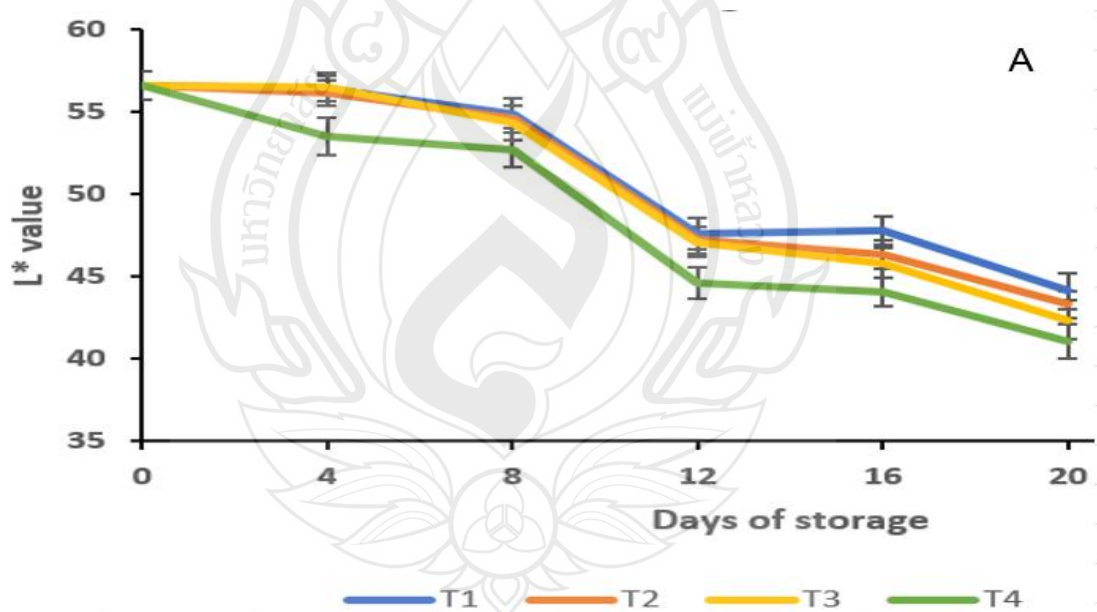
#### 4.2.3 Color

One of the most essential quality parameters influencing tomato appearance is the skin and flesh color. A chroma meter is used to measure color and this is measured against the Hunter a, b, and L scale. On a scale of 0 to 100, L indicates darkness to brightness, more negative a show an increase in greenness, and more positive a show an increase in redness. On the same scale, more negative b shows an increase in blueness and more positive b shows an increase in yellowness. Color development in tomatoes involves lower L value readings and a change from negative to positive a values (Tilahun et al., 2017b). In this study, the values of L\* declined whereas a\* and b\* increased in all the treatments during the storage period of tomatoes (Figure 4.7). L\* value in T4 (quadruple ratio) decreased over time very fast, followed by the other CO<sub>2</sub> pad treatments than the control.

The value of a\* continued to increase throughout storage in all treatments but was more pronounced in the control until the end of storage. An increase in the a\* value directly correlates with lycopene production (Tilahun et al., 2017a). T4 exhibited lowest a\* value than all the treatments, especially with the control. An increase in a\* value is associated with a decrease of greenness and an increase of redness in tomatoes (Fagundes et al., 2015). D'Aquino et al. (2016) also reported similar results where color values were lower than the control. The brightness (b\*) of tomatoes continued to increase in all the treatments but changed slowly in T4 (quadruple ratio) from the beginning of storage until the end of storage.

The red saturation (hue angle) continued to decrease as days progressed. Hue angle changes were delayed more especially from day 12 in T4 (quadruple ratio) at 73.14° compared with the control at 63.57°. These changes continued to be slow in T4

(63.08°) at the end of storage compared to the control with 54.26. Another significant change of hue angle was also found in all the treatments but this reduction was significantly delayed in T4 throughout the storage period. These results are in accordance with Tilahun et al. (2021), who reported that red color development changes as ripening progresses because of the transformation of chloroplasts to chromoplasts (Figure 4.8). A reduction of hue<sub>ab</sub> indicates a change of hue towards the red color. D'Aquino et al. (2016) also reported similar results of hue parameter reduction during storage of cherry tomatoes. Color changes of tomatoes under MAP is delayed due to its relation to a decrease during metabolic mechanism that breaks down chlorophyll pigments, synthesizes lycopene and  $\beta$ -carotene during storage time (Oliveira-Bouzas et al., 2021). More color changes were observed in the control samples. The values of L\*, a\*, b\* and hue angle changed significantly slowly more especially in T4 than the control.



**Figure 4.7** Peel Color Changes of Tomatoes: L\* (A), a\* (B), b\* (C) and Hue Angle (D) during Storage in LDPE plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significance Difference Using Test of the Mean ±SE)

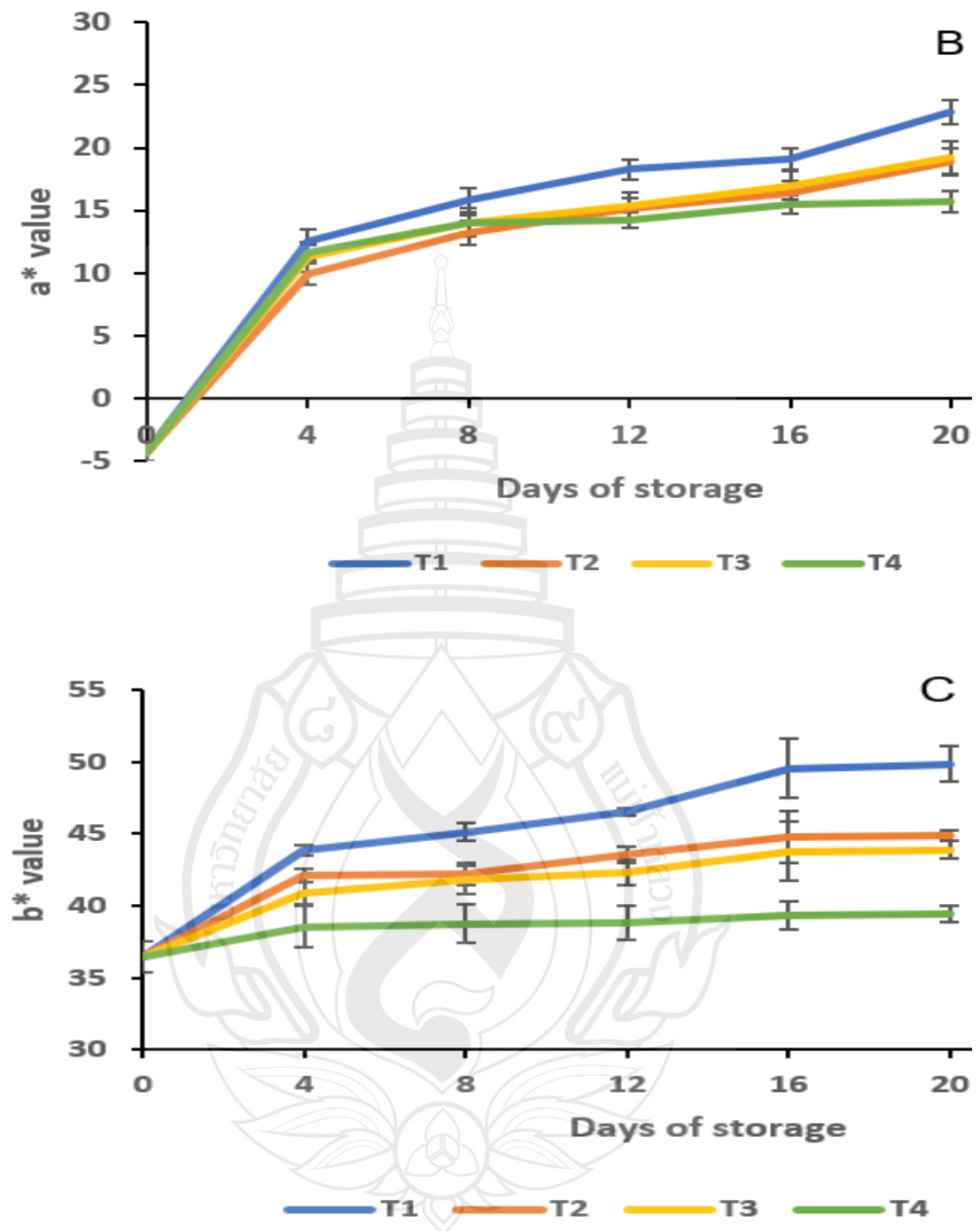
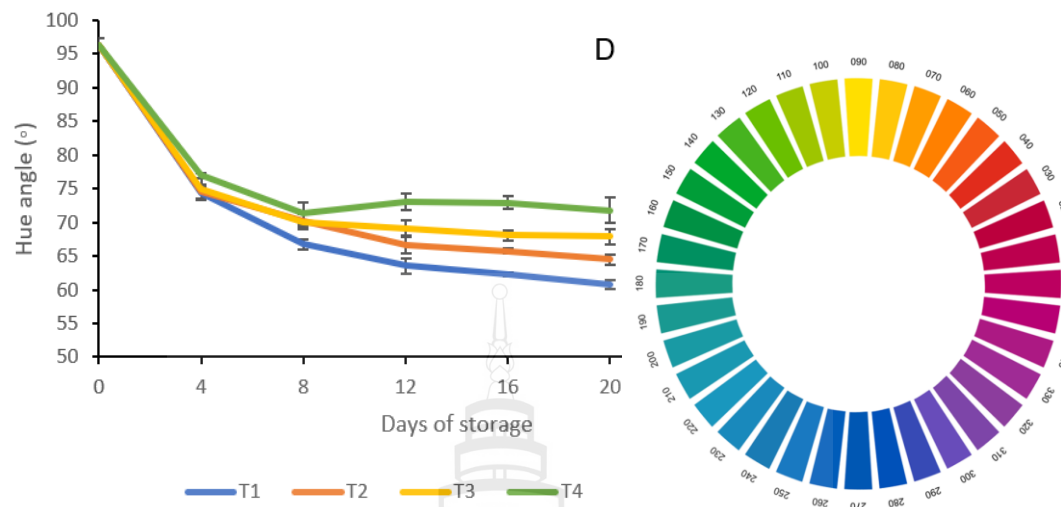
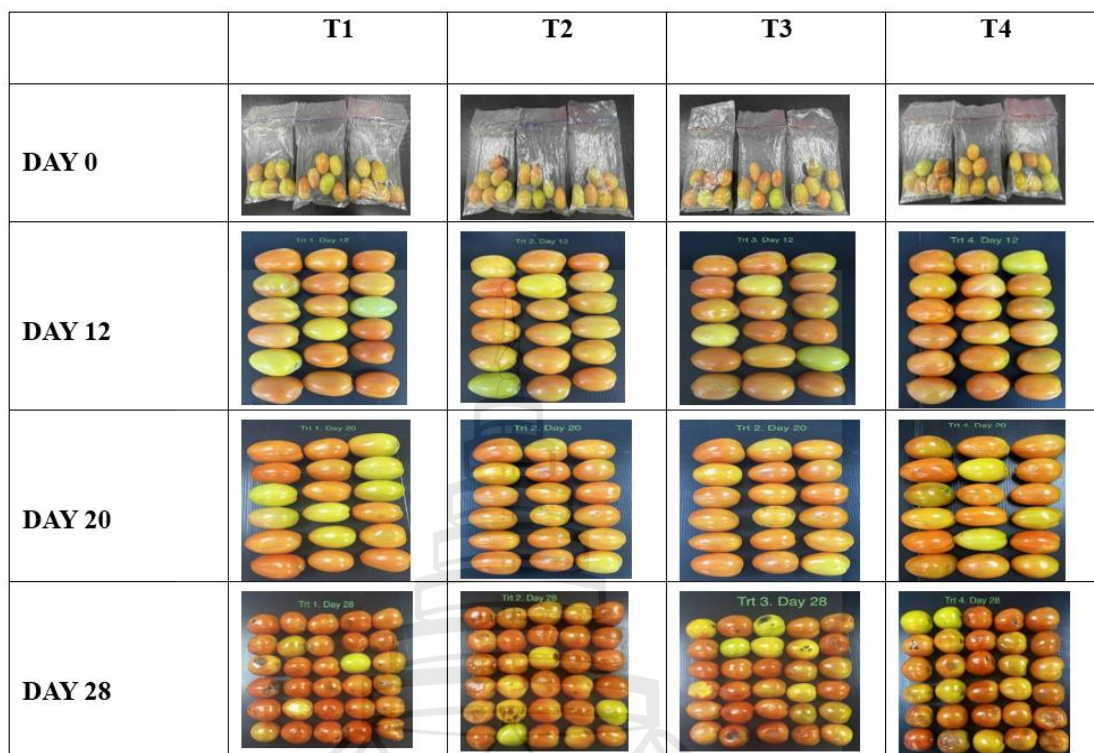


Figure 4.7 (continued)



**Figure 4.7 (continued)**



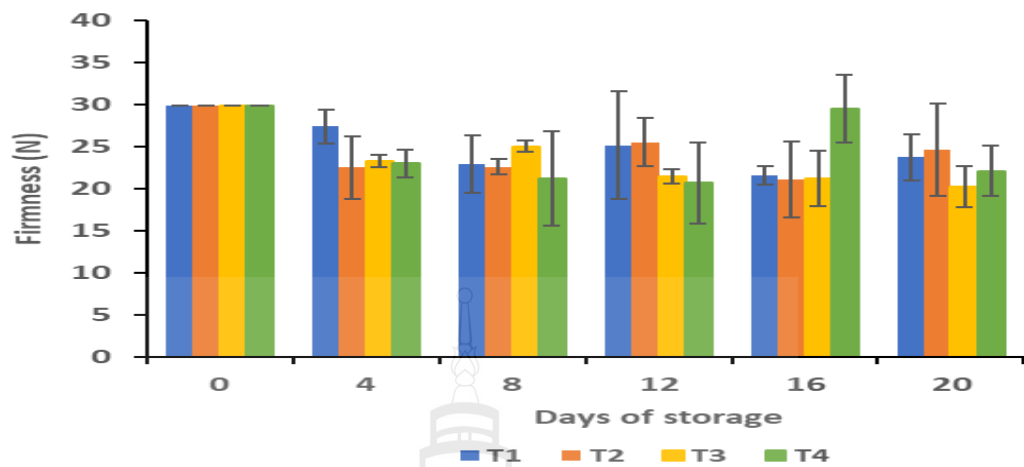


**Note** Active MAP did not significantly affect firmness, Ascorbic acid, TSS and TA of tomatoes in LDPE films during storage period of 20 days at  $6\pm 1^\circ\text{C}$  as shown in Figure 4.9, 4.10 and 4.12 below:

**Figure 4.8** Appearances of Tomatoes in Packaging without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) Stored at  $6\pm 1^\circ\text{C}$  for 28 Days

#### 4.2.4 Firmness

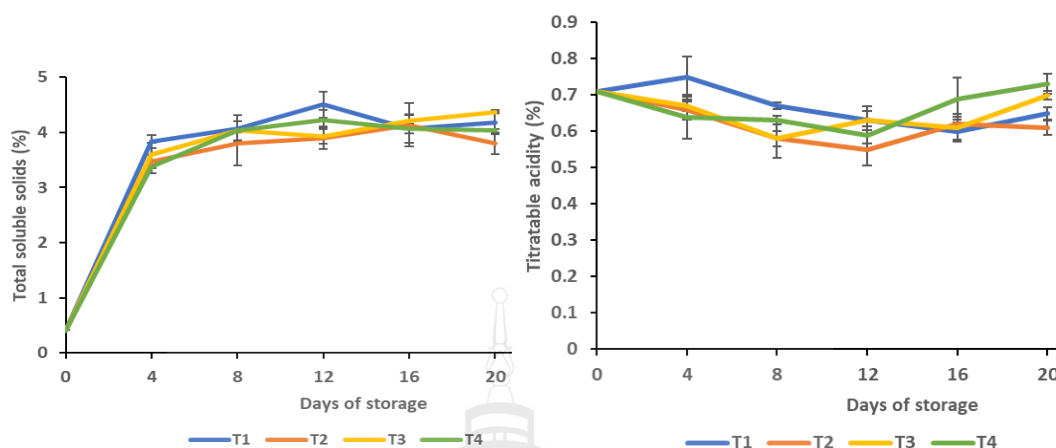
No significant differences were observed in experiment 2 in firmness (Figure 4.9). In one study higher firmness was recorded in green than ripe tomatoes as expected at the beginning. During their study, their findings were supported by the fact that tasters gave green tomatoes an average hardness score of 8.6 compared to 6.3 for mature tomatoes. There was no significant difference with storage time, as the similar case occurred in our study (Oliveira-Bouzas et al., 2021).



**Figure 4.9** Firmness of Tomatoes in LDPE during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significance Difference Using Test of the Mean ±SE)

#### 4.2.5 TSS and TA

There was no significant difference between TSS and TA in our study (Figure 4.10). Similarly, Oliveira-Bouzas, Pita-Calvo, Lourdes Vázquez-Odériz, et al. (2021) reported that although mature tomatoes had a greater initial TSS content (4.50%) than green tomatoes (3.67%), there was no significant difference in TSS of green tomatoes during their storage period. In another study, the TSS contents of the figs increased with storage, whereas the TA concentrations decreased. Both the increase in fig TSS content and the decrease in TA content were postponed by MCP + MAP treatment (Wang et al., 2023).



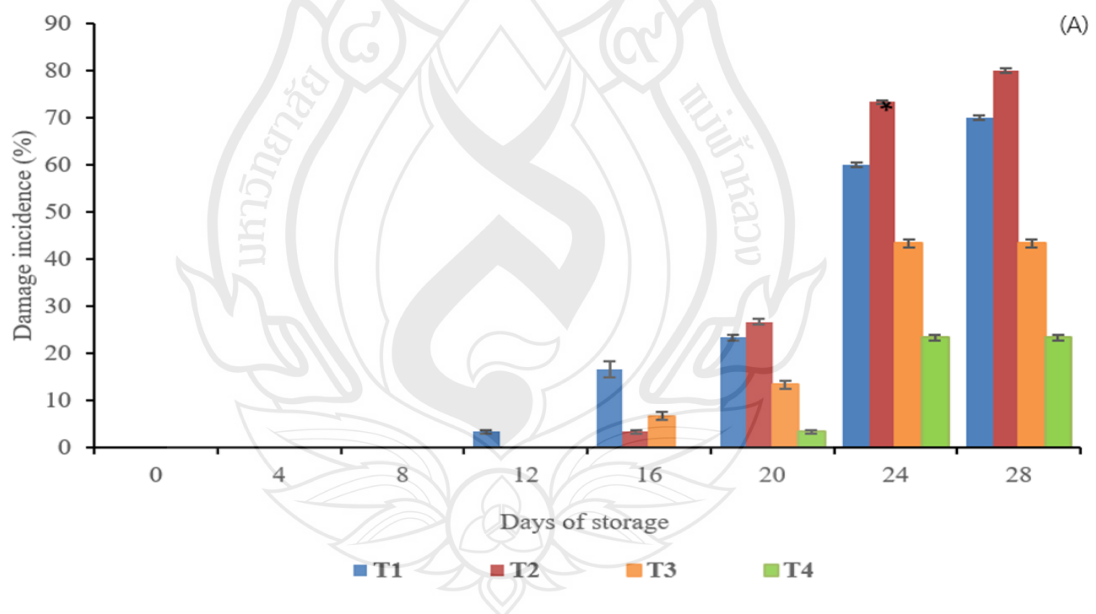
**Figure 4.10** TSS and TA of Tomatoes during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significance Difference Using Test of the Mean ±SE)

#### 4.2.6 Damage Incidence and Severity

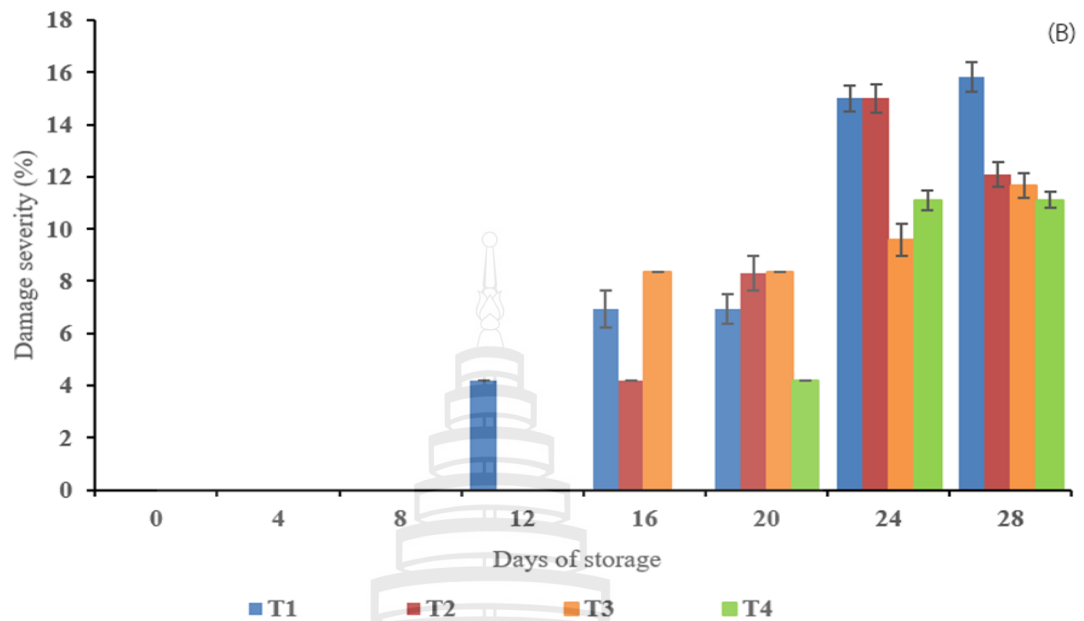
The presence of decay started to show in the control after 8 days at a rate of 3.33% (Figure 4.11). Damage incidence continued to increase throughout storage in other treatments except for T4 (quadruple ratio) which started to display the symptoms of DI on day 20 of storage at the lowest rate of 3.33%. The pattern of DI continued to increase in T2 (single ratio), followed by the control especially from day 24 until the end of storage. CO<sub>2</sub> pads especially T4 and T3 showed the lowest rates of damage incidence until the end of storage. T4 delayed damage until day 20 at the lowest rates of 3.33%. At the end of storage, T2 (single ratio) had the highest decay rate of 80%, followed by the control at 70%.

All treatments showed higher DS especially from day 24 until the end of storage. The control and T2 (single ratio) exhibited the highest disease severity versus T4 (quadruple ratio) from day 24-28 of storage. After 20 days, all treatments were infected with the disease. The lowest significant change of DI was recorded in T4 (quadruple ratio) than other treatments towards the end of storage. Another significant difference was observed between all treatments. Both DI and DS were less pronounced

in T4 (quadruple ratio) which started to show the infection after 16 days of storage. The results showed that CO<sub>2</sub>-pad with increased ratios (especially T4) delayed decay rate of tomatoes better than other treatments when stored at 6±1 °C up to 20 days. Safari et al. (2020) reported the highest DI and DS in the control until the end of storage. Liguori et al. (2015) studied the effects of passive and active modified atmosphere packaging conditions on quality parameters of minimally processed table grapes during cold storage and found that increased CO<sub>2</sub> in packages did not have any effect in reducing decay but instead, it can cause harm to the tissues making grapes more prone to decay. However, tomatoes in all the treatments showed some softening and water-soaked patches during cold storage caused by chilling injury, especially after 16 days of storage. Hong and Gross (2001) highlighted that low levels of ethylene concentration in containers can generate a condition suitable for the development of chilling injury symptoms.



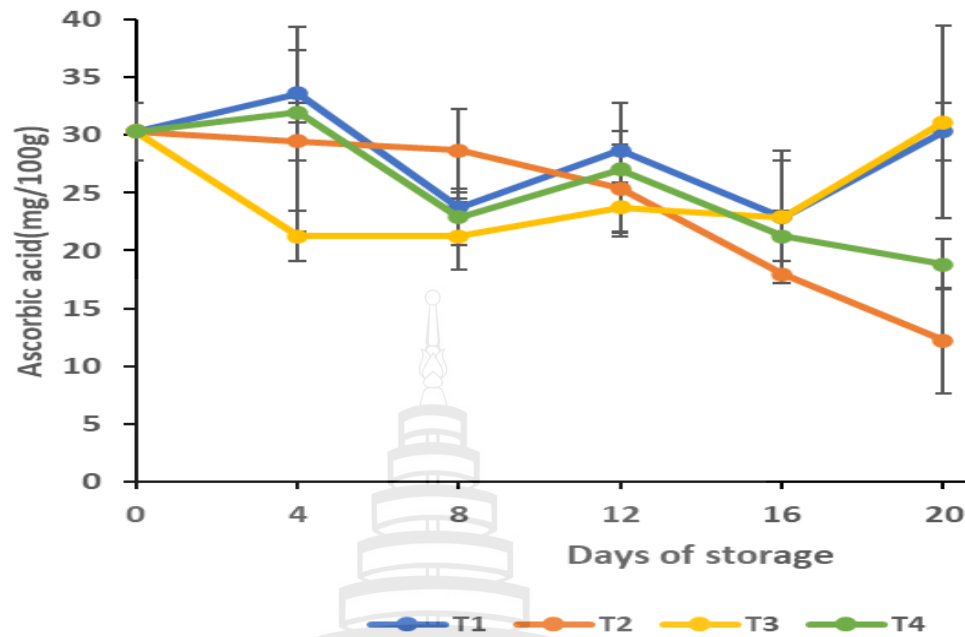
**Figure 4.11** Damage incidence (A) and Severity (B) of Tomatoes during Storage in LDPE plastic films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 28 Days (Means Showing Significance Difference Using Test of the Mean ±SE)



**Figure 4.11 (continued)**

#### 4.2.7 Ascorbic Acid

Figure 4.12 illustrates that there were no significant changes in ascorbic content. Oliveira-Bouzas et al. (2021) observed a similar trend. They observed higher contents of ascorbic acid in mature tomatoes than in green tomatoes during storage period. A slight increase of ascorbic acid at the pink stage was reported, without any significant changes between treatments. Ascorbic content increased unevenly at the light red stage. The lowest changes were reported with 1-MCP and 1-MCP + MAP. However, Nimitkeatkai et al. (2022) reported that active packaging delayed an increase of ascorbic acid content in carambola fruit. Additionally, Sun et al. (2024) observed a significant reduction of ascorbic acid in tomatoes with increased CO<sub>2</sub> levels.



**Figure 4.12** Ascorbic Acid Content of Tomatoes during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significance Difference Using Test of the Mean ±SE)

#### Summary (Experiment 2)

1. The escalated CO<sub>2</sub> (T4) significantly delayed peel color changes of tomatoes.
2. T4 performed better up to 20 days because damage incidence was first observed on the same day at the lowest rate of 3.33%.
3. There was high damage (disease incidence and chilling injury) at 6±1°C in most of the treatments, especially from day 24-28 in the control and T2. Further inquiry is needed to determine the cause of the softening and water-soaking symptoms on tomatoes during cold storage.
4. Active MAP did not significantly affect firmness, total soluble solids, titratable acidity and ascorbic acid of tomatoes at 6±1°C.

Based on the above results, which proved that CO<sub>2</sub> pad (T4) can delay color changes and damage rate of tomatoes up to 20 days, a quadruple concentration of

1g(0.556g NaHCO<sub>3</sub> + 0.444g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>) was increased to 3g (1.668g NaHCO<sub>3</sub> + 1.332g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>) to suit the size of the plastic bag (LDPE) in bulk packaging. In addition, the CO<sub>2</sub> emitter with a ratio of 3g(NaHCO<sub>3</sub> + C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>) ( T1) was selected for use with the larger tomato package (1000g/bag), in contrast to employing a gas mixture (5% CO<sub>2</sub> + 5% O<sub>2</sub> + 90% N<sub>2</sub>) flushing to establish the active MAP (T2). A storage temperature of 12±2°C which is recommended for mature green stage by Tilahun et al. (2019) was selected for experiment 3 because tomatoes in T4 displayed softening and water-soaking symptoms from day 20 during cold storage (6±1°C).

### **4.3 Experiment 3: Application of CO<sub>2</sub> Emitter Compared to Active MAP with 5% CO<sub>2</sub>, 5% O<sub>2</sub>, and 90% N<sub>2</sub> in Bulk-size Packaging of Tomatoes Stored at 12±2°C**

The characteristics of tomatoes maintained at 12±2°C for 30 days were examined.

#### **4.3.1 Gas Composition**

Gas composition changes in MAP depend on storage temperature, the ratio of mass product / plastic film surface, permeability of the film and product respiration rate (Paulsen et al., 2019). CO<sub>2</sub> and O<sub>2</sub> concentration of tomatoes in LDPE films are shown in Figure 4.13. As usual, the concentration levels of CO<sub>2</sub> increased and O<sub>2</sub> decreased from the initial stage of storage. These results were similar to Suparlan and Itoh (2003) who also reported an increase of CO<sub>2</sub> and a decrease of O<sub>2</sub> in tomatoes packed with LDPE films during the first few days of storage. In their study, the patterns in the gas composition for both treated and untreated tomatoes were similar, even though there was a slight change which was a bit higher in treated tomatoes compared to untreated tomatoes. Another study also reported increased CO<sub>2</sub> and decreased O<sub>2</sub> concentrations in pomegranate samples under Active MAP than the control at an ambient temperature (25 °C) (Rokalla et al., 2022).

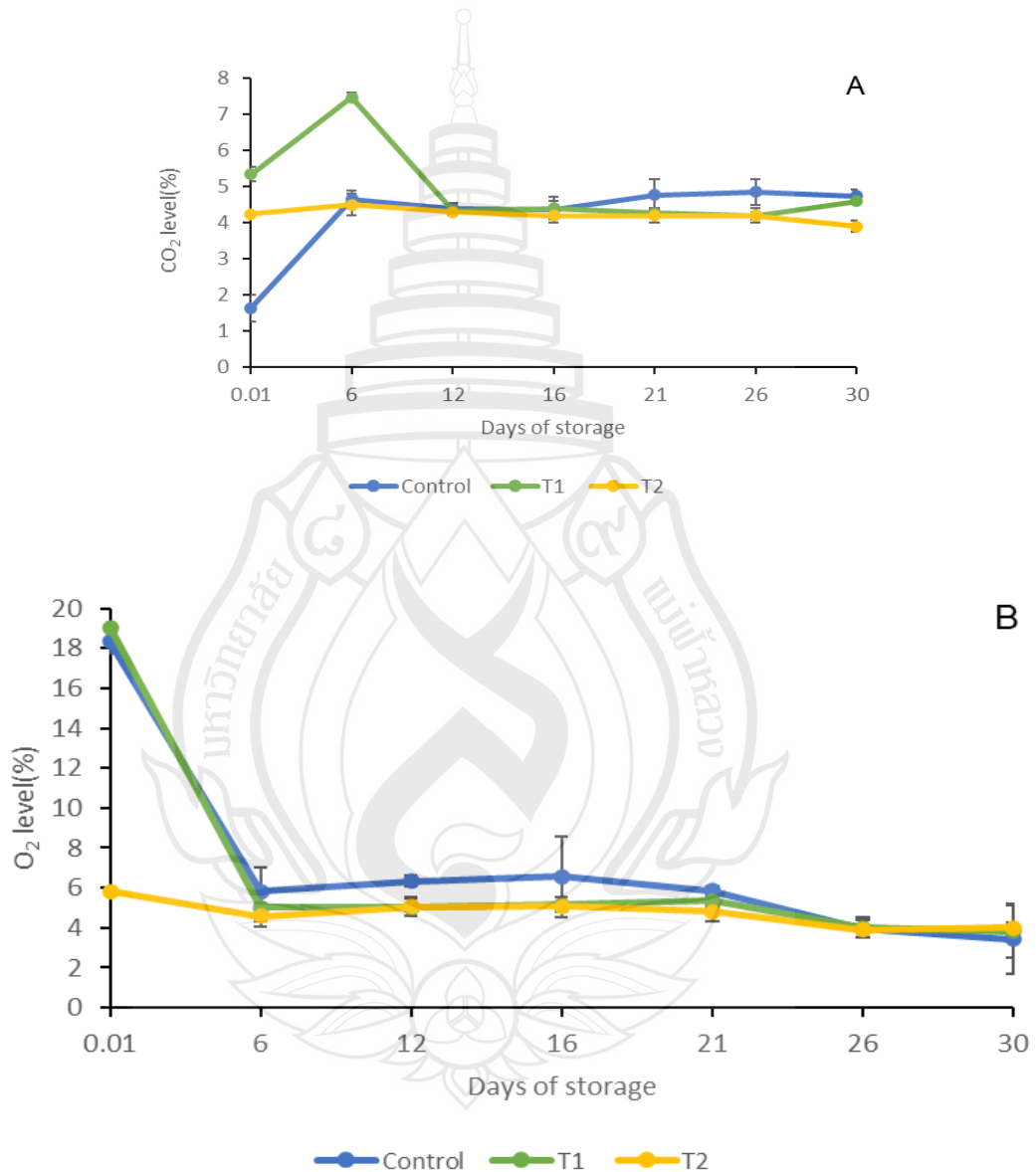
An increase of CO<sub>2</sub> was more pronounced in T1 (5.33%) from the beginning of storage and started to decline from Day 12 reaching a steady state until the end of

storage. T1 was followed by T2 (4.23%) and the lowest CO<sub>2</sub> level was found in the control (1.63%). There was a significant difference between all the treatments, with T1 showing the highest level of CO<sub>2</sub> concentration from day 0 (after 10 minutes of sealing the packages). A peak of CO<sub>2</sub> levels was observed in T1 (Rokalla et al., 2022) at 7.47% on day 6 of storage, displaying a great significant difference compared to other treatments. The CO<sub>2</sub> concentration in T2 was in a steady state from the initial stage until the end of storage. After such an increase from the beginning of storage, the CO<sub>2</sub> concentration then declined in all the treatments reaching the same steady state until the end of storage.

O<sub>2</sub> concentration levels declined in all the treatments from Day 0 (after 10 minutes of sealing the packages) up to Day 6, and afterwards reached a steady state until the end of storage. There was a significant difference of low O<sub>2</sub> in T2 compared to both the control and T1 on day 0 up to day 6 compared to other treatments as the gas was flushed directly in the plastic films before sealing. T1 and T2 continued to show low O<sub>2</sub> concentration from day 6 until the end of storage while the control showed the highest O<sub>2</sub> throughout the storage period. There was no significant difference in the O<sub>2</sub> between T1 and T2 from day 6 until the end of storage. In another study, Domínguez et al. (2016) reported that an increased CO<sub>2</sub> and reduced O<sub>2</sub> concentrations were more pronounced in bags containing *Delizia* tomatoes due to the higher respiration rate shown by the cultivar. Similar results were also reported by Bailén et al. (2006), who observed a sharp increase in CO<sub>2</sub> and reduced O<sub>2</sub> concentration levels in MAP packages. On the other hand, Suparlan and Itoh (2003) explained that this reduction of CO<sub>2</sub> might be caused by high RH in the plastic film causing dissolution of CO<sub>2</sub> in water since the gas is highly soluble in water.

According to Ye et al. (2012), active MAP uses higher CO<sub>2</sub> concentrations and lower O<sub>2</sub> to inhibit microbial growth, reduce product respiration, preserve quality and extend shelf life. However, this increased CO<sub>2</sub> and reduced O<sub>2</sub> concentrations should not exceed a crucial threshold. The authors reported that CO<sub>2</sub> concentrations above 12% reduced firmness and promoted enzymatic browning in *Agaricus* mushrooms, resulting from cell membrane degradation. MAP3 treatment (2% O<sub>2</sub>+13% CO<sub>2</sub>) packages had the highest CO<sub>2</sub> concentrations, which may explain why they had lower firmness than

MAP1 (2% O<sub>2</sub>+7% CO<sub>2</sub>) and MAP2 (2% O<sub>2</sub>+10% CO<sub>2</sub>). Excessive CO<sub>2</sub> buildup inside the package can lead to physiological injuries to the produce, which can cause browning and off-flavors in products such as mushrooms. Contrarily, Afifi (2016) reported that active MAP (7.5% O<sub>2</sub> + 15% CO<sub>2</sub>) improved fruit storage and maintained the quality of strawberry fruits.



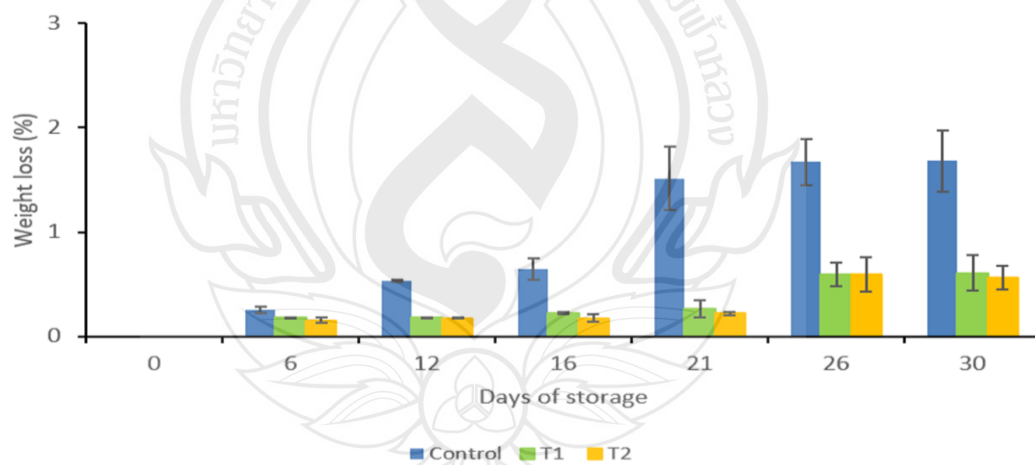
**Figure 4.13** CO<sub>2</sub> (A) and O<sub>2</sub> (B) Concentrations Inside LDPE Packages of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significance Difference Using Test of the Mean ±SE)

### 4.3.2 Weight Loss

Weight loss of tomatoes packaged in LDPE films is shown in Figure 4.14. The prolonged storage period of tomato weight loss increased as ripening progressed. This effect has also been observed by Akbudak et al. (2007). Weight loss was less pronounced in T1(0.18%) and T2(0.17%) from day 6 until the end of storage (0.61 % and 0.56%) respectively. T1 and T2 exhibited significantly lower weight loss from day 6 until the end of storage compared to the control. This loss increased slowly in packages with active MAP such as in T1 (CO<sub>2</sub> pads) and T2 (mixed gas) without any significant difference. The highest weight loss was observed in the control from day 6 (0.26%) and continued to increase until the end of storage (1.68%) due to increased respiration and ethylene production which was observed throughout storage. T1 and T2 delayed weight loss over the storage period. Similar results were reported by Nimitkeatkai et al. (2022), who found out that active packaging postponed weight loss of carambola fruit. The author also stated that respiration can also cause weight loss in fresh commodities by consuming carbon atoms. A similar trend of highest weight loss was observed by Afifi (2016) in untreated MAP (control). The results of our study are also in line with Taye et al. (2017) who reported more weight loss in the control, followed by 3% CO<sub>2</sub> treatment and the lowest recorded after 5 days of storage in 5% CO<sub>2</sub> treatment. The authors continued to explain that the highest weight loss was found in untreated fruits (control) than treated fruits due to high respiration and ethylene rates that occurred during storage. Taye et al. (2017) concluded that an application of CO<sub>2</sub> (5%) can reduce weight loss in tomatoes because of reduced respiration rates and ethylene production. In contrast, Domínguez et al. (2016) reported that a reduction in ethylene production does not affect weight loss, and explained that weight loss reduction is caused by water condensation inside plastic packages during the storage period.

According to Paulsen et al. (2019), the difference in weight loss is due to the RH in which tomatoes were stored during the storage period. They explained that the RH in their study was higher (98%) hence weight loss was not used as a parameter to determine shelf life of cherry tomatoes. On another note, do Nascimento Nunes (2009) reported that the maximum allowed weight loss for tomatoes to be unsaleable ranges

from 6-7%. The weight loss during our study was lower than the maximum acceptable weight loss. At the end of storage T1 and T2 in this study showed the lowest weight loss and these results proved that active MAP significantly delayed weight loss compared to the control (passive). These results are in accordance with a study conducted by Ye et al. (2012) on Effects of Active MAP on Postharvest Quality of Shiitake Mushrooms (*Lentinula edodes*) stored at cold storage, which indicated that at the end of the storage period the control group had a total weight loss of 10.8%, but the mushrooms stored in the MAP1, MAP2, and MAP3 treatments showed weight loss of 6.8, 4.9, and 5.3%, respectively. This suggests that active MAP was beneficial in reducing weight loss more than the control (passive). This similar trend was also in line with Afifi (2016) who reported that strawberry fruits stored in active MAP1 (7.5% O<sub>2</sub> +15% CO<sub>2</sub>) showed the lowest weight loss % over all storage periods at 0°C+ shelf life at 10°C, compared to other treatments in both seasons of research. Bailén et al. (2006) also reported that changes in color, firmness and weight loss were slower in tomato packages with active MAP (GAC or GAC-pd).



**Figure 4.14** Weight Loss of Tomatoes in LDPE plastic Films during Storage Period of 30 Days at 12±2°C (Means Showing Significance Difference Using Test of the Mean ±SE)

### 4.3.3 Color

Tomato ripening is a process that involves the breakdown of chlorophyll and the accumulation of carotenes. The values of  $L^*$ ,  $a^*$ , and  $b^*$  represent the proportions of white to black, red to green, and yellow to blue, respectively. The ratio of  $L^*$  value reduced over storage period of tomatoes (Figure 4.15A), indicating a darkening of the fruits (Radzevičius et al., 2009). Nimitkeatkai et al. (2022) observed an increase of  $L^*$  and  $a^*$  values, as well as a decrease in hue angle value over storage, which occurred more quickly in control samples than in fruits in active packages. In our study, the control exhibited the highest  $L^*$  values throughout the storage period. Low significant values were pronounced in T1 and T2 than the control over the storage period. These changes were also observed by Panebianco et al. (2024) who reported that  $L^*$  value decreased throughout storage as a result of tomato skin color becoming dark and dull due to pigments increase responsible for color changes from yellow-green to red. The reduction of parameter  $L^*$  in this study was observed more in the second sampling time (day 6) of storage especially in T1 and T2 than the control. A similar trend was observed by Paulsen et al. (2019) who reported a reduction of  $L^*$  especially in the first week of storage causing skin color to become dark due to maturity. Tilahun et al. (2017b) also reported a slight reduction of  $L^*$  values during the storage period in all the cultivars. Radzevičius et al. (2009) explained that this reduction may be associated with the beginning of carotenoid production, since lycopene and  $\beta$ -carotene levels accumulate with each stage of fruit maturity. As a result of the accumulation of these carotenoids, the tomato red color darkened, as shown by a reduction in color brightness ( $L^*$  value).

Hunter  $a^*$  parameter evaluates the ripening process of tomato fruits better than  $L$  and  $b$  values (Tilahun et al., 2019b). During ripening  $a^*$  value changes from negative (green) to positive (red color) due to chlorophyll degradation and lycopene synthesis (Panebianco et al., 2024). Our results showed an increase of  $a^*$  parameter throughout the storage period (Figure 4.15B). Control samples were the only ones that exhibited the highest significant value of  $a^*$  throughout storage. An  $a^*$  parameter increased from the beginning until the end of storage as follows; -4.3 to 10.26 (C), -4.3 to -0.77 (T1) and -4.3 to 2.11 (T2). These changes showed a significant increase in red color over the storage period. A great significant difference in the lowest value of  $a^*$  was observed in

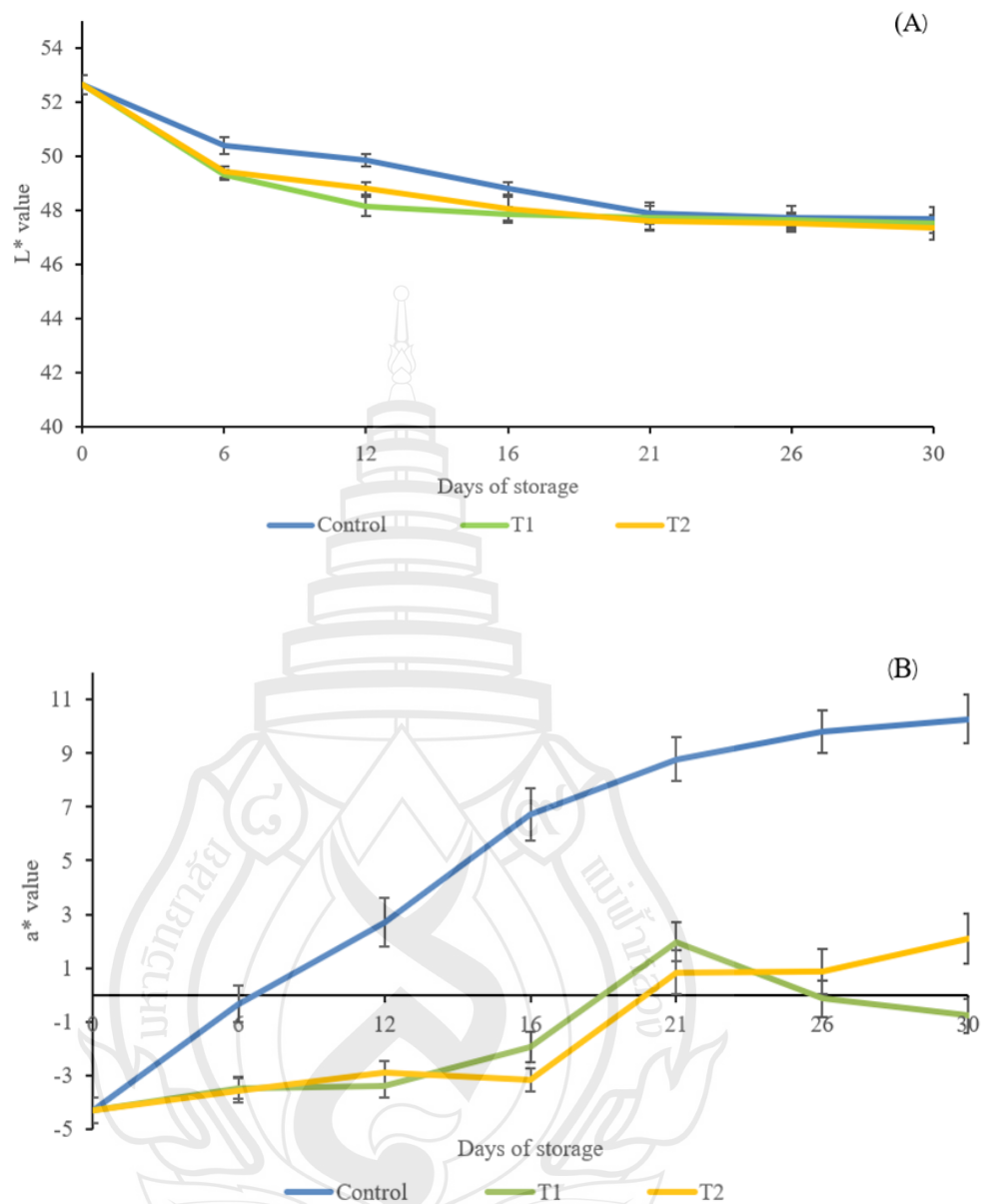
T1 and T2 than the control throughout the storage period. However, there were no significant differences between T1 and T2. Furthermore, T1 displayed the lowest significant difference than T2 from day 26 until the end of storage. These results are in accordance with other studies where red color development increased as storage period progressed due to the conversion of chloroplasts into chromoplasts (Fagundes et al., 2015; Tilahun et al., 2021). The results are also in line with Radzevičius et al. (2009) who reported in their study that the highest increase was observed between the first ripening stage, when the fruits were fully green, and the second ripening stage, when the tomatoes began to become red. The green fruits of the cultivar 'Jurgiai' had the lowest red-to-green color ratio with a negative value (-3.7 NBS units). The highest color index  $a^*$  (28.9 NBS units) was observed in totally ripened tomatoes of the hybrid "Vaisa". Tilahun et al. (2017b) also observed that an increase in  $a^*$  parameter is associated with lycopene synthesis thus an increment in lycopene accumulation. In another study, Tilahun et al. (2021) highlighted that MAP+CO<sub>2</sub> had the lowest  $a^*$  value on the 15th day at 10 °C. However, on the 11th day at 20 °C, there was no significant difference between the two. If CO<sub>2</sub> pretreatment is combined with low temperature storage, this could indicate a longer distribution time for cherry tomatoes. The ratio of  $b^*$  value reduced over storage period of tomatoes (Figure 4.15C). The control displayed the highest  $b^*$  values throughout the storage period, whereas T1 and T2 showed a less decrease of  $b^*$  value without any significant differences. The control exhibited the highest significance increase than the other two treatments from day 6 until 26 of storage period. These changes were also observed by Afifi (2016) who indicated that  $b^*$  value declined as storage period progressed due to development of the red color. In contrast, from our results, Nimitkeatkai et al. (2022), reported that there was no significant difference in  $b^*$  value, but the value in the control tended to be higher than that of the fruits stored in active packages.

Chroma increased during storage but later declined as ripening progressed (Figure 4.15D). The highest significant value was more pronounced in the control than in T1 and T2 from the initial stage of storage until the end. T1 and T2 exhibited the lowest values throughout storage period. T1 recorded the lowest significant change of chroma than T2 on day 26 until the end of storage. Another significant change was

observed at the end of storage between all the treatments. A similar trend was found in one study which indicated that as the tomatoes turned from green to light red, chroma increased, and then declined when they reached the red stage. During their study, chroma of the hybrid “Vaisa” increased throughout the ripening process. However, they argued that chroma is not a reliable indication of tomato ripening since it is simply a representation of the purity or saturation of a particular color (different colors might have the same chroma values). Tomato ripening is characterized by the simultaneous presence of various colors, as lycopene (red),  $\beta$ -carotene (orange), xanthophylls, and hydroxylated carotenoids (yellow) are produced from a colorless precursor (phytoene) while chlorophyll is broken down into colorless compounds. When tomatoes are fully ripe, chroma can be a useful predictor of customer acceptability since it represents the purity or saturation of color (Radzevičius et al., 2009).

Hue angle is regarded as the most essential parameter in the perception of tomato quality, because exterior fruit color correlates better with color perception by the human eye. (Radzevičius et al., 2009). The hue angle of tomato fruits decreased throughout storage as shown in Figure 4.15(E). At the beginning of the storage period hue angle was  $94.51^\circ$ . This angle decreased significantly in the control especially from day 6 until the end of storage which could be related to maturation of tomatoes. The reduction of hue angle from the initial stage of storage ( $94.51^\circ$ ) until the end was  $70.83^\circ$ ,  $91.78^\circ$  and  $79.99^\circ$ , respectively. Change of hue angle was delayed significantly in T1 and T2 from day 6 than the control until the end of storage. In addition, T1 delayed hue angle significantly more than T2 from day 26-30 of storage. T1 and T2 maintained hue angle more than the control until the end of storage. Furthermore, there was a significant difference between all the treatments on the last day of storage. Sabir et al. (2020) observed similar changes when tomatoes were stored under the storage temperature of  $5^\circ\text{C}$  (85-90% RH) and indicated that during harvest, hue angle was recorded as  $102.7^\circ$  for breaker and  $78.1^\circ$  for pink fruits. The author continued to explain that there was a significant decrease of this angle as storage progressed and this reduction was more observed after 7 days in pink fruits, possibly due to ripening processes. After storage, hue angle of fruit skin ranged from  $61.6^\circ$ (control) to  $64.5^\circ$  (MAP) in breaker fruits, whereas in pink fruits ranged from  $56.7^\circ$ (control) and  $56.4^\circ$  (MAP).

The findings in this study are also in line with Oliveira-Bouzas et al. (2021) who reported initial values of hue angle and  $a^*$  parameter as 50.95 and 13.80, respectively in matured tomatoes while in green tomatoes were 88.23 and 0.61, respectively. These variations showed color changes of tomatoes throughout ripening, from green to red (Figure 4.16). A similar trend in our study was also observed by Radzevičius et al. (2009) who reported that the hue angle of all the cultivars under investigation reduced significantly after each measurement. The “Jurgiai” cultivar had the highest hue angle, which reduced from 97 degrees in green fruits to 42 degrees in fully ripened fruits. The cultivar “Neris” exhibited the lowest color angle value; only 79 degrees in fully ripened fruits, which declined to 32 degrees. T1 (CO<sub>2</sub>-pad) and T2 (5% O<sub>2</sub> + 5% CO<sub>2</sub> + 90% N<sub>2</sub>) maintained better color than the control throughout storage period. Similar findings were observed by Taye et al. (2017) who reported that cherry tomatoes stored under 5% CO<sub>2</sub> treatment delayed color changes compared to the 3% CO<sub>2</sub> treatment and control (untreated) over the storage period. Our findings were consistent with those of other studies. Buescher (1979) also observed that tomatoes treated with 5-10% CO<sub>2</sub> delayed color changes, however, the author reported that the use of more than 10% CO<sub>2</sub> to delay ripening and extend shelf life is not recommended for turning tomatoes. Fagundes et al. (2015) also found a significant difference in all color parameters over storage period (21 days) in cherry tomatoes under a modified atmosphere (5% O<sub>2</sub> + 5% CO<sub>2</sub>). Nimitkeatkai et al. (2022) also confirmed in their study, that active packaging delayed color changes, which could be attributed to a reduction in the partial pressure of O<sub>2</sub>, and the ethylene biosynthesis and its activity. Previous investigations had been examined with continuous reduced O<sub>2</sub> levels, proving that active packaging can prevent color changes of carambolas which was attributable to the reduced O<sub>2</sub> concentrations during storage. This could be due to oxidative reactions which occur in the fruit peel in the presence of O<sub>2</sub>, whereas active packaging may delay the oxidation reaction, resulting in delayed color changes in the fruit. Additionally, the reduced ethylene level in the active packaging might contribute to color maintenance of carambola.



**Figure 4.15** Peel Color Changes L\* (A), a\* (B), b\* (C), Chroma (D) and Hue Angle (E) of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significance Difference Using Test of the Mean ±SE)

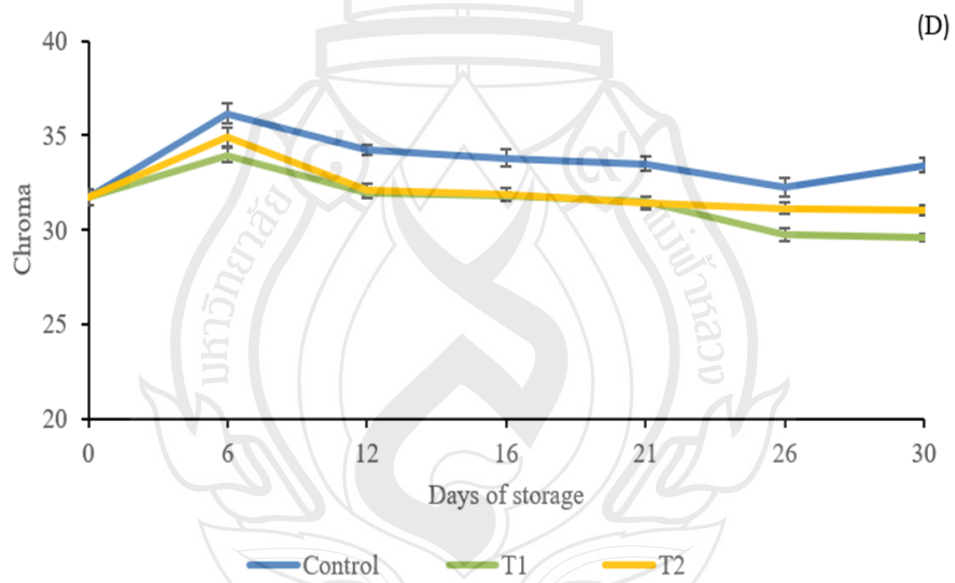
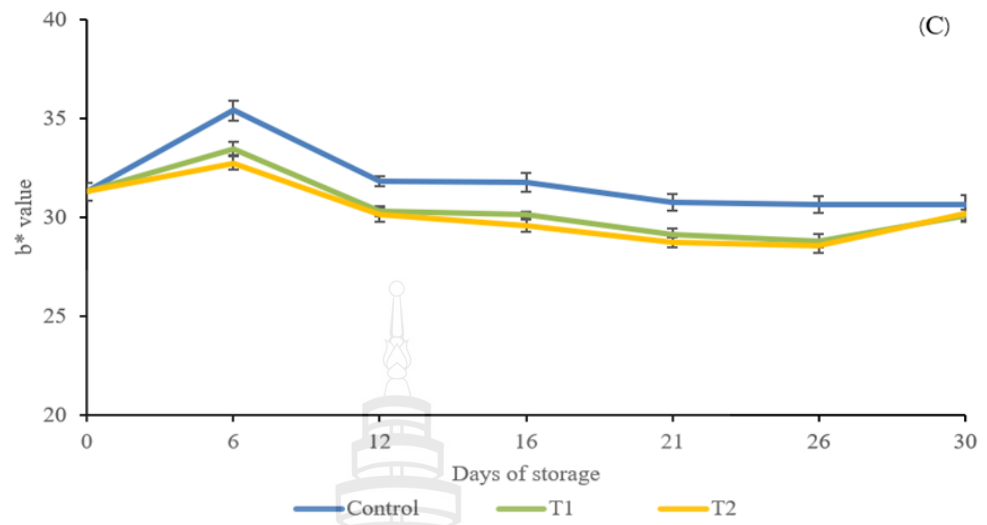


Figure 4.15 (continued)

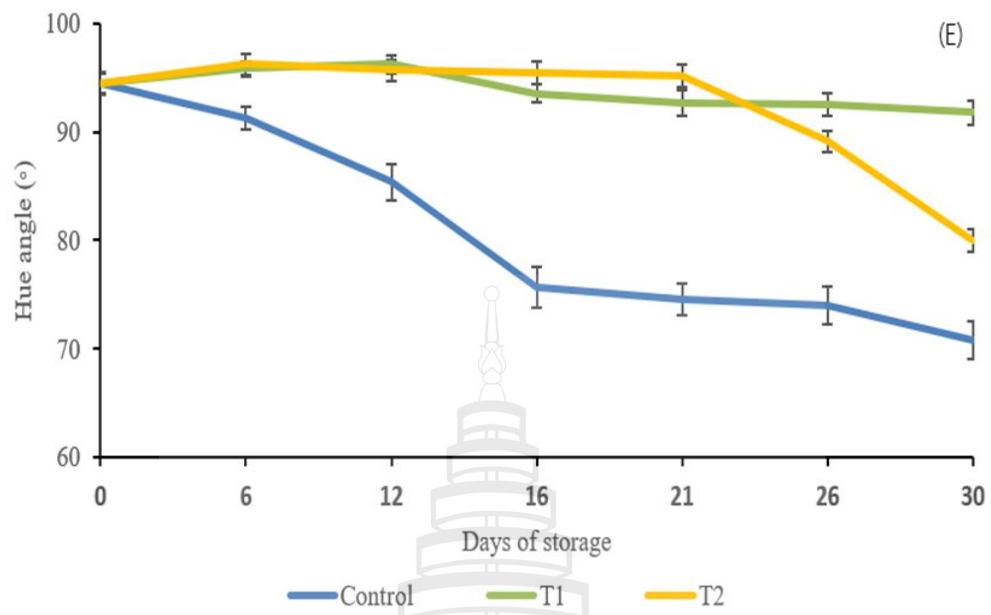
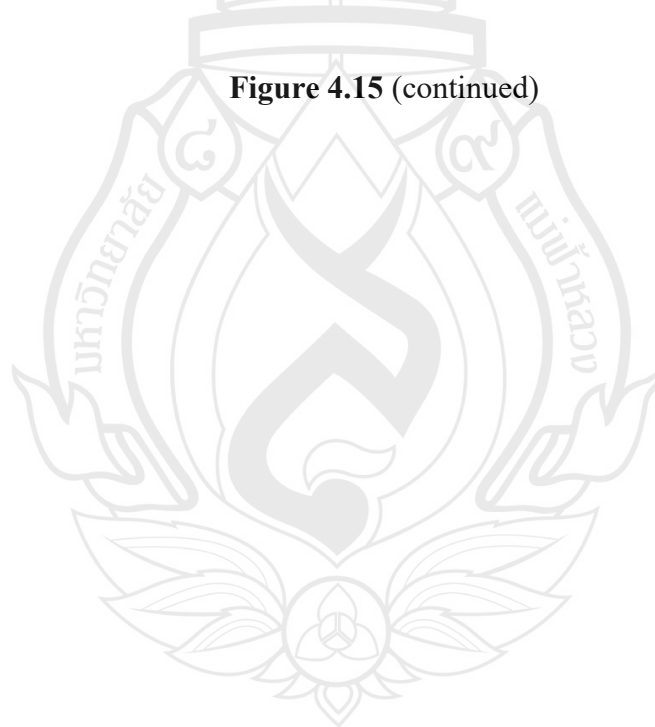














Figure 4.15 (continued)



**Table 4.1** Appearances of Tomatoes in Different Treatments during Storage Period of 30 Days at  $12\pm 2^{\circ}\text{C}$

	Control	T1 (CO <sub>2</sub> Pad)	T2 (Mixed Gas)
<b>Day 0</b>			
<b>Day 12</b>			
<b>Day 16</b>			
<b>Day 30</b>			

#### 4.3.4 Firmness

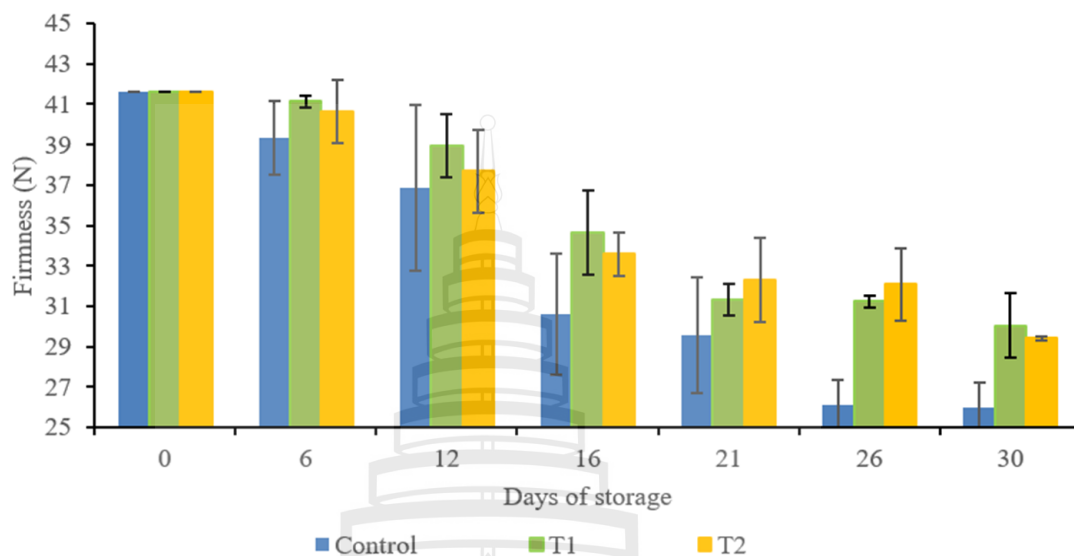
Firmness decreased during storage as shown in Figure 4.17, similar observation was reported by Domínguez et al. (2016). The initial firmness was 41.6N and this value decreased throughout the storage in all the treatments. Firmness reduction was more observed in the control compared to other treatments throughout storage period. At the end of storage firmness was recorded as 25.99N, 30.05N and 29.41N (Control, T1 and T2), respectively. T1 and T2 recorded the highest firmness until the end of storage without any significant difference. The control showed the lowest significant difference on day 26 up to 30 of storage than other treatments. T1 and T2 maintained firmness more than the control until the end of storage. These results were in accordance with other findings. Taye, Tilahun, Seo, et al. (2017) found out that cherry tomatoes treated

with 5% CO<sub>2</sub> treatment showed higher firmness than those treated with 3% CO<sub>2</sub> treatment and the control throughout the storage time. The results are also in agreement with Paulsen et al. (2019) who reported that tomatoes subjected to reduced O<sub>2</sub> levels showed higher firmness compared with the ones exposed to higher O<sub>2</sub> levels due to enzyme activity which causes softening of walls (polygalacturonase and galacturonase). The author explained that by reducing O<sub>2</sub> concentrations can delay the activity of these enzymes, hence retaining firmness of tomatoes.

Similar results were also reported by Fagundes et al. (2015) who studied the effect of active modified atmosphere and cold storage on the postharvest quality of cherry tomatoes and reported that tomatoes with the highest weight loss (control) also had a greater reduction in firmness. Our results are also in line with Afifi (2016) who reported that fruit firmness was maintained in active MAP1 (7.5% O<sub>2</sub> +15% CO<sub>2</sub>) and MAP2 (10% O<sub>2</sub> +10% CO<sub>2</sub>) treatments for 15 days at 0°C + 2 days at 10°C while passive MAP treatment-maintained firmness for only 6 days at 0°C + 2 days at 10°C, but thereafter lost it more quickly until the end of storage. Their study concluded that strawberries stored in active MAP1 or MAP2 were the most successful treatments in minimizing the loss of firmness, with no significant differences between them. On the other hand, passive MAP was less efficient in reducing the loss of fruit firmness. The authors explained that the beneficial impact of MAP in maintaining fruit firmness might be attributed to the fact that active MAP can effectively restrict the permeability of the cell membrane. Furthermore, Domínguez et al. (2016) explained that MAP and high humidity inside the packages can delay ripening associated with the change in firmness. According to their report, it has been shown that MAP decreases the activity of some enzymes (pectin esterase and polygalacturonase) in the cell wall degradation process. The author continued to explain that there is a correlation between fruit softening and ethylene.

The results of our study are also in agreement with Tilahun et al. (2021) who also showed that cherry tomatoes in Active MAP, MAP + CO<sub>2</sub>, and MAP + 1-MCP showed higher firmness than in MAP during a period of 15 days at 10 °C. In another study conducted in commercial active packaging maintaining physicochemical

qualities of carambola fruit during cold storage, it was confirmed that active packaging maintained firmness during the storage period (Nimitkeatkai et al., 2022).



**Figure 4.16** Firmness of Tomatoes in LDPE Plastic Films during Storage Period of 30 Days at  $12\pm 2^\circ$  (Means Showing Significance Difference Using Test of the Mean  $\pm$  SE)

#### 4.3.5 Ethylene Production and Respiration Rate

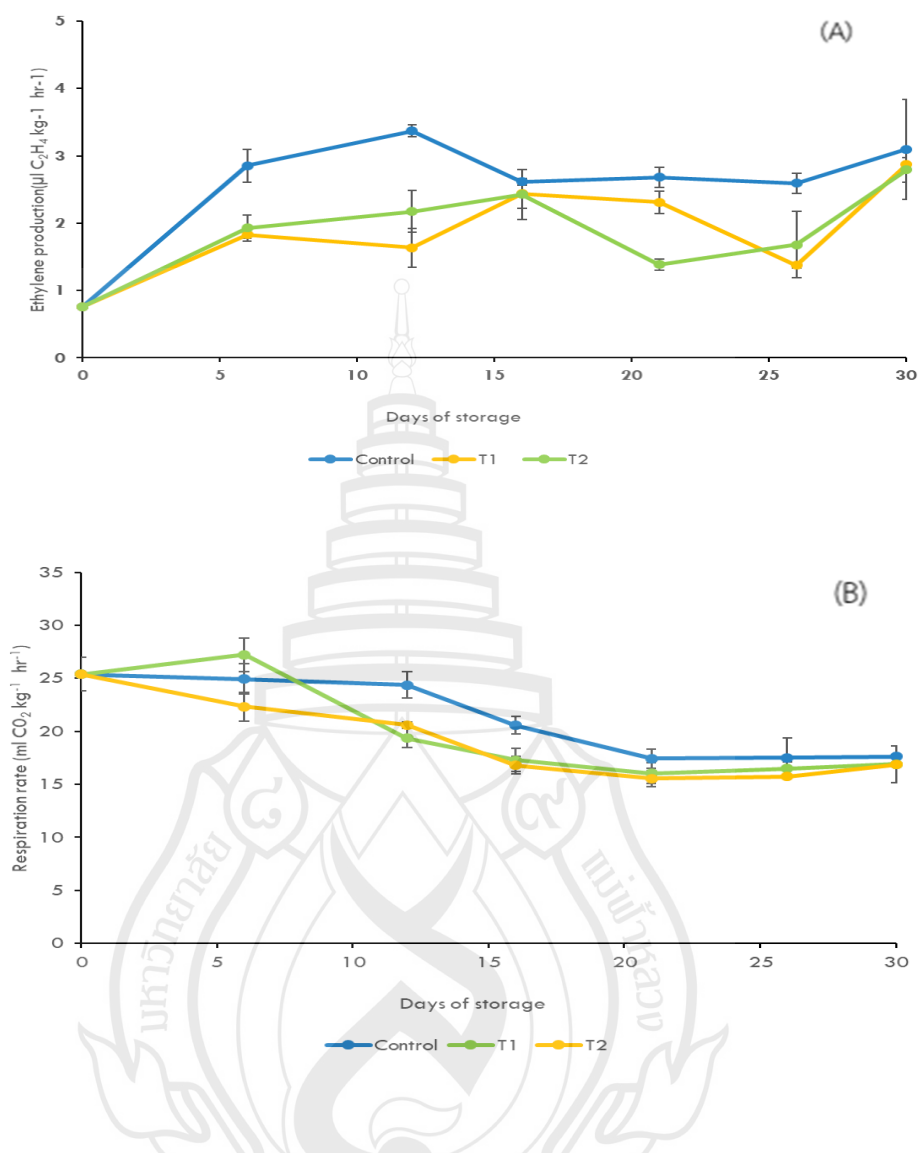
Figure 4.18 shows ethylene production and respiration rates from tomatoes packed in LDPE bags. There was an increase of ethylene concentration throughout the storage period. A peak of ethylene content was observed within the first 16 days of storage especially in the control. Similar results were found by Fagundes et al. (2015), who reported a peak of ethylene production in the first 15 days of storage. During their study, MAP reduced ethylene production of cherry tomatoes stored at  $5^\circ\text{C}$ . The authors explained that an increased  $\text{CO}_2$  and reduced  $\text{O}_2$  concentration can delay ripening and senescence process by reducing ethylene synthesis and perception of ethylene changes in respiration rates such as starch sugars, chlorophyll and changes to cell wall constituents during ripening and senescence. In another study, a peak of ethylene production was recorded on the 9th day of storage at both  $10$  and  $20^\circ\text{C}$ , except MAP

at 20 °C, which reached its peak earlier on the 7th day. The authors continued to explain that packaging methods delayed fruit ripening by reducing ethylene production during storage at temperatures of 10 and 20 °C (Tilahun et al., 2021).

After 16 days of storage, ethylene production started to decline in T1 and T2, whereas the control continued with the highest ethylene rates until the end of storage. T1 and T2 displayed the lowest significant rates of ethylene production until the end of storage. A significant difference between T1 and T2 was observed on days 12 and 20. The control exhibited the highest significant rates of ethylene production throughout the storage period. Taye et al. (2017) reported the same trend of lower ethylene production in 5% CO<sub>2</sub> treatment followed by 3% CO<sub>2</sub> treatment compared to the control (untreated fruits) from both stages of maturity. This happened because ethylene production was inhibited in CO<sub>2</sub> treatment due to its competitive action which assisted in regulating ethylene biosynthesis during storage period. Higher CO<sub>2</sub> levels can inhibit the production of ethylene, which is responsible for ripening.

Respiration rate declined throughout the storage in all the treatments. However, there was a peak of respiration rate in T1 (27.21 ml kg<sup>-1</sup> hr<sup>-1</sup>) on day 6 which later declined until the end of storage probably due to increased CO<sub>2</sub> at the initial stage. In contrast, Taye et al. (2017) reported a peak of respiration rate on day 1 in all treatments. During their study, a reduction of respiration rate was recorded after day 1 in all treatments, with the highest reduction rate recorded in the control and 3% CO<sub>2</sub> treatment compared to 5% CO<sub>2</sub> treatment throughout the storage period. Active MAP packages (T1 and T2) exhibited lowest significant rates of respiration compared to the control throughout the storage period. A reduction of respiration rate was also observed by Tilahun et al. (2021) in all treatments as storage period progressed at temperatures of 10 and 20 °C. The authors reported the highest respiration rate at the beginning of storage in both storage temperatures. Furthermore, relatively lowest rates of respiration for cherry tomatoes were observed in their study at the storage temperature of 10°C. Taye et al. (2017) also reported a similar trend of low respiration rates under 5% CO<sub>2</sub> treatment as compared to 3% CO<sub>2</sub> treatment and the control throughout the storage period.

During our study, the control exhibited highest significant rates of respiration compared to other treatments until the end of storage. Increased respiration activity is associated with tomato maturation. This increase is linked with the maximum point of maturity and the beginning of senescence. When this stage is reached respiration rate will decrease quickly (Paulsen et al., 2019). During the first hours of storage respiration rate becomes high due to the high O<sub>2</sub> concentrations inside the package. As storage period progresses, respiration rate decreases because the available O<sub>2</sub> for consumption by the fruit also reduces (Fagundes et al., 2015). Results in this study are in agreement with previous findings which observed reduced respiration rates due to increased CO<sub>2</sub> concentration levels which in turn had an effect on the changes in the activities of some enzymes that accelerate ripening and senescence (Taye et al., 2017). Manasa et al. (2018) revealed that restricting O<sub>2</sub> may decrease respiration rate, hence prolonging the shelf life of produce by postponing the oxidative breakdown of complex constituents. Altering the packaging atmosphere by elevating carbon dioxide (CO<sub>2</sub>) levels and reducing oxygen (O<sub>2</sub>) concentrations can substantially reduce the respiration rate of tomatoes. This inhibits senescence and ripening, enabling tomatoes to retain freshness for an extended duration. In another study, Wang et al. (2023) reported that the carbon dioxide levels in the MAP+1-MCP treatment were lower than those in the MAP treatment during cold storage. The author continued to explain that a comparable study indicated that 1-MCP delayed persimmon post-ripening and reduced respiration rate when compared to MAP treatment alone. Therefore, it could be deduced that 1-MCP + MAP treatment can delay post-ripening of figs as a result of low respiratory activity. In a related study, Tilahun et al. (2021) observed that respiration rates decreased over storage days at both 10 and 20 °C. However, this investigation found lower values for fruits kept at 10 °C. These results imply that packing treatment could reduce the respiration rate and prolong the distribution duration.



**Figure 4.17** Ethylene and Respiration Rates of Tomatoes in LDPE plastic Films during Storage Period of 30 Days at 12±2°C (Means Showing Significance Difference Using Test of the Mean ±SE)

#### 4.3.6 Decay Percentage

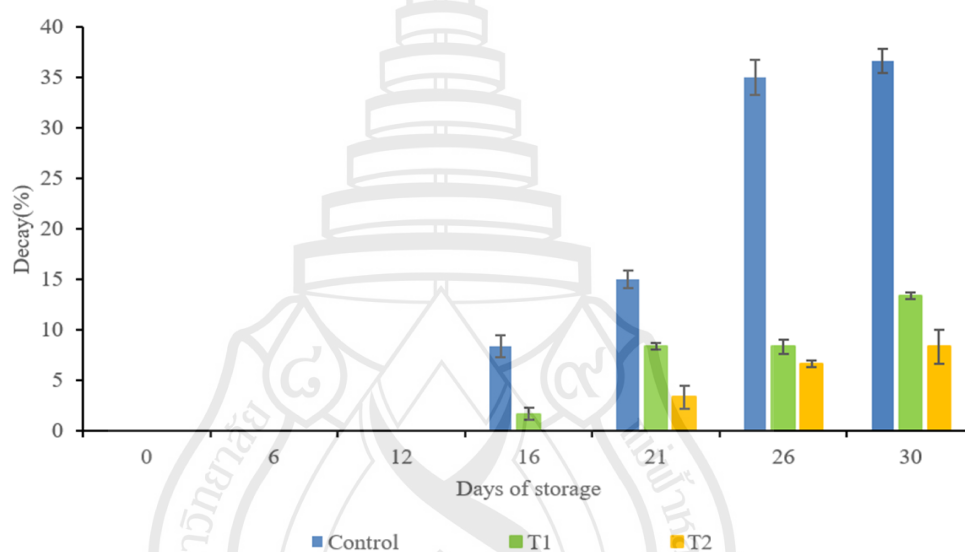
The decay percentage increased with storage time (Figure 4.19). A similar observation was reported by Afifi (2016) who reported an increase in decay in strawberry fruits over storage period. During this study, the presence of decay was recorded for the first time in the control and T1 on day 16 of storage. However, decay percentage was much lower in T1(1.67%) than in the control (8.33%). On the other

hand, according to the study conducted by Tilahun et al. (2021) decay was first recorded on day 9 on the control MAP at 10°C. The authors continued to explain that decay was first observed from day 11 of storage in Active MAP (high CO<sub>2</sub>) and MAP with 1-MCP. Decay progressed over the storage and it was more pronounced in the control compared to other treatments especially from day 26 (35%) and 30 (36.67%). The control continued to exhibit higher significance rates of decay than other treatments until the end of storage. No decay was recorded in T2 until day 21 at the lowest rate of 3.33%. Furthermore, T1 and T2 recorded lower rates of decay than the control throughout the storage period due to increased CO<sub>2</sub> which inhibited the microbial growth on tomatoes. This trend of lowest rates continued until the end of storage (T1 =13.33% and T2 =8%). T2 displayed the lowest significant changes than T1 throughout the storage. In addition, T2 also displayed the lowest (8%) significant value than all treatments on the last day of storage.

Our results are in accordance with Afifi (2016) who indicated that strawberry fruits treated with active MAP had lower decay rates during storage and shelf life compared to passive MAP or untreated MAP (control) in both seasons. At the end of their storage, more decay was observed in passive MAP and untreated MAP (control). The author emphasized that active MAP may reduce decay and fungal development by delaying fruit senescence and inhibiting microbial growth. They further explained that CO<sub>2</sub> has two mechanisms through which it suppresses microbial activity: it dissolves in the product's water and negatively affects the enzymatic and biochemical processes in both the product and microorganism cells (Afifi, 2016). Bailén et al. (2006) also observed decay after 21 days of storage whereby 40% of bags displayed fungal growth. The decay increased up to 100% after 28 days. However, tomatoes with GAC or GAC-Pd started to decay after 21 days. Furthermore, the presence of decay in tomatoes was significantly lower (39%) for GAC-Pd and with GAC (65%). The author concluded that tomatoes in the control were redder and darker and also displayed a higher occurrence of fungal growth than those treated with GAC-Pd and with GAC.

In a study conducted by Hansen et al. (2016) on the Effect of vacuum or modified atmosphere packaging (MAP) in combination with a CO<sub>2</sub> emitter on quality parameters of cod loins, they demonstrated that the addition of CO<sub>2</sub> emitter improved

the microbiological and sensory quality preservation of both MAP and vacuum packaged loins. They indicated that the vacuum package with CO<sub>2</sub> emitter retained quality at least as well as MAP, with a gas to product ratio of 1.6/1. The shelf life was extended by 2-3 days between MAP+ CO<sub>2</sub> emitter and MAP (13 days vs 9 days) and between vacuum + CO<sub>2</sub> emitter and vacuum (9 days vs 7 days). Furthermore, MAP+CO<sub>2</sub> emitter had 6 days longer shelf life than vacuum. The vacuum+CO<sub>2</sub> emitter exhibited similar sensory quality as MAP with low headspace (“MAP”).



**Figure 4.18** Decay Percentage of Tomatoes Packed in LDPE plastic Films during Storage Period of 30 Days at 12±2°C (Means Showing Significance Difference Using Test of the Mean ±SE)

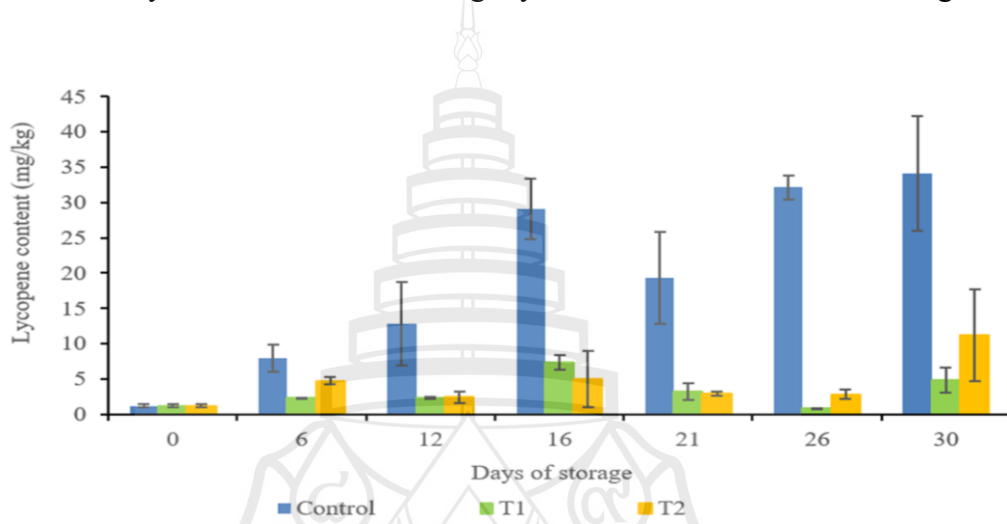
#### 4.3.7 Lycopene

An increase of lycopene was observed throughout storage (Figure 4.20), a similar observation was reported by Domínguez et al. (2016). Radzevičius et al. (2009) also found out that lycopene concentration in all tomatoes under evaluation increased significantly throughout fruit ripening. Lycopene accumulation increased throughout the storage in all treatments but was more pronounced in the control. This increase was first recorded on day 6 in all the treatments with the least significant content recorded

in T1 (2.31 mg/kg) than other treatments. Lycopene accumulation continued to increase over storage period but declined from day 21 until 26 in T1 (3.17- 0.8 mg/kg) and T2 (2.94 - 2.8 mg/kg). However, a slight increase was observed on the last day of storage in T1 and T2, while the control continued to display higher significant changes of lycopene accumulation until the end of storage than the two. Our results are in line with Paulsen et al. (2019) who reported that an increase of lycopene accumulation was observed during storage period but thereafter declined after 2 weeks of storage at 7°C in all the treatments. In addition, Tilahun et al. (2019b) also reported that lycopene content increases after breaker stage, and at the mature red stage it already contains 95% of all colored carotenoids and 73% of the total carotenoids. The control exhibited a greater significant change of lycopene accumulation showing the highest content than other treatments from day 6 until the end of storage. T1 and T2 maintained lycopene content until the end of storage with significant changes on day 6 and 26. Similar results were also reported by Fagundes et al. (2015) who found that cherry tomatoes stored in 5% O<sub>2</sub>, 5% CO<sub>2</sub>, and 90% N<sub>2</sub> atmosphere showed a lower increase of lycopene content. This effect was also observed by Taye et al. (2017) who reported that 5% CO<sub>2</sub> treatment delayed lycopene accumulation at the end of the storage.

In another study, Domínguez et al. (2016) reported that control samples showed the highest lycopene content followed by tomatoes packaged in perforated bags while the lowest lycopene was observed in PP bags. The authors continued to explain that increased CO<sub>2</sub> can inhibit ethylene action concluding that CO<sub>2</sub> and O<sub>2</sub> concentration play a vital role on lycopene content in tomatoes. Our findings were also in accordance with Radzevičius et al. (2009) who found out that the highest lycopene content was recorded in fully ripened fruits and lower concentrations were reported in ripened fruits as well as the highest chroma value (40.0 NBS units). According to Domínguez et al. (2016), lycopene content increases as maturity progresses. Contrarily, Paulsen et al. (2019) reported that temperature and other storage conditions, variety, environmental conditions throughout the plant growth, cultivation technologies, harvest season, and maturity have an impact on lycopene synthesis. Furthermore, Jagadeesh et al. (2011) indicated that lycopene accumulation is influenced by air temperature, with lower concentrations observed in fruit stored at low temperatures.

Our findings are also in agreement with Oliveira-Bouzas et al. (2021) who observed higher amounts of lycopene in mature tomatoes than in green ones, which is consistent with the tomato color analysis. Lycopene biosynthesis was found in packaged ripe tomatoes after 7 days of storage, followed by a reduction, whereas in our study lycopene accumulation was observed in the control (ripe) from day 6, then declined on day 21-26 and thereafter slightly increased until the end of storage.



**Figure 4.19** Lycopene Content of Tomatoes in LDPE plastic Films during Storage Period of 30 Days at  $12\pm 2^{\circ}\text{C}$  (Means Showing Significance Difference Using Test of the Mean  $\pm$ SE)

#### Summary (Experiment 3)

1. Active MAP ( $\text{CO}_2$  emitter and  $5\%\text{CO}_2+5\%\text{O}_2+90\%\text{N}_2$  gas flushing) at  $12\pm 2^{\circ}\text{C}$  delayed weight loss, firmness, color changes, lycopene accumulation, decay rate and reduced ethylene production and respiration rate of tomatoes up to 21 days during cold storage.

## CHAPTER 5

### CONCLUSION

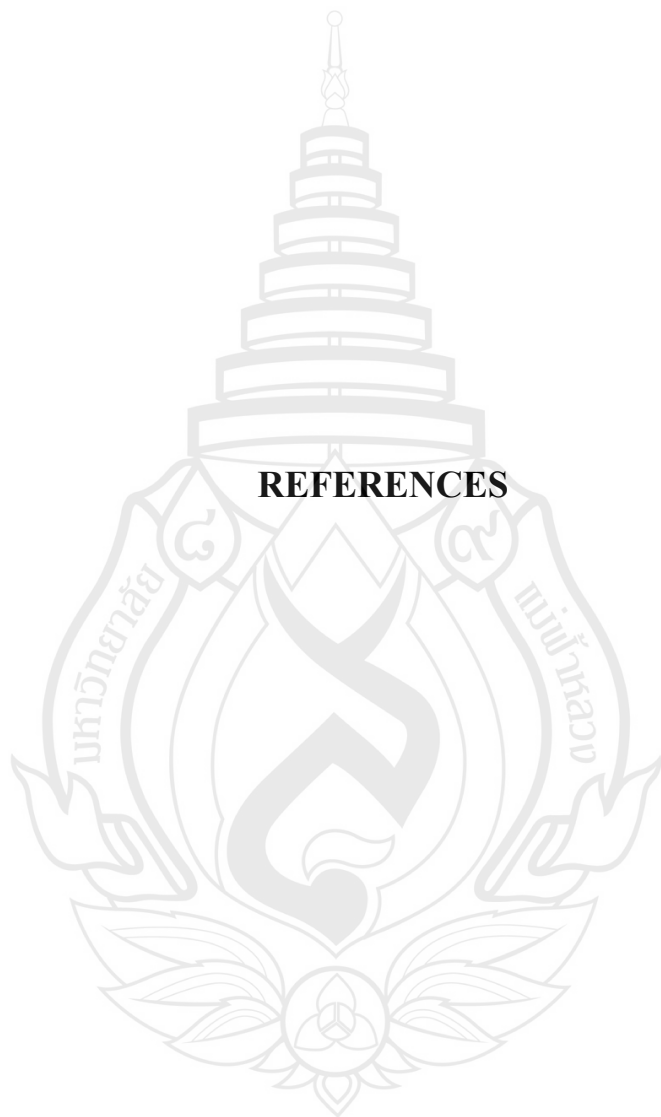
#### 5.1 Conclusion

5.1.1 The overall results suggest that Active MAP with CO<sub>2</sub> emitters at a concentration of 3g (1.668g NaHCO<sub>3</sub> + 1.332g C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>) in bulk size packaging at 12±2°C can be an alternative preservation technique that can be used instead of mixed gas to preserve the quality and extend the shelf life of mature green tomatoes for 21 days.

5.1.2 Moreover, the technique requires less equipment, more affordable and can be prepared more easily than mixed gas.

#### 5.2 Suggestion

The combination of MAP and CO<sub>2</sub> emitters presents a promising method for maintaining the quality and extending the shelf life of tomatoes during cold storage hence the technique can be recommended for bulk packaging on bigger scales in longer distance markets since it is easily accessible and cheaper to purchase contributing to a more sustainable food supply chain.



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## REFERENCES

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**APPENDICES**

## APPENDIX A

### EXPERIMENT 1

**Table A1** CO<sub>2</sub> Concentrations of Tomatoes in LDPE Plastic Films with Different Treatments Stored at 6±1°C for 21 Days (Means Showing Significance Difference using Test of the Mean ±SE)

Treatments	CO <sub>2</sub> Concentrations (%)							
	Days of storage (6±1°C)							
	D1	D3	D6	D9	D12	D15	D18	D21
T1 (CONTROL- passive MAP) @25°C	3.00±0.20	3.67±0.26	3.63±0.27	4.20±0.10	4.50±0.20	3.90±0.20	3.90±0.30	3.65±0.55
T7 (LDPE- passive MAP)	3.50±0.00	5.47±0.23	5.60±0.15	5.05±0.15	4.25±0.15	3.57±0.12	3.40±0.06	2.85±0.05
T8 (CO <sub>2</sub> Emitter)	4.25±0.25	5.35±0.15	6.10±0.28	5.80±0.10	4.53±0.14	3.60±0.20	3.60±0.12	3.05±0.24
T9 (5%CO <sub>2</sub> ,5% O <sub>2</sub> , 90%N <sub>2</sub> )	5.43±0.09	4.95±0.35	4.75±0.05	4.75±0.15	4.07±0.11	3.73±0.09	3.40±0.40	2.83±0.07
T10 (99.5% N <sub>2</sub> )	2.40±0.10	3.62±0.04	3.66±0.04	4.03±0.12	3.93±0.03	3.65±0.05	3.25±0.03	3.00±0.06
T11 (Ethylene scavenger)	3.70±0.20	5.40±0.12	5.50±0.12	4.47±0.09	3.90±0.15	3.45±0.13	3.25±0.09	3.00±0.10

**Table A2** O<sub>2</sub> Concentrations of Tomatoes in LDPE Plastic Films with Different Treatments Stored at 6±1 °C for 21 Days (Means Showing Significance Difference using Test of the Mean ±SE)

Treatments	O <sub>2</sub> Concentrations (%)							
	Days of storage (6±1°C)							
	D1	D3	D6	D9	D12	D15	D18	D21
T1 (CONTROL- passive MAP) @25°C	18.35±0.25	7.74±0.51	7.02±0.40	7.85±0.09	9.40±0.01	10.65±0.35	11.75±0.95	12.00±2.11
T7 (LDPE- passive MAP)	17.00±0.10	10.5±0.10	10.1±0.00	10.9±0.00	13.55±0.65	14.95±0.65	15.8±0.10	16.55±0.15
T8 (CO <sub>2</sub> Emitter)	16.65±0.45	10.55±0.25	7.87±0.83	8.44±1.48	11.09±1.41	14.75±0.25	15.00±0.10	16.25±0.25
T9 (5%CO <sub>2</sub> ,5% O <sub>2</sub> , 90%N <sub>2</sub> )	4.41±0.27	6.14±1.03	7.18±0.80	9.52±0.59	12.15±0.85	13.25±0.85	14.15±1.85	16.9±0.50
T10 (99.5% N <sub>2</sub> )	2.66±0.35	3.01±0.23	6.64±0.77	8.30±0.59	11.22±0.93	14.05±0.66	15.43±0.06	16.4±0.15
T11 (Ethylene scavenger)	16.60±0.20	9.36±0.12	9.49±0.39	11.30±0.40	13.4±1.10	14.80±0.50	15.45±0.05	16.25±0.15

**Table A3** CO<sub>2</sub> Concentrations of Tomatoes in LDPE Plastic Films with Different Treatments Stored at 12±2°C for 21 Days (Means Showing Significance Difference using Test of the Mean ±SE)

Treatments	CO <sub>2</sub> Concentrations (%)							
	Days of storage (12±2°C)							
	D1	D3	D6	D9	D12	D15	D18	D21
T1 (CONTROL-passive MAP) @25°C	3.00±0.20	3.67±0.26	3.63±0.27	4.20±0.10	4.50±0.20	3.90±0.20	3.90±0.30	3.65±0.55
T7 (LDPE-passive MAP)	3.35±0.16	6.85±0.25	5.06±0.09	4.40±0.11	4.30±0.06	4.30±0.00	3.85±0.13	3.30±0.07
T8 (CO <sub>2</sub> Emitter)	3.97±0.13	7.26±0.07	5.28±0.09	4.65±0.03	4.46±0.12	4.40±0.14	4.43±0.37	3.87±0.44
T9 (5%CO <sub>2</sub> ,5% O <sub>2</sub> , 90%N <sub>2</sub> )	5.3±0.20	5.23±0.09	5.00±0.10	4.84±0.07	4.80±0.11	4.55±0.06	4.43±0.17	4.3±0.21
T10 (99.5% N <sub>2</sub> ,)	2.55±0.05	4.27±0.07	4.05±0.25	4.47±0.12	4.20±0.20	4.30±0.10	4.10±0.20	4.2±0.40
T11 (Ethylene scavenger)	3.73±0.41	6.54±0.18	4.96±0.20	4.50±0.24	4.25±0.15	4.00±0.00	3.85±0.25	3.50±0.20

**Table A4** O<sub>2</sub> Concentrations of Tomatoes in LDPE Plastic Films with Different Treatments Stored at 12±2°C for 21 Days (Means Showing Significance Difference using Test of the Mean ±SE)

Treatments	O <sub>2</sub> Concentrations (%)							
	Days of storage (12±2°C)							
	D1	D3	D6	D9	D12	D15	D18	D21
T1 (CONTROL- passive MAP) @25°C	18.35±0.25	7.74±0.51	7.02±0.40	7.85±0.09	9.40±0.01	10.65±0.35	11.75±0.95	12.00±2.11
T7 (LDPE- passive MAP)	16.85±0.05	6.03±0.25	7.01±0.53	8.50±1.21	10.14±0.18	11.05±0.55	11.30±0.10	11.58±1.48
T8 (CO <sub>2</sub> Emitter)	16.25±0.15	6.46±0.43	6.22±0.05	7.96±0.55	9.34±0.08	10.30±0.61	11.30±0.80	9.94±1.76
T9 (5%CO <sub>2</sub> ,5% O <sub>2</sub> , 90%N <sub>2</sub> )	4.15±0.19	3.54±0.28	4.90±1.05	7.11±1.16	8.28±1.37	8.58±1.62	10.10±0.20	10.65±0.05
T10 (99.5% N <sub>2</sub> )	1.66±0.17	3.51±0.11	6.14±0.10	7.66±0.25	7.67±1.27	8.08±0.68	9.37±2.34	10.32±2.58
T11 (Ethylene scavenger)	16.60±1.00	7.94±0.58	7.12±1.20	8.43±0.35	9.97±0.03	10.2±0.10	11.15±0.35	10.85±0.35

**Table A5** Score of Maturity (color) of Tomatoes in LDPE Plastic Films with Different Treatments Stored at  $6\pm 1^\circ\text{C}$  for 21 Days (Means Showing Significant Difference using Test of the Mean  $\pm$ SE)

Treatments	Color (Score)							
	Days of storage ( $6\pm 1^\circ\text{C}$ )							
	D0	D3	D6	D9	D12	D15	D18	D21
T1 (CONTROL-passive MAP) @ $25^\circ\text{C}$	3.08 $\pm$ 0.08	3.11 $\pm$ 0.11	4.00 $\pm$ 0.00	4.17 $\pm$ 0.00	4.75 $\pm$ 0.08	5.71 $\pm$ 0.10	5.78 $\pm$ 0.11	5.89 $\pm$ 0.06
T2 (LDPE-passive MAP)	2.67 $\pm$ 0.16	2.97 $\pm$ 0.12	3.50 $\pm$ 0.29	3.58 $\pm$ 0.34	3.67 $\pm$ 0.00	3.89 $\pm$ 0.22	4.00 $\pm$ 0.17	4.28 $\pm$ 0.20
T3 (CO <sub>2</sub> Emitter)	2.33 $\pm$ 0.38	3.04 $\pm$ 0.55	3.25 $\pm$ 0.48	3.25 $\pm$ 0.48	3.46 $\pm$ 0.53	3.46 $\pm$ 0.53	3.58 $\pm$ 0.54	3.71 $\pm$ 0.59
T4 (5%CO <sub>2</sub> , 5% O <sub>2</sub> , 90%N <sub>2</sub> )	2.80 $\pm$ 0.20	3.37 $\pm$ 0.17	3.39 $\pm$ 0.24	3.54 $\pm$ 0.23	3.84 $\pm$ 0.23	3.88 $\pm$ 0.24	4.00 $\pm$ 0.42	4.33 $\pm$ 0.26
T5 (99.5% N <sub>2</sub> )	3.00 $\pm$ 0.00	3.89 $\pm$ 0.06	3.93 $\pm$ 0.04	3.97 $\pm$ 0.03	4.00 $\pm$ 0.00	4.00 $\pm$ 0.00	4.11 $\pm$ 0.06	4.25 $\pm$ 0.08
T6 (Ethylene scavenger)	2.86 $\pm$ 0.14	3.39 $\pm$ 0.39	3.71 $\pm$ 0.13	4.22 $\pm$ 0.05	4.39 $\pm$ 0.06	4.39 $\pm$ 0.06	4.67 $\pm$ 0.07	4.67 $\pm$ 0.17

**Table A6** Score of Maturity of Tomatoes in LDPE Plastic Films with Different Treatments Stored at  $12\pm 2^\circ\text{C}$  for 21 Days (Means Showing Significant Difference using Test of the Mean  $\pm$ SE)

Treatments	Color (Score)							
	Days of storage ( $12\pm 2^\circ\text{C}$ )							
	D0	D3	D6	D9	D12	D15	D18	D21
T1 (CONTROL- passive MAP) @ $25^\circ\text{C}$	3.08 $\pm$ 0.08	3.11 $\pm$ 0.11	4.00 $\pm$ 0.00	4.17 $\pm$ 0.00	4.75 $\pm$ 0.08	5.71 $\pm$ 0.10	5.78 $\pm$ 0.11	5.89 $\pm$ 0.06
T7 (LDPE- passive MAP)	2.70 $\pm$ 0.30	3.25 $\pm$ 0.53	3.67 $\pm$ 1.17	3.75 $\pm$ 1.08	3.92 $\pm$ 1.25	4.25 $\pm$ 1.25	4.50 $\pm$ 1.17	4.92 $\pm$ 0.75
T8 (CO <sub>2</sub> Emitter)	3.00 $\pm$ 0.00	3.25 $\pm$ 0.18	3.34 $\pm$ 0.53	3.42 $\pm$ 0.41	4.00 $\pm$ 0.27	4.25 $\pm$ 0.34	5.08 $\pm$ 0.25	5.34 $\pm$ 0.17
T9 (5%CO <sub>2</sub> ,5% O <sub>2</sub> , 90%N <sub>2</sub> )	3.20 $\pm$ 0.20	3.08 $\pm$ 0.07	3.11 $\pm$ 0.09	3.50 $\pm$ 0.50	3.59 $\pm$ 0.59	3.67 $\pm$ 0.66	4.00 $\pm$ 1.00	4.50 $\pm$ 0.67
T10 (99.5% N <sub>2</sub> )	2.76 $\pm$ 0.15	3.03 $\pm$ 0.23	3.16 $\pm$ 0.33	3.46 $\pm$ 0.28	3.67 $\pm$ 0.48	4.00 $\pm$ 0.51	4.34 $\pm$ 0.60	4.42 $\pm$ 0.42
T11 (Ethylene scavenger)	3.00 $\pm$ 0.00	3.50 $\pm$ 0.27	4.00 $\pm$ 0.00	4.47 $\pm$ 0.11	4.67 $\pm$ 0.00	4.83 $\pm$ 0.00	5.50 $\pm$ 0.00	5.67 $\pm$ 0.00

**Table A7** Damage Incidence of Tomatoes in LDPE Plastic Films with Different Treatments Stored at  $6\pm 1^\circ\text{C}$  for 21 Days (Means Showing Significant Difference using Test of the Mean  $\pm$ SE)

Treatments	Damage incidence (%)							
	Days of storage ( $6\pm 1^\circ\text{C}$ )							
	D0	D3	D6	D9	D12	D15	D18	D21
T1 (CONTROL-passive MAP) @25°C	0.00± 0.00	0.00± 0.00	0.00± 0.00	6.67±0. 24	13.33± 0.37	13.33± 0.37	16.67± 0.55	16.67± ±0.55
T7 (LDPE-passive MAP)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00±0. 00	0.00±0. 00	0.00±0. 00	0.00±0. 00	3.33± 0.20
T8 (CO <sub>2</sub> Emitter)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00±0. 00	3.33±0. 20	3.33±0. 20	3.33±0. 20	6.67± 0.24
T9 (5%CO <sub>2</sub> ,5% O <sub>2</sub> , 90%N <sub>2</sub> )	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00±0. 00	0.00±0. 00	0.00±0. 00	0.00±0. 00	13.33± ±0.20
T10 (99.5% N <sub>2</sub> )	0.00± 00	0.00± 0.00	0.00± 0.00	0.00±0. 00	0.00±0. 00	0.00±0. 00	6.67±0. 24	10.00± ±0.24
T11 (Ethylene scavenger)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00±0. 00	0.00±0. 00	3.33±0. 20	3.33±0. 20	6.67± 0.24

**Table A8** Damage Incidence of Tomatoes in LDPE Plastic Films with Different Treatments Stored at  $12\pm 2^\circ\text{C}$  for 21 Days (Means Showing Significant Difference using Test of the Mean  $\pm$ SE)

Treatments	Damage incidence (%)							
	Days of storage ( $12\pm 2^\circ\text{C}$ )							
	D0	D3	D6	D9	D12	D15	D18	D21
T1 (CONTROL- passive MAP) @ $25^\circ\text{C}$	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	6.67 $\pm$ 0. 24	13.33 $\pm$ 0.37	13.33 $\pm$ 0.37	16.67 $\pm$ 0.55	16.67 $\pm$ 0.55
T7 (LDPE- passive MAP)	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0. 00	0.00 $\pm$ 0. 00	3.33 $\pm$ 0. 20	3.33 $\pm$ 0. 20	10.00 $\pm$ 0.40
T8 (CO <sub>2</sub> Emitter)	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0. 00	0.00 $\pm$ 0. 00	3.33 $\pm$ 0. 20	6.67 $\pm$ 0. 24	6.67 $\pm$ 0. .24
T9 (5%CO <sub>2</sub> ,5% O <sub>2</sub> , 90%N <sub>2</sub> )	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0. 00	6.67 $\pm$ 0. 24	10.00 $\pm$ 0.24	13.33 $\pm$ 0.37	13.33 $\pm$ 0.37
T10 (99.5% N <sub>2</sub> )	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0. 00	0.00 $\pm$ 0. 00	0.00 $\pm$ 0. 00	10.00 $\pm$ 0.24	13.33 $\pm$ 0.20
T11 (Ethylene scavenger)	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0. 00	0.00 $\pm$ 0. 00	0.00 $\pm$ 0. 00	13.33 $\pm$ 0.37	13.33 $\pm$ 0.37

## APPENDIX B

### EXPERIMENT 2

**Table B1** CO<sub>2</sub> Concentrations Inside LDPE Packages of Tomatoes LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) Stored at 6±1°C for 20 days (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	CO <sub>2</sub> concentrations (%)					
	Days of storage					
	D1	D4	D8	D12	D16	D20
T1(Control-passive MAP)	1.73±0.15	4.7±0.26	5.37±0.37	4.80±0.30	4.00±0.23	3.67±0.09
T1 (single ratio)	3.23±0.13	5.03±0.64	4.47±0.47	4.471±0.52	4.17±0.18	3.97±0.07
T3 (double ratio)	5.77±0.15	5.70±0.21	5.13±0.15	4.70±0.06	4.27±0.20	3.83±0.09
T4 (quadruple ratio)	8.13±0.07	6.03±0.63	4.83±0.30	5.23±0.18	4.70±0.17	3.87±0.20

**Table B2** O<sub>2</sub> Concentrations Inside LDPE Packages of Tomatoes LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) Stored at 6±1°C for 20 days (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	O <sub>2</sub> concentrations (%)					
	Days of storage					
	D1	D4	D8	D12	D16	D20
T1 (Control-passive MAP)	18.63±0.22	8.43±1.07	6.78±0.83	3.97±0.70	5.38±0.95	4.10±0.91
T1 (single ratio)	18.87±0.09	11.17±0.70	8.32±2.77	6.70±1.94	5.49±1.16	5.68±1.12
T3 (double ratio)	18.3±0.17	11.07±0.75	8.47±0.45	6.93±0.89	4.95±0.88	5.44±1.64
T4 (quadruple ratio)	17.77±0.09	12.87±0.70	10.12±0.35	5.52±0.62	2.76±0.88	4.07±0.84

**Table B3** Weight loss of Tomatoes during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Weight loss (%)					
	Days of storage					
	D0	D4	D8	D12	D16	D20
T1 (Control-passive MAP)	0.00±0.00	0.24±0.03	0.21±0.02	0.29±0.02	0.37±0.03	0.39±0.05
T1 (single ratio)	0.00±0.00	0.13±0.04	0.21±0.03	0.31±0.10	0.38±0.09	0.48±0.06
T3 (double ratio)	0.00±0.00	0.34±0.05	0.36±0.03	0.49±0.11	0.60±0.08	0.64±0.10
T4 (quadruple ratio)	0.00±0.00	0.37±0.03	0.44±0.07	0.69±0.13	0.79±0.21	0.97±0.22

**Table B4** Peel Color Changes of Tomatoes: L\* value during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	L* value of peel					
	Days of storage					
	D0	D4	D8	D12	D16	D20
T1 (Control-passive MAP)	56.61±0.87	56.42±0.79	54.91±0.91	47.64±0.94	47.79±0.86	44.13±1.09
T1 (single ratio)	56.61±0.87	56.14±0.75	54.57±0.79	47.23±0.83	46.36±0.87	43.31±0.81
T3 (double ratio)	56.61±0.87	56.53±0.86	54.32±1.04	47.10±0.94	45.82±0.91	42.39±1.16
T4 (quadruple ratio)	56.61±0.87	53.49±1.12	52.69±1.05	44.62±0.93	44.07±0.87	41.09±1.05

**Table B5** Peel Color Changes of Tomatoes: a\* value during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	a* value of peel					
	Days of storage					
	D0	D4	D8	D12	D16	D20
T1 (Control-passive MAP)	-4.34±0.67	12.57±0.88	15.85±0.94	18.28±0.78	19.12±0.86	22.83±0.98
T1 (single ratio)	-4.34±0.67	9.94±0.88	13.22±0.98	15.09±0.93	16.33±0.96	18.89±1.06
T3 (double ratio)	-4.34±0.67	11.26±1.17	14.06±1.18	15.37±1.12	16.98±1.11	19.21±1.32
T4 (quadruple ratio)	-4.34±0.67	11.62±0.67	13.99±0.68	14.24±0.63	15.49±0.76	15.71±0.83

**Table B6** Peel Color Changes of Tomatoes:  $b^*$  value during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	$b^*$ value of peel					
	Days of storage					
	D0	D4	D8	D12	D16	D20
T1 (Control-passive MAP)	36.47±2.82	43.89±1.01	45.14±3.29	46.51±0.33	49.54±4.10	49.84±2.48
T1 (single ratio)	36.47±2.82	42.14±1.63	42.19±3.57	43.54±2.81	44.79±3.59	44.86±1.84
T3 (double ratio)	36.47±2.82	40.89±2.25	41.81±4.39	42.32±4.62	43.80±7.38	43.91±2.51
T4 (quadruple ratio)	36.47±2.82	38.56±4.03	38.77±4.11	38.82±3.32	39.30±4.51	39.45±2.66

**Table B7** Peel Color Changes of Tomatoes: Hue Angle during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Hue angle of peel					
	Days of storage					
	D0	D4	D8	D12	D16	D20
T1(Control-passive MAP)	96.39±0.94	74.38±0.91	66.73±0.83	63.57±1.12	62.28±0.24	60.84±0.65
T1 (single ratio)	96.39±0.94	74.64±1.06	70.26±2.91	66.62±1.23	65.74±0.43	64.49±0.81
T3 (double ratio)	96.39±0.94	74.97±1.55	70.10±1.06	69.09±1.14	68.05±0.81	67.91±1.16
T4 (quadruple ratio)	96.39±0.94	76.94±0.45	71.41±1.60	73.14±1.24	72.93±0.89	71.82±1.96

**Table B8** Firmness of Tomatoes during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days) (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Firmness (N)					
	Days of storage					
	D0	D4	D18	D12	D16	D20
T1 (Control-passive MAP)	29.91±0.00	27.36±1.13	22.93±1.96	25.14±3.71	21.55±0.62	23.73±1.59
T1 (single ratio)	29.91±0.00	22.52±2.14	22.59±0.53	25.51±1.65	21.06±2.60	24.65±3.16
T3 (double ratio)	29.91±0.00	23.29±0.41	25.03±0.38	21.44±0.50	21.22±1.92	20.22±1.43
T4 (quadruple ratio)	29.91±0.00	23.00±0.94	21.17±3.25	20.66±2.75	29.47±2.33	22.09±1.74

**Table B9** Total soluble solids (TSS) of Tomatoes during Storage in LDPE plastic films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days) (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	TSS (%)					
	Days of storage					
	D0	D4	D18	D12	D16	D20
T1 (Control-passive MAP)	0.41±0.00	3.83±0.12	4.07±0.23	4.5±0.23	4.07±0.26	4.17±0.20
T1 (single ratio)	0.41±0.00	3.47±0.12	3.80±0.40	3.9±0.21	4.13±0.39	3.80±0.20
T3 (double ratio)	0.41±0.00	3.60±0.20	4.03±0.03	3.93±0.15	4.20±0.12	4.37±0.03
T4 (quadruple ratio)	0.41±0.00	3.37±0.12	4.03±3.18	4.23±0.18	4.07±0.09	4.03±0.03

**Table B10** Titratable acidity (TA) of Tomatoes during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days) (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	TA (%)					
	Days of storage					
	D0	D4	D18	D12	D16	D20
T1 (Control-passive MAP)	0.71±0.00	0.75±0.06	0.67±0.01	0.63±0.04	0.60±0.02	0.65±0.02
T1 (single ratio)	0.71±0.00	0.66±0.03	0.58±0.05	0.55±0.04	0.62±0.02	0.61±0.02
T3 (double ratio)	0.71±0.00	0.67±0.01	0.58±0.02	0.63±0.03	0.61±0.04	0.70±0.01
T4 (quadruple ratio)	0.71±0.00	0.64±0.06	0.63±0.01	0.59±0.02	0.69±0.06	0.73±0.03

**Table B11** Damage incidence of Tomatoes during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days) (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Damage incidence (%)							
	Days of storage							
	D0	D4	D8	D12	D16	D20	D24	D28
T1 (Control-passive MAP)	0.00± 0.00	0.00± 0.00	0.00± 0.00	3.33± 0.45	16.67± 1.73	23.33± 0.57	60.00± 0.51	70.00± 0.37
T1 (single ratio)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	3.33±0. 45	26.67± 0.67	73.33± 0.40	80.00± 0.37
T3 (double ratio)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	6.67±0. 89	13.33± 0.89	43.33± 0.87	43.33± 0.87
T4 (quadruple ratio)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00±0. 00	3.33±0. 45	23.33± 0.57	23.33± 0.57

**Table B12** Damage Severity of Tomatoes during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days) (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Damage Severity (%)							
	Days of storage							
	D0	D4	D8	D12	D16	D20	D24	D28
T1 (Control-passive MAP)	0.00± 0.00	0.00± 0.00	0.00± 0.00	4.17± 0.00	6.94± 0.71	6.94± 0.57	15.00± 0.51	15.83± 0.56
T1 (single ratio)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	4.17± 0.00	8.30± 0.67	15.00± 0.53	12.08± 0.48
T3 double ratio)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	8.33± 0.00	8.33± 0.00	9.58± .63	11.67± 0.49
T4 (quadruple ratio)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	4.17± 0.00	11.10± 0.37	11.10± 0.31

**Table B13** Ascorbic acid content of Tomatoes during Storage in LDPE Plastic Films without CO<sub>2</sub> Emitter (T1) and with CO<sub>2</sub> Emitters (T2 = Single Ratio, T3 = Double Ratio, T4 = Quadruple Ratio) at 6±1°C for 20 Days) (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Ascorbic acid content (mg/100g)					
	Days of storage					
	D0	D4	D18	D12	D16	D20
T1 (Control-passive MAP)	30.30±2.47	33.59±5.75	23.73±0.82	28.66±1.64	22.90±5.69	30.30±2.47
T1 (single ratio)	30.30±2.47	29.48±7.84	28.66±3.58	25.37±3.77	17.97±0.00	12.22±4.57
T3 (double ratio)	30.30±2.47	21.26±2.17	21.26±2.96	23.73±2.17	22.90±4.93	31.12±8.34
T4 (quadruple ratio)	30.30±2.47	31.94±0.82	22.90±2.47	27.01±5.75	21.26±2.17	18.80±2.17

## APPENDIX C

### EXPERIMENT 3

**Table C1** CO<sub>2</sub> Concentrations Inside LDPE Packages of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	CO <sub>2</sub> concentrations (%)						
	Days of storage						
	D1	D6	D12	D16	D21	D26	D30
CONTROL	1.63±0.38	4.65±0.25	4.40±0.15	4.37±0.23	4.77±0.43	4.85±0.35	4.73±0.19
T1 (CO <sub>2</sub> - pad)	5.33±0.20	7.47±0.13	4.33±0.03	4.40±0.31	4.27±0.07	4.20±0.20	4.60±0.06
T2 (mixed gas)	4.23±0.03	4.50±0.30	4.30±0.10	4.20±0.20	4.20±0.21	4.20±0.10	3.90±0.15

**Table C2** O<sub>2</sub> Concentrations Inside LDPE Packages of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	O <sub>2</sub> concentrations (%)						
	Days of storage						
	D1	D6	D12	D16	D21	D26	D30
CONTROL	18.33±0.59	5.81±1.23	6.33±0.28	6.58±2.03	5.85±0.24	3.93±0.45	3.43±1.75
T1 (CO <sub>2</sub> - pad)	19.03±0.03	5.00±0.69	5.01±0.45	5.15±0.35	5.34±0.25	4.00±0.51	3.83±1.33
T2 (mixed gas)	5.81±0.19	4.59±0.52	5.05±0.48	5.09±0.12	4.82±0.51	3.89±0.09	3.99±0.24

**Table C3** Weight Loss of Tomatoes in LDPE plastic Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Weight loss (%)						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	0.00±0.00	0.26±0.03	0.53±0.01	0.65±0.10	1.51±0.31	1.67±0.22	1.68±0.29
T1 (CO <sub>2</sub> - pad)	0.00±0.00	0.18±0.00	0.18±0.00	0.22±0.01	0.26±0.08	0.59±0.11	0.61±0.17
T2 (mixed gas)	0.00±0.00	0.16±0.02	0.17±0.01	0.18±0.03	0.22±0.01	0.59±0.17	0.56±0.11

**Table C4** Peel Color Changes of L\* value of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	L* value of peel						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	52.65±0.35	50.39±0.31	49.84±0.23	48.82±0.22	47.91±0.39	47.74±0.44	47.70±0.43
T1 (CO <sub>2</sub> - pad)	52.65±0.35	49.31±0.20	48.15±0.37	47.84±0.31	47.71±0.46	47.64±0.27	47.50±0.35
T2 (mixed gas)	52.65±0.35	49.42±0.22	48.81±0.22	48.05±0.44	47.61±0.33	47.54±0.31	47.36±0.44

**Table C5** Peel Color Changes of a\* value of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	a* value of peel						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	-4.30±0.46	-0.35±0.68	2.69±0.91	6.72±0.96	8.78±0.82	9.82±0.79	10.26±0.90
T1 (CO <sub>2</sub> - pad)	-4.30±0.46	-3.47±0.41	-3.37±0.45	-1.93±0.56	1.98±0.74	-0.14±0.67	-0.77±0.65
T2 (mixed gas)	-4.30±0.46	-3.55±0.45	-2.89±0.44	-3.16±0.42	0.84±0.82	0.86±0.84	2.11±0.93

**Table C6** Peel Color Changes of b\* value of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	b* value of peel						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	31.30±0.44	35.39±0.53	31.83±0.25	31.76±0.47	30.76±0.44	30.65±0.42	30.66±0.45
T1 (CO <sub>2</sub> - pad)	31.30±0.44	35.39±0.36	30.30±0.25	30.13±0.15	29.11±0.34	28.81±0.32	30.10±0.27
T2 (mixed gas)	31.30±0.44	32.75±0.35	30.15±0.36	29.58±0.29	28.72±0.25	28.55±0.33	30.18±0.42

**Table C7** Peel Color Changes of Chroma value of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Chroma value of peel						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	31.73±0.44	36.15±0.54	34.23±0.28	33.80±0.45	33.49±0.36	32.25±0.47	33.42±0.40
T1 (CO <sub>2</sub> - pad)	31.73±0.44	33.95±0.36	31.96±0.28	31.76±0.21	31.46±0.26	29.72±0.34	29.58±0.17
T2 (mixed gas)	31.73±0.44	34.91±0.48	32.13±0.32	31.87±0.31	31.39±0.34	31.12±0.31	31.07±0.27

**Table C8** Peel Color Changes of Hue angle of Tomatoes in LDPE Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Hue angle of peel						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	94.51±0.88	91.31±1.07	85.37±1.69	75.63±1.90	74.50±1.46	74.05±1.75	70.83±1.70
T1 (CO <sub>2</sub> - pad)	94.51±0.88	95.84±0.65	96.29±0.83	93.52±0.84	92.69±1.20	92.57±1.01	91.78±1.11
T2 (mixed gas)	94.51±0.88	96.26±0.76	95.71±0.89	95.49±0.74	95.20±0.91	89.13±1.45	79.99±1.98

**Table C9** Firmness of Tomatoes in LDPE plastic Films during Storage Period of 30 Days at 12±2° (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Firmness (N)						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	41.6±0.00	39.33±1.81	36.85±4.09	30.60±3.00	29.59±2.86	26.12±1.25	25.99±1.24
T1 (CO <sub>2</sub> - pad)	41.6±0.00	41.13±0.29	38.95±1.57	34.63±2.07	31.34±0.79	31.23±0.32	30.05±1.61
T2 (mixed gas)	41.6±0.00	40.62±1.55	37.67±2.04	33.59±1.07	32.28±2.08	32.09±1.80	29.41±0.09

**Table C10** Ethylene production of Tomatoes in LDPE plastic Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Ethylene production (µl C <sub>2</sub> H <sub>4</sub> kg <sup>-1</sup> hr <sup>-1</sup> )						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	0.76±0.01	2.85±0.24	3.37±0.09	2.61±0.05	2.68±0.15	2.59±0.15	3.09±0.74
T1 (CO <sub>2</sub> - pad)	0.76±0.01	1.83±0.05	1.63±0.29	2.44±0.22	2.31±0.16	1.37±0.04	2.87±0.03
T2 (mixed gas)	0.76±0.01	1.93±0.19	2.17±0.31	2.43±0.37	1.39±0.08	1.68±0.49	2.79±0.18

**Table C11** Respiration Rates of Tomatoes in LDPE plastic Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

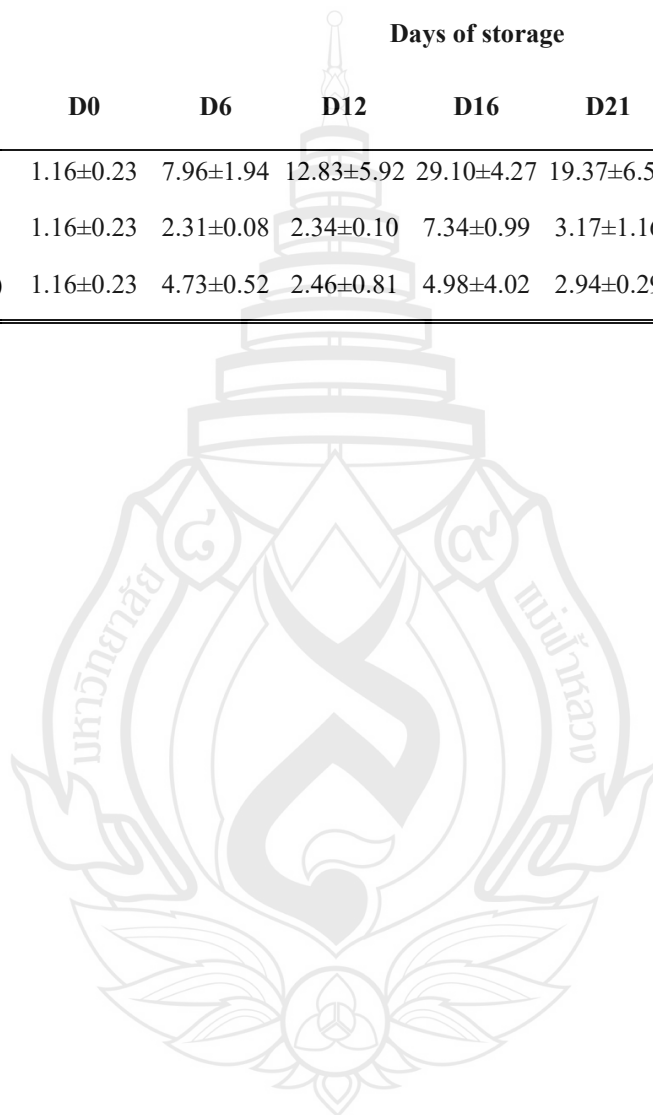
Treatments	Respiration rates (ml kg <sup>-1</sup> hr <sup>-1</sup> )						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	25.38±1.58	24.94±1.45	24.38±1.21	20.57±0.81	17.42±0.87	17.50±1.85	17.61±0.07
T1 (CO <sub>2</sub> - pad)	25.38±1.58	27.21±1.59	19.35±0.89	17.28±1.10	16.03±0.97	16.48±0.64	16.91±1.74
T2 (mixed gas)	25.38±1.58	22.32±1.36	20.60±0.29	16.79±0.82	15.56±0.75	15.75±0.04	16.85±0.03

**Table C12** Decay Percentage of Tomatoes Packed in LDPE plastic Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Decay (%)						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	0.00±0.00	0.00±0.00	0.00±0.00	8.33±1.08	15.00±0.88	35.00±1.73	36.67±1.20
T1 (CO <sub>2</sub> - pad)	0.00±0.00	0.00±0.00	0.00±0.00	1.67±0.58	8.33±0.33	8.33±0.67	13.33±0.33
T2 (mixed gas)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	3.33±1.15	6.67±0.33	8.33±1.67

**Table C13** Lycopene Content of Tomatoes in LDPE plastic Films during Storage Period of 30 Days at 12±2°C (Means Showing Significant Difference using Test of the Mean ±SE)

Treatments	Lycopene content (mg/kg)						
	Days of storage						
	D0	D6	D12	D16	D21	D26	D30
CONTROL	1.16±0.23	7.96±1.94	12.83±5.92	29.10±4.27	19.37±6.52	32.11±1.72	34.11±8.73
T1 (CO <sub>2</sub> - pad)	1.16±0.23	2.31±0.08	2.34±0.10	7.34±0.99	3.17±1.16	0.80±0.03	4.86±1.81
T2 (mixed gas)	1.16±0.23	4.73±0.52	2.46±0.81	4.98±4.02	2.94±0.29	2.80±0.63	11.21±6.45





**CURRICULUM VITAE**

## CURRICULUM VITAE

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