EFFECT OF UV-C IRRADIATION BEFORE AND AFTER PARTIAL VACUUM PACKING ON SHELF LIFE OF FRESH-CUT 'PHULAE' PINEAPPLE

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IN
POSTHARVEST TECHNOLOGY AND INNOVATION

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THIS THESIS IS A PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN POSTHARVEST TECHNOLOGY AND INNOVATION

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2024

THESIS APPROVAL

MAE FAH LUANG UNIVERSITY

FOR

MASTER OF SCIENCE

IN POSTHARVEST TECHNOLOGY AND INNOVATION

Thesis Title: Effect of UV-C Irradiation Before and After Partial Vacuum Packing on Shelf Life of Fresh-cut 'Phulae' Pineapple

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ACKNOWLEDGEMENTS

Firstly, I would like to express my deepest gratitude to my beloved advisor, Assistant Professor Dr. Phunsiri Suthiluk, whose expertise, understanding, logical suggestions, valuable academic guidance, and patience greatly improved my graduate experience. Without her guidance and persistent help, this thesis would not have been possible.

I wish to thank the members of my dissertation committee, especially the chairperson of my defence committee, Associate Professor Dr. Varit Srilaong and my examiner, Assistant Professor Dr. Wirongrong Tongdeesoontorn. Your invaluable suggestions and constructive feedback have significantly enhanced the quality of my work. I deeply appreciate my co-advisor, Assistant Professor Dr. Sutthiwal Setha, whose insightful lectures, patience, kindness, and encouragement have inspired me throughout my research journey.

Thanks to the instructors, Mae Fah Luang University's School of Agro-Industry staff, the Office of Postgraduate Studies, and the S3 and S7 lab technicians at the Scientific & Technological Instrument Center. Your unwavering support and knowledge sharing have been crucial in my academic career. I want to express my gratitude to Mae Fah Luang University for providing the financial support necessary to complete this work, as well as to the School of Agro-Industry, the Scientific and Technological Instruments Center, and Better Fruits Co., Ltd. Finally, I would like to thank my family, especially my parents and colleagues, for their unwavering support and encouragement throughout this journey. Your love and patience have been my strength. Thank you all for your contributions and for being part of this journey.

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ABSTRACT

Fresh-cut 'Phulae' pineapple is popular for local consumption and export markets. However, the short shelf life due to the initial microbial contamination is the main problem with this product. Thus, the study aimed to compare the effects of UV-C irradiation before and after partial vacuum packaging on the quality changes of fresh-cut 'Phulae' pineapple. Two doses of UV-C radiation, including 800 and 1200 J/m² were applied to fresh-cut 'Phulae' pineapple before or after packed with 80 % of the vacuum package. The treated samples were then kept under 5±1°C. From the result, UV-C radiation significantly slows down the loss of firmness, reduces juice leakage and decreases microbial populations, including bacteria, yeast, and mold. Among UV-C treatments before and after vacuum packaging, the result showed that direct exposure to UV-C at 800 and 1200 J/m² before packaging proved more effective than UV-C treatment applied after packaging, especially in the microbial population.

Therefore, the dose of 1200 J/m^2 irradiated before packaging was chosen for simulating transportation due to its lowest total plate count of 4.01 log CFU/g. The transport condition was simulated according to the local fresh-cut company in Chiang Rai. The samples were kept at 0–4 ℃ for 24 hours, then loaded by pack in the foam box with ice and stored in the room for 12 hours. After that, samples were transferred to 10–15 ℃, imitating the shelf temperature. The results showed that after 10 days of storage, the sample without UV-C irradiation (control) contained escalated internal gas and provided fermented odors. In addition, the TPC of the control was 2 log CFU/g higher than that of the irradiated sample. However, the treated sample was found sound in the vacuum packing condition, and TPC was 4.74 log CFU/g at 2 weeks of storage.

Irradiating with UV-C at 1200 J/m² before vacuum packaging offered a trustworthy alternative for maintaining the sensory qualities of fresh-cut ‘Phulae’ pineapple during transportation.

Keywords: Fresh-cut, Shelf Life, UV-C, Partial Vacuum Packing, Microbial

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ABBREVIATIONS AND SYMBOLS

°C	Degree Celsius
J/m²	Joule per meter square
µL	Microliters
AA	Ascorbic Acid
VP	Vacuum Package
g	Gram
H	Hour
L	Liter
TA	Titratable Acidity
TSS	Total Soluble Solid
PDA	Potato Dextrose Agar
mL	Milliliter
sec	Second
DPPH	2,3-Diphenyl-1-picrylhydrazyl
JL	Juice Leakage

CHAPTER 1

INTRODUCTION

1.1 Introduction to the Research Problem and its Significance

The pineapple (*Ananas comosus*) is a popular tropical fruit worldwide. One of the pineapple varieties from Thailand is called a 'Phulae' pineapple, referred to as 'Queen'. One of the biggest growing regions for pineapples is the province of Chiang Rai, particularly in the Nang Lae district, where pineapple is grown all year round (Ministry of Agriculture and Cooperatives (MOAC), 2008). 'Phulae' pineapple fruit is tiny, weighing 150-1000g. Therefore, it is also known as "baby pineapple". The fruit's skin will become yellow or greenish-yellow when fully ripe, and the skin is rather thick and suitable for long-distance transport. Fresh pineapple has a comparatively light golden color, is crunchy, and has an appealing aroma. Thailand is one of the largest pineapple exporters, and 'Phulae' has a proficient export market to China, Korea, and the United Arab Emirates. When the fruits are exported, the producer makes fruits as ready-to-eat food, and the price can be increased, however, the fresh-cut fruits are not easy to transport because of their short shelf life.

Fresh-cut fruits are essential in modern lifestyles and food systems, and they are an essential part of the value-added food industry, which supports the development of the retail, food processing, and agricultural sectors. However, the economic benefits of fresh-cut fruits and vegetables are restricted due to their short shelf life, and they are highly perishable. The primary issue is linked to multiple food-related disease outbreaks. Fresh cuts produce losses during transportation due to different environmental effects such as time duration, temperature, and relative humidity. Organoleptic quality, particularly of fresh-cut food, is impacted by fermentation that occurs during storage. Due to the cutting effect, Fresh-cut fruit can deteriorate from dropping sugar levels, water soaking, enzymatic conditions, and discoloration.

Pineapple is at risk for fermentation due to its high sugar content, which can result in unpleasant flavors or an alcohol-like taste.

The main problems with fresh-cut ‘Phulae’ pineapples are odor changes and microorganisms' presence. To maintain the quality of fresh-cut products, techniques such as hot water treatment, controlled atmosphere storage, and modified atmosphere packaging are used to maintain the quality of fresh-cut products and extend their life. On the other hand, non-thermal and non-chemical disinfection techniques like high-pressure processing, germicidal ultraviolet (UV-C) irradiation, pulsed UV treatment, cold plasma, and ultrasound are used for food safety or extending the shelf life of minimally processed foods (Kramer et al., 2017). Many studies show that UV-C can maintain the quality of fresh-cut fruits and extend their shelf life. Another popular method of food preservation is vacuum packaging, which preserves the firmness of fresh produce while reducing weight loss and browning index and extending the shelf life of perishables (Watts, 2022). Vacuum packaging (VP) is used in the commercial industry to limit oxygen, especially for seafood, meat, fresh fruits, and vegetables. It can also prevent the enzymatic browning of cut vegetables and fruits and control pathogenic bacteria' survival and growth. It reduces the amount of oxygen in the storage atmosphere, slows the respiration rate of the stored product and inhibits the growth of microorganisms (Jemni et al., 2016).

Based on previous research, this study aimed to investigate the effect of UV-C treatment before and after vacuum packaging on the shelf-life extension of fresh-cut ‘Phulae’ pineapple. The results were helpful as a guideline for fresh-cut ‘Phulae’ pineapple factories to maintain the quality and safety of the products.

1.2 Objectives

1.2.1 To study the effect of UV-C irradiation before and after partial vacuum packaging on microbial reduction and shelf life extension of fresh-cut ‘Phulae’ pineapple at 5°C storage.

1.2.2 To investigate quality changes of UV-C treated fresh-cut ‘Phulae’ pineapple during simulated domestic transportation

1.3 Scope of Research

There were two sections in this experiment. Part I clarified the effectiveness of UV-C treatment by using before and after partial vacuum packaging on microbial reduction and shelf life extension. Quality changes for two weeks of storage at 5±1°C were observed. Microbial reduction was focused on aerobic plate count (APC), and yeast and mould count (YMC) were determined. Physiochemical properties (color, firmness, pH, total soluble solid, titratable acidity) and bioactive compounds, including vitamin C and antioxidant activity in terms of DPPH scavenging activity, were analyzed. The best condition of UV-C treatment was then selected for the Part II experiment. Quality changes of UV-C treated sample packed in a vacuum package were observed at each step during transport simulation. Transportation conditions were simulated according to the actual situation of land transportation from a fresh-cut factory in Chaing Rai to Bangkok.

1.4 Research Output

1.4.1 Suitable condition of UV-C treatment for microbial reduction and shelf life extension of fresh-cut 'Phulae' pineapple

1.4.2 At least 12 days shelf life of fresh-cut 'Phulae' pineapple

1.4.3 A guideline for UV-C application in fresh-cut 'Phulae' pineapple for commercial

1.5 Research Outcome

1.5.1 Sustainability of 'Phulae' pineapple producers in terms of income and improve their living quality

1.5.2 The opportunity for the fresh-cut company to expand their domestic market

1.6 Location of Research

Postharvest Technology Laboratory, Scientific and Technological Instruments Center, Mae Fah Luang University, Chiang Rai, Thailand.

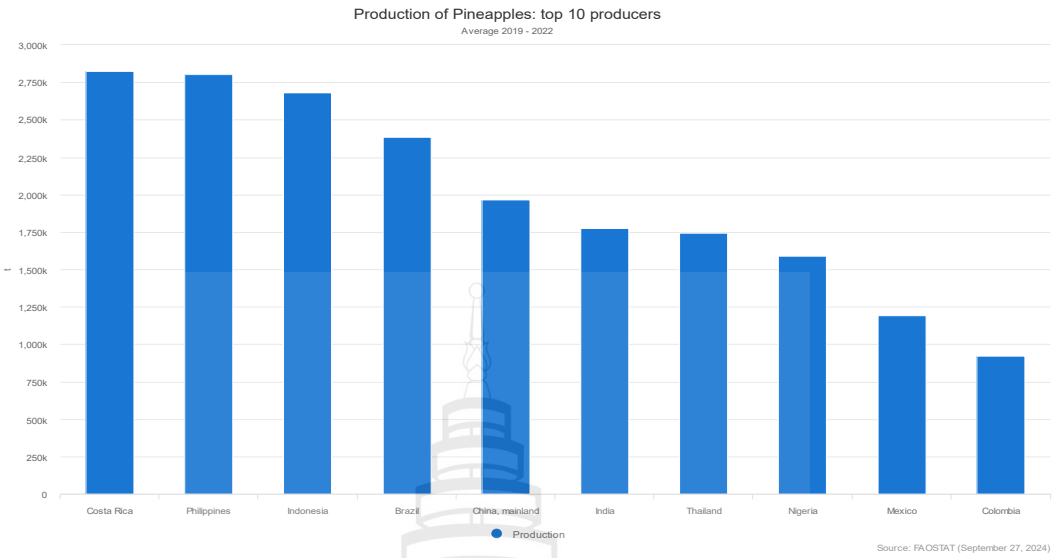
CHAPTER 2

LITERATURE REVIEW

2.1 Pineapple

After mangoes and bananas, pineapple (*Ananas comosus*) is the third-most important tropical fruit crop in the world trade. Pineapples are cultivated in various ways, depending on their size, shape, sweetness, skin color, and flesh color. Native to South America, pineapples are widely cultivated in tropical and subtropical regions around the world. Pineapples are an excellent source of vitamins, a powerful antioxidant which supports skin hydration and immune system function. Pineapples are consumed in various forms, either as an independent snack or as a component of fruit salads and smoothies. Pineapples can also be fermented to make beverages like tepache, a traditional Mexican drink. One of Thailand's most well-known pineapple export varieties is the ‘Phulae’ pineapple variety, which is also popular in the domestic market.

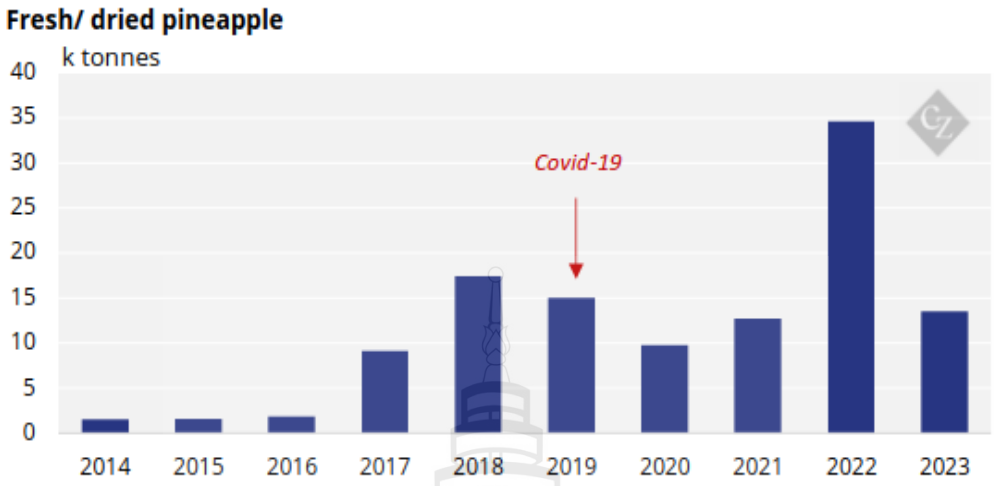
According to the Food and Agriculture Organization of the United Nations, Costa produced the largest pineapple in the world from 2017 to 2021. Other major pineapple-producing countries include the Philippines, Brazil, Thailand, and Indonesia. Thailand is one of the world’s largest producers and exporters of pineapples. In 2022, Thailand produced approximately 1.712 million metric tons of pineapples according to the Food and Agriculture Organization of the United Nations (FAO) data.



Source FAOSTAT (2022)

Figure 2.1 World Production of Top Ten Countries Pineapple between 2019 to 2022

The production of pineapples in Thailand has steadily increased over the past few years, with a 10% increase in production from 2016 to 2023, as shown in Figure 2.2. In Thailand, three cultivars, smooth Cayenne, Queen and Spanish, are planted (Vanijajiva, 2012) and ‘Phulae’ pineapple, referred to as Queen, is an economically important crop in Thailand for domestic and international marketplaces. ‘Phulae’ pineapple is tiny, 100-120 mm in diameter, and has a sweet and crispy texture. Most ‘Phulae’ pineapples grow in the northern part of Thailand. According to the Department of Agricultural Economics (DOAE) 2023, ‘Phulae’ Pineapple are harvested area of 27,510 rai in Chaing rai and ‘Phulae’ pineapple fruit has developed into a significant commercial fruit, and demand for it is increasing in the domestic and export markets.



Source DOAE (2023)

Figure 2.2 Historical Pineapple Export Volume in Thailand

Note Credited to Thet Hsu Hsu Aung

Figure 2.3 'Phulae' Pineapple from Thailand

Fresh-cut tropical fruits are in high demand from consumers worldwide and freshly cut pineapple fruit is highly valued for sweetness, juiciness, and taste. On the other hand, changes in color, texture, appearance, taste, and microbial development, which are impacted by packaging situations, storage temperature, cultivar, and maturity stage, limit the product's shelf life (Marrero, 2006). The quality and shelf life of fresh-cut fruit has been examined using several treatments. The two major

techniques used to reduce undesirable quality changes and extend the shelf life of fresh-cut pineapples are modified atmosphere packaging and refrigeration. On the other hand, fresh-cut fruit has also been protected from lack of moisture and water loss using edible coverings. Each fruit piece with a coating creates a sort of modified atmosphere by acting as a gas barrier around it. At a suitable temperature and relative humidity, it is expected to reduce water losses and increase the fresh-cut product's shelf life (Rojas-Graü et al., 2008).

2.2 Maturity Index of Pineapple

For both the fresh market and the fresh-cut company, the stage of maturity at harvest is essential because it impacts product composition, postharvest tolerance to handling, and shelf life of intact fruits and vegetables. Pineapple maturity stages are divided into five clear stages: development, young or premature, mature, ripe, and senescence (Romli & Murad, 2022). Each stage is characterized by physiological and biochemical changes affecting the fruit's quality attributes, including sweetness, acidity, and texture.

According to studies in food engineering, when grading or classifying pineapple maturity, the fruit's outward appearance and physical qualities, which are related to its texture and color, can be used as a guideline. The maturity index of ‘Phulae’ pineapple is an important indicator used to determine the optimal time for harvesting the fruit. It is based on several factors such as fruit size, color, sugar content and acidity. Pineapples of the highest quality are juicy, sweet, and fragrant with few defects. While more ripe fruit is excellent for close-range transportation, pineapples that have not advanced along the maturity index are suitable for long-range transportation. The microbial load on fresh-cut pineapples can vary significantly depending on the maturity at harvest and the handling practices employed. There are several reasons to produce fresh-cut pineapple, but the primary ones are to increase consumer convenience and prolong shelf life without sacrificing quality. Because they are ready to eat, fresh-cut pineapples are becoming more and more popular as they satisfy the convenience and health demands of modern consumers.

Premature (Green) Mature (Yellow and Green) Ripe (Yellow)

Source Arwatchananukul (2024)

Figure 2.4 The Appearance of ‘Phulae’ Pineapple at Different Stages of the Maturity

2.3 Chemical Composition of Pineapple

Pineapples are a rich source of various nutrients and bioactive compounds that include bromelain, a group of enzymes that can break down proteins and various antioxidants such as Vitamin C, ß-carotene, and flavonoids (Bartholomew, 2003). Similarly, the health benefits of pineapple are attributed to various phytochemicals and their functional bioactivities, which support metabolic processes and promote overall human health (Hossain & Rahman, 2011). These bioactive compounds have been linked to antioxidant, anti-inflammatory, and immune-boosting properties, making pineapple a valuable component in maintaining physiological balance and enhancing wellness. Ascorbic acid, niacin, thiamin, sugars, organic acids, vitamins (ascorbic acid, niacin, and thiamin), and minerals (magnesium, manganese, and copper) are all present in pineapple in substantial quantities (de Ancos et al., 2017). The proteolytic enzyme bromelain, also found in pineapple fruit, is essential for the bromelain's therapeutic actions and the digesting process. Bromelain has numerous potential applications as an anti-inflammatory, antioxidant, anti-cancer, and cardioprotective agent (Zdrojewicz et al., 2018). Pineapple crowns and leaf fibers are inexpensive, renewable, biodegradable, and plentiful (Prado & Spinacé, 2019). According to Asim et al., 2015 Pineapple fiber has various chemical components, such

as cellulose (79 to 83%), lignin (5 to 15%), pectin (1%), hemicellulose (19%), wax (2%), and ash content (1%). Hemicellulose, cellulose, and pectin are the three main fibers found in pineapple. Pineapple fiber is an important natural fiber with excellent flexural stiffness and tensile strength.

Table 2.1 Bioactive Compounds and Antioxidant Capacities of 'Phulae' Pineapple

Bioactive compounds and Antioxidant Capacities	**'Phulae' pineapple**
Vitamin C (mg/100 g FW)	18.88
β-carotene (μg/100 g FW)	3.35
Total phenolics (mg GAE/100g FW)	26.20
DPPH (mol TE/100g FW)	118.18
FRAP (mol AAE /100g FW)	165.28

Source Kongsuwan et al. (2009)

Pineapple's smell profile and volatile organic components are useful for monitoring the quality control of raw and processed pineapple-based goods during storage and shelf life. However, not all volatile substances are the primary sources of scent. Based on fruit quality, most volatile chemicals oversee pineapple's complex flavor composition (Mohd Ali et al., 2020).

2.4 Post-harvest Losses of Fresh-cut Pineapple

Producers and retailers are particularly concerned about post-harvest losses of fresh-cut pineapple since they could potentially result in considerable financial losses and a decrease in the supply of this well-liked fruit. These losses can occur due to various factors, including physiological deterioration, microbial spoilage, and inadequate handling practices. The changes in metabolism that follow cutting are one of the main reasons for post-harvest losses in fresh-cut pineapple. Because of their increased surface area exposure to air, fresh-cut pineapples remain particularly susceptible to water loss, which accelerates dehydration (Liao et al., 2023).

Microbial spoilage is another critical factor contributing to post-harvest losses. Fresh-cut pineapples are highly susceptible to bacterial and fungal contamination because of their high sugar content and exposed fruit tissues, which provide the perfect conditions for microbial growth (Baligad et al., 2023). Post-harvest losses of 'Phulae' pineapples from rot and disease during storage at commercial storage temperatures (10-13°C) have been a problem for export (Casas-Junco et al., 2024). Product leakage, which can be especially severe in translucent fruit, browning frequently because of freezing damage, and microbial growth are the main causes of fresh-cut losses. Due to its absence of protective skin, fresh-cut pineapple loses moisture quickly, which lowers its firmness and quality. After bruising and preparing fresh-cut items, bacterial and yeast growth can quickly become a serious issue (Paull, 2018). Cutting the pineapple breaks down its cell structure, which results in textural deterioration and enzymatic browning. Higher temperatures accelerate this degradation.

2.5 Quality Changes of Fresh-cut Pineapple during Transportation

Fresh-cut fruit processing is well known to promote faster deterioration compared to its intact counterpart (Barbosa-Cánovas et al., 1998). Fresh-cut fruits are subject to quality losses during processing, Transportation, and storage. They are prone to enzymatic browning, which occurs when phenolic compounds in the fruit react with oxygen. Fresh-cut fruits are susceptible to microbial spoilage, which can lead to off-flavors, odors, and reduced shelf life; various bacteria, yeasts, and molds can cause microbial spoilage. Since thermal treatment would impair fruit freshness likelihood, non-thermal physical treatment has been proposed to extend shelf life (Manzocco et al., 2016). Fermentation during storage influences organoleptic quality, particularly the odor of freshly cut produce. cut fruits deteriorate because of sugar fermentation, water soaking, enzymatic conditions, discoloration, and other factors which could intensify the development of off-aromas and off-flavors. Furthermore, microbes, carbon dioxide, and storage conditions can all contribute to degradation and odor. Several studies have studied the relationship between microbial growth and storage temperature. When fresh-cut pineapple was stored at 4°C for 14 days, mold

started appearing, but only after four days when the temperature was raised to 20°C (O'Connor-Shaw, 1994). When yeast and mold are involved in the fermentation process, acetic acid, ethanol, and CO_2 may be found. The temperature condition has a significant impact on the shelf life of fresh-cut products. The main problems with fresh-cut 'Phulae' pineapple are changes in odor and the presence of microorganisms over acceptable levels.

During transportation, the structure of the pineapple and its composition are related to the damage and injuries that exacerbate the physiochemical and microbiological alterations, leading to quality losses. 'Phulae' pineapple is easily bruised during handling, transportation, and storage. When unexpected acceleration or deceleration occurs during transitional movements (such as conveying to temporary storage facilities, shipping, or airfreighting), it can cause significant energy dissipation and damage to fruit. Bruising Can lead to discoloration, soft spots, and reduced shelf life. Fruit shifts randomly inside the packaging units during transportation because of to minimize these quality losses, it is important to handle store and transport 'Phulae' pineapple properly. This includes careful harvesting, gentle handling, proper packing, controlled temperature and humidity during transportation and prompt delivery to the market vibrational forces from the vehicle caused by sudden changes in the road profile (Cherono & Workneh, 2018). Depending on the intensity, direction, and length of the displacement, these forces can reach thresholds that result in damage and a loss of quality.

2.6 Microbiological Spoilage

Fresh-cut fruits are at risk of microbiological spoilage due to the cutting of tissues. Several well-known bacteria that can enter produce at any stage along the farm-to-fork continuum can cause contamination and microbiological spoilage of fruits and vegetables (Siroli et al., 2017). Gram-positive, Gram-negative, and fungi-related organisms, including yeasts and molds, frequently cause fruits and vegetables to become spoiled. In various stages of the product's manufacturing, pathogenic and spoilage microorganisms can infect new products and, in the absence of treatments that

can remove bacteria, can reach the end consumer (Barth et al., 2009). Fresh-cut pineapple is a perishable food susceptible to microbiological spoilage. Like other fresh-cut fruits, pineapple is susceptible to microbial deterioration because of its high water and sugar content, which encourages the growth of microorganisms.

Pineapple, like other fruits, contains sugars and nutrients that can support the growth of microorganisms such as bacteria, yeasts, and molds. One of the most common spoilage microorganisms in fresh-cut pineapples is yeast and mold. This yeast can grow rapidly in the presence of sugar and moisture, and it can cause the fruit to ferment, resulting in the production of alcohol and carbon dioxide. Other spoilage microorganisms that can affect fresh-cut pineapple include bacteria such as *Pseudomonas* and *Aeromonas* and molds such as *Penicillium and Aspergillus*. (Beaulieu, 2002). Molds can grow on the surface of the pineapple, especially in areas where the juices have been released due to cutting. The environment condition, including moisture content, temperature and storage conditions, impact the presence of these fungi, and can significantly alter the microbial community associated with fresh-cut pineapple.

2.7 Temperature

Pineapple can easily spoil if it is not kept at the right temperature and humidity. To prevent spoilage and maintain the quality of fresh-cut pineapple during transportation, it is important to keep it at a temperature between 0-2°C, which is the optimal temperature range for most fresh produce. The shelf life of fresh-cut products is mostly affected by the temperature condition. In general, fresh-cut fruits should be stored at a cool temperature to help maintain their freshness and prevent the growth of microorganisms. The ideal storage temperature for fresh-cut fruits depends on the type of fruits and the specific storage conditions. In general, most fresh-cut fruits should be stored in the refrigerator at a temperature between 0-5°C. This can help to slow down the rate of ripening and help to maintain the fruit's texture and flavor (Jobling, 2000). When storing fresh-cut fruits, it is important to follow any specific storage instructions provided on the packaging (Manthou et al., 2021). Additionally, pineapple fruits are

sensitive to low temperatures, and physiological problems are frequently linked to cold storage. Internal browning (IB), which is brought on by exposure to low temperatures after harvest, is the physiological condition that affects pineapple fruit the most. The quality and shelf life of fresh-cut products are also impacted by temporary storage between harvesting and processing; generally, the longer the delay before processing, the shorter the shelf-life will be. By reducing its storage life and lowering its market value in industrialized countries, chilling damage results in 25% postharvest losses. Ascorbic acid, dietary fiber, phenolic compounds, and organic acids are just a few of the nutrients found in abundance in citrus fruits (Hussain, 2019).

2.8 Packaging

Fresh fruit and vegetable packaging primarily defends against mechanical damage, microbial contamination, and other postharvest handling-related problems. Smooth surfaces and boundaries, resistance to staking, appropriate size and form for the goods, simple handling, optimum ventilation for cooling, and availability are all requirements for packaging. Common types of packaging used for fresh-cut pineapple are PET (Polyethylene Terephthalate) or PP (Polypropylene), PET, PVC or polyolefin, and MAP.

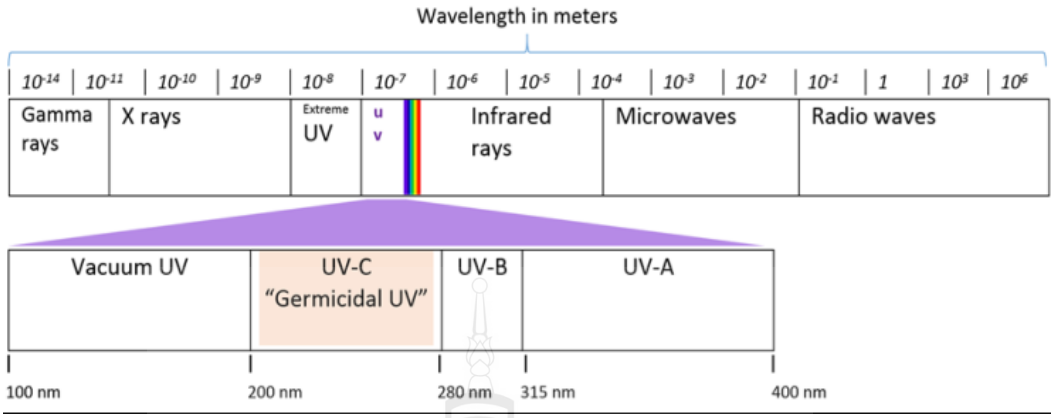
Some packages must have water loss barriers or meet other specific requirements. The packaging material and equipment used for packing the pineapples should be clean and contaminant-free. Fresh- cut pineapples should be packaged in a container that can maintain a temperature of 0-5 ºC during transportation and storage. The temperature range helps to slow down the growth of microorganisms, which can spoil the product. Modified atmosphere packaging, Vacuum Packaging and refrigeration are the main tools used to slow undesirable quality changes and increase the shelf-life of fresh-cut pineapples.

Vacuum packing (VP) is a particularly efficient method for materials where oxygen can cause chemical or biological modifications. Another popular method of food preservation is vacuum sealing, which preserves the firmness of fresh produce while reducing weight loss and browning index and extending the shelf life of

perishables. Fresh fruits and vegetables, freshly prepared fruits and vegetables, fresh and precooked seafood, and other products are available in vacuum packaging in the marketplaces (Watts, 2022). Vacuum packaging is a method of packaging that removes the air from the package and hermetically seals it (Yamaguchi, 1990). It reduces the amount of oxygen in the storage atmosphere, slows the respiration rate of the stored product and inhibits the growth of microorganisms. Most Bacteria spoilage associated with food spoilage need O_2 to grow and survive inside the package. The system also prevents the enzymatic browning of cut vegetables and fruits and controls pathogenic bacteria' survival and growth (Jemni et al., 2016). Damdam et al. (2023a) investigated the combined effects of UV-C irradiation and vacuum sealing on extending the shelf life of strawberries and tomatoes, reporting an increase of 124.41% for strawberries and 54.41% for tomatoes. Vacuum packaging alone can extend the shelf life of strawberries by an additional 1–3 days (Damdam et al., 2023a). Denoya et al. (2015) studied the combination of Vacuum packaging and high-pressure processing in fresh-cut peaches. The result showed that vacuum packaging prevented the preservation of the color (Denoya et al., 2015).

2.9 UV-C treatment

Plants are subjected to the ultraviolet (UV) radiation found in sunlight because they use it for photosynthesis. Vacuum UV, UV-A, UV-B, and UV-C are the four subtypes of UV radiation as in the figure. Sunlight near the earth's surface does not contain UV-C (200-280 nm) radiation because it is absorbed by ozone in the upper and middle layers of the atmosphere (Kim et al., 2022). The term "germicidal" refers to a property of UV-C that causes germs to disappear immediately. However, the ability of microorganisms to naturally resist UV-C is a key factor in the germicidal effects of UV radiation. UV-C irradiation disrupts the DNA of microorganisms like bacteria, viruses, and molds, rendering them unable to replicate and causing spoilage or illness.



Source Umagiliyage and Choudhary (2018)

Figure 2.5 Four Ultraviolet Regions in the Electromagnetic Spectrum

UV-C light treatment is the strongest germicidal effect among the UV wavelengths used as an economically and environmentally friendly technique(Sari et al., 2016). UV-C restricts physiological processes such as ripening, senescence, and sprouting and lessens or blocks the population of microbial pathogens. UV-C treatments have been shown to delay the ethylene peak in tomatoes (Umagiliyage & Choudhary, 2018; Maharaj et al., 1999) and to reduce chlorophyll degradation and softening across various horticultural commodities (Civello et al., 2006). Additionally, UV-C exposure has been linked to increased antioxidant accumulation (Cantos et al., 2001; González-Aguilar et al., 2007) and the prevention of physiological disorders such as chilling injury (Vicente et al., 2005). These effects underscore the potential of UV-C treatments as a valuable tool in postharvest management to enhance shelf life and maintain quality in fresh produce. According to Diesler et al. (2019), UV-C radiation between the wavelengths of 250 and 260 nm inactivated bacteria, yeasts, and numerous forms of mold. The non-penetrating nature of UV-C radiation restricts its application to the surface decontaminating food products (Fan et al., 2017).

Fresh and freshly cut produce treated with UV radiation is just as effective, if not more so, at preventing the growth and survival of organisms that cause disease and deterioration. The treatments removed desiccation and decreased pectin solubilization, softening, and decay and might be viewed as an efficient supplemental technology to cold storage because they did not significantly change sugars, acids, or antioxidants (Rodoni et al., 2012). The dose of UV-C irradiation depends on different fruits and

vegetables, and the times required for the development of maximum protection after UV-C treatment also vary depending on the commodities (Gimeno et al., 2022). According to Pataro et al. (2015), fresh tomatoes' shelf life can be extended by up to 21 days. At a storage temperature of 20°C, an 18 J/cm2 UV-C irradiation is applied. Similar to this, another study (Pinheiro et al., 2015) found that UV-C light (0.324.83 kJ/m² at 254 nm) treatment could extend the shelf life of tomatoes by up to 15 days.

2.9.1 Treatment of UV-C Irradiation on Fresh and Fresh-cut Produce

Numerous reports have been made of harmful microbes contaminating fresh produce during pre- and post-harvest operations. In most cases, during fresh-cut operations, contamination begins at the surface of intact produce and subsequently spreads through internal regions (Achen & Yousefa, 2001). Studies have shown that UV irradiation of fresh and fresh-cut vegetables is just as effective as some chemical sanitizers at lowering the growth and survival of rotting and disease-causing organisms. Kim and Hung observed that UV-C irradiation treatment is more efficient than electrolyzed water and ozone treatments at reducing E. coli O157:H7 in blueberries. The properties of the item's surface, the UV fluence, the mode of irradiation delivery, and the type and location of organisms were discovered to play significant roles, even though UV irradiation is effective for the surface decontamination of fresh produce. The following revealed that fresh, freshly cut fruits and vegetables are treated with UV-C light.

In addition to its antibacterial properties, UV-C irradiation has been demonstrated to affect fresh-cut produce's biochemical reactions. According to studies, the creation of phenolic molecules, which are recognized for their antioxidant qualities, can be stimulated by UV-C radiation. This increase in antioxidant capability can lessen oxidative stress and pineapple browning in fresh-cut fruits (Valerga, 2023). The induction of phenolic biosynthesis is very important as this not only makes the product more nutrient-dense but also improves its looks, both of which are essential for customer acceptableness (Valerga, 2023).

Table 2.2 UV-C treatment effect on Organisms of Fresh-cut Fruits and Vegetables

Produce	Organisms	UV treatment	Reduction (log CFU/g)	Light source	Reference
Broccoli	*E. coli* O157:H7	24mJ/cm²	3.3	G36T6Model4, 136 Germicidal light	(Huang et al., 2015)
Lettuce	*Salmonella Typhimurium Listeria monocytogenes*	Distance 10-15cm Exposure time 0.5to10 min	1.45,1.35,2.12 log at 25°C 0.31,0.57 1.16 log at 4°C	5G6T5Lamps (254nm)	(Kim et al., 2013)
Pineapple	Spoilage organisms	200 mJ/²cm Packaged in	2 log yeast and lactic acid bacteria.	415W/G15T8 Lamps	(Manzoccoet al., 2016b)

2.9.2 Effect UV-C Light Irradiation on the Quality of the Product

UV-C irradiation is a useful tool in many fields because, when used properly, it provides a balance between preserving product quality and maintaining safety. UV irradiation treatment has been incorrectly linked to nutritional and sensory quality deterioration. Many investigations showed that exposing fresh produce to UV light before storage helped reduce the emergence of postharvest diseases (Turtoi, 2013). Studies indicating how UV radiation treatment affects the quality of freshly cut fruits and vegetables are shown in Table 3. Fruit's nutritional value is hardly affected by UV-C treatment when applied in moderation. Since it doesn't produce heat, antioxidants and vitamins like C and phenolic compounds are typically retained. Due to pigment deterioration, UV-C exposure can cause color changes in light-sensitive items like fresh juices or vegetables. According to certain research, UV-C treatment can prevent enzymatic browning in fruits by blocking the polyphenol oxidase enzyme in fruits like avocados and apples.

Table 2.3 Effect of UV-C light treatment on the Quality of Fresh and Fresh-Cut Fruits and Vegetables

Produce	Test Conditions	Major quality changes	Reference
'Phulae' Pineapple	UV-C at1,320mJ/cm² for 10min: 2640mJ/cm² for20 min 3690mJ/cm² for 30 min	- Internal browning reduces during storage at 10°C for 28 days - Disease incidence decreased in UV-C dose - Significant increase in TPC	(Sari, 2016)
Spinach	UV pulse irradiation1,000 mJ/cm²	- Increased respiration rate and enhanced the activities of superoxide dismutase, ascorbate peroxide and phenylalanine ammonia-lyase	(Xu, 2016)
Blueberries	Aq.ClO and UV-C treatment	- Treatment with 2mg/L CIO combined with 4kJ/m² inhibited the increase of respiration rate, weight loss, decay incidence and MDA content, the delayed decline of firmness, color and TSS	(Agüero, 2016)

2.9.3 Combination of UV-C Irradiation and Vacuum Packaging

Combining UV-C irradiation with vacuum packaging is an effective strategy in food preservation, especially for extending shelf life and reducing spoilage. The combination of UV-C and vacuum packaging has also been shown to positively impact the retention of key nutrients in fruits and vegetables. Xin et al.(2024) observed that vacuum packing preserved color and freshness by decreasing oxidation, while UV-C irradiation inhibited microorganisms that spoil on fresh-cut lettuce (Xin et al., 2024). The combination of UV-C irradiation and vacuum package increased shelf life by 12.41% and 54.41% for strawberries and quartered tomatoes (Damdam et al.,

2023b). Since UV-C and vacuum packaging are non-thermal methods, they do not raise the food's temperature, which helps retain the natural texture, flavor, and appearance of heat-sensitive foods. UV-C radiation can enhance the postharvest conservation of blueberries by maintaining their color and nutritional profile, which is essential for consumer acceptance (Campero et al., 2023).

Although UV-C is effective in reducing the microbial load, it may also change the food items' sensory qualities. The use of UV-C light can lead to undesirable changes such as texture softening, browning, and aroma deterioration over time (Guerrero-Beltr· n & Barbosa-C· novas, 2004). Moreover, the vacuum environment may further exacerbate these effects by limiting the food's exposure to protective atmospheres. UV-C irradiation can cause the degradation of certain packaging materials, particularly plastics. This degradation can weaken the physical integrity of the packaging, leading to potential leaks or contamination of the product inside. While vacuum packaging reduces oxygen and limits aerobic spoilage, residual oxygen left in the packaging can react with UV-C-treated fat-containing foods, leading to lipid oxidation. This oxidation, especially in high-fat foods like beef and chicken can change the flavor and smell and induce rancidity (A. N. Damdam et al., 2023).

2.10 Impact of Simulated Transport Conditions

The purpose of simulated transport circumstances is to replicate the actual stresses that food items experience during handling and transportation. The main key factors include temperature fluctuation, mechanical vibrations and shocks, humidity Variations and long storage. Temperature fluctuations, both high and low, can accelerate respiration rates in produce, affect microbial growth, and impact texture and color. Under simulated transport situations, others studied the microbiological stability of vacuum-packaged meat exposed to UV-C irradiation, and the result indicated that while initial microbial loads were significantly reduced, temperature fluctuations during transport led to a gradual increase in microbial populations, though still lower than untreated controls (Moreira et al., 2021). Microbial activity can rise during transportation if the temperature increases, which could lessen the UV-C

treatment's effectiveness. Higher temperatures can promote anaerobic pathogens or spoiling organisms, including *Clostridium botulinum*, even while vacuum packaging inhibits the growth of aerobic microorganisms. In research on UV-C and vacuum packaged blueberries, Ning et al.(2022) found that simulated transport conditions involving moderate temperature fluctuations led to a reduction in vitamin C levels.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Materials

3.1.1 Raw Materials

Peeled 'Phulae' pineapples were obtained from a pineapple orchard in Nanglae district, Chiang Rai, Thailand. The best pineapples were at the commercial maturity stage (fully ripened stage). Samples were packed in a foam box with ice and transported to the laboratory immediately after peeling without any treatment.

3.1.2 Chemicals

Table 3.1 List of Chemical Reagents for Analysis Methods

Chemicals	Chemicals
Vitamin C	**Microbe analysis**
- Acetic acid	- Potato Dextrose Agar
- Ascorbic acid	- Plate count agar
- 2, 6-Dichloroindophenol	
- Metaphosphoric acid	
- Sodium bicarbonate	
DPPH radical scavenging activity	
- 2,2-diphenyl-1-picryhydrazyl	
- Methanol	

Table 3.2 Equipment Needed for Experiment

Equipment	Model/Brand	Manufacturing/Country
UV-C chamber	Custom-made	MFU, Thailand
Spectrophotometer	Genesys 10S UV-Vis	Becthai Bangkok Equipment & Chemical Co., Ltd.
Centrifuge	MPW-352R	Gibthai Co., Ltd.
Vacuum package machine		
Colorimeter	Color Quest XE Hunter Lab	
pH meter	Binder	Scientific Promotion Co., Ltd
Balance	Satorius/ED2240	Company Scientific Graphics promotion
Hand refractometer	Atago automatic	
Incubator	30-1060	Memmert GmbH, GERMANY

3.2 Method

Part I: Effect of UV-C Irradiation Before and After Partial Vacuum Packaging on Microbial Reduction and Shelf Life of Fresh-cut ‘Phulae’ Pineapple

3.2.1 Sample Preparation

Peeled ‘Phulae’ pineapples were washed with RO water and cut into four pieces vertically. The samples were soaked in a 2% NaCl solution for 1 minute, and the excess water was drained. The working area, boards, knives, containers, and all equipment used in the process were sanitized with 70% ethanol.

3.2.2 UV-C Treatment

The UV-C irradiation chamber equipped in the laboratory was used in this experiment (Figure 3.1).

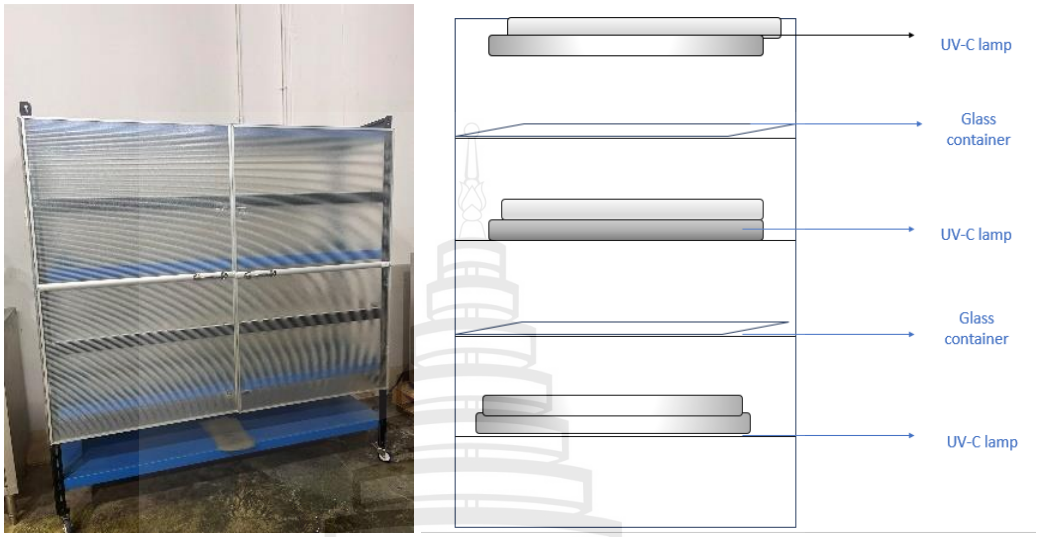


Figure 3.1 UV-C Irradiation Chamber and Schematic Diagram of UV-C Chamber

The pineapple pieces were placed on a rack with UV-C lights 25 cm above and below the rack. The intensity of the UV-C lamp used was 12 J/m², which was calculated with a digital UV-C meter (LUTRON UVC-254SD, Taiwan). The UV-C radiation applied before and after packaging in a vacuum package was set up for the following up.

3.2.3 UV-C Treatment Applied Before Packaging in Vacuum Package (VP)

Samples were treated in the UV-C chamber for 80 or 120 sec to obtain 800 and 1200 J/m^2 UV-C radiation, respectively, and then aseptically packed (180-200 g) per pack in which 80% Vacuum conditions were set up. Samples without UV-C treatment were packed in a vacuum package and used as a control sample.

3.2.4 UV-C Treatment Applied After Packaging in a Vacuum Package (VP)

Samples of about 180-200 g per pack under 80% vacuum conditions, were treated in the UV-C chamber for 102 or 137 sec to obtain 800 and 1200 J/m^2 UV-C radiation, respectively. According to the Vacuum packaging materials, the intensity of UV-C radiation decreased by 20% and to obtain a specific dosage, the radiation of time was increased.

All samples were kept at 5 ± 1°C, and sampling was done every two days until 14 days of storage. Quality changes were determined, including physiochemical properties, bioactive compounds, antioxidant activity, and microbial properties.

3.3 Determination of Physicochemical Quality

3.3.1 Color

The color was measured on the middle of pineapple slices by colorimeter and it was expressed by the values of L *, a *, b *, and ΔE. Five measures were taken on each side of two sticks for each sample.

$$\Delta E_H = [(L_2-L_1)^2 + (a_2-a_1)^2 + (b_2-b_1)^2]^{1/2}$$

3.3.2 Firmness

The texture analyser (TA.XT plus, UK) was used to determine fruit firmness, and results were reported in g/force. Five fruits per treatment were selected as a destructive approach before analysis using the shearing test. For the shearing test, Blade side with Knives was used.

3.3.3 pH

The samples were directly analysed using the pH meter (Binder, Scientific Promotion Co., Ltd). Before the analysis, the pH meter was calibrated using pH 4.0 and 7.0 standard buffer solution.

3.3.4 TSS and TA

Pineapple juice was arranged from a 10 g slice of each fruit and used for chemical analysis. The juice was analysed for total soluble solids (TSS) by using a digital refractometer (ATAGO PAL-1, Japan), and titratable acidity (TA) by using a Brix-Acidity meter (ATAGO, Tokyo, Japan).

3.3.5 Juice Leakage

Juice Leakage was determined following Montero-Calderón and colleagues (2008).To test for juice leakage, the packages were set up at a 20° angle for five minutes, and the collected liquid was measured using a 5-mL syringe. The results were

expressed as the amount of liquid recovered per 100 grams of the package's fresh-cut fruit.

3.4 Determination of Vitamin C

The AOAC (2000) technique was utilized to determine the vitamin C concentration. Fifty millilitre Erlenmeyer flasks were filled with five millilitres of a metaphosphoric acid-acetic acid solution. After adding two millilitres of the sample, the indophenol dye solution was used to titrate the samples until a rose-pink hue developed and persisted for at least five seconds. Next, calculate by.

$$mg\ of\ vitamin \frac{C}{mL} = (X - B) \times \frac{F}{E} \times \frac{V}{Y}$$

Where,

X = mL for sample titration

B = average mL for sample blank titration

F = titer of dye (= mg vitamin C equivalent to 1.0 mL indophenol standard solution

E = mL assayed

V = volume of the initial assay solution

Y = volume of sample aliquot titrated

3.5 Determination of Antioxidant Activity

DPPH Radical Scavenging Activity

The method outlined by Khalaf et al. (2008) was employed, with slight modifications, to evaluate the free radical scavenging activity of the sample. A 50 µL aliquot of the sample was combined with 2 mL of a 0.06 mM methanolic DPPH solution. The mixture was vortexed to ensure thorough homogenization, and then incubated in the dark for 30 minutes to facilitate the reaction.

Absorbance was subsequently recorded at 517 nm using a Thermo Fisher Scientific Genesys 20 spectrophotometer (Model 4001/4, Cat. 4001-03, Betchai Bangkok Equipment & Chemical Co. Ltd, Thailand). The results were quantified as milligrams of ascorbic acid equivalents per 100 grams of sample material, with ascorbic acid standards prepared in a 0–200 μg/mL concentration range.

$$\text{DPPH} = \frac{\text{Concentration std curved} \times \text{total vol. of extract} \times \text{dilution factor} \times 100 \times 100}{\text{Weight of sample} \times 1000}$$

$$\text{Percent (\%) inhibition} = \frac{\text{Absorbance of blank} - \text{Absorbance of sample} \times 100}{\text{Absorbance of blank}}$$

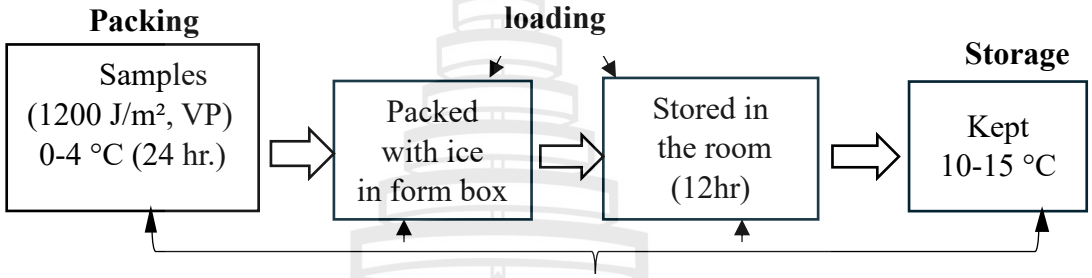
3.6 Determination of Microbial Properties

Microbial analysis was determined following the Bacteriological Analytical Manual. 25 g of samples were put into a stomacher bag, added with 225 ml of peptone water and then stomached for 2 min. Nine ml of sterile peptone solution was prepared for at least two dilution factors for dilution. One ml of stomach sample was transferred into the first 9-ml test tube (dilution factor 1/100 or 2/100) and 1 ml of sample was placed onto the plate. Total plate count (TPC) and the amount of yeast and mold were determined using the pour plate method on plate count agar and potato-dextrose agar, respectively, and expressed in log CFU/g fruit. The plates were incubated at 35°C for 24 hr (TPC) and 25°C for 3-5 days (yeast and mold).

3.7 Part II: Quality Changes of UV-C Treated Sample Packed in a Partial Vacuum Package During Simulated Transportation

Sample Preparation

The best condition of UV-C irradiation from Part I was selected to treat with fresh-cut 'Phulae' pineapple. The condition during domestic transportation was set to imitate transportation from Chiang Rai to Bangkok, as shown in Figure 3.2.



Note ▲ means sampling was done for quality determination at each step until 14 Days

Figure 3.2 Experiment on Quality Changes of UV-C (1200 J/m², VP) treated Sample packed in Partial Vacuum Package during Simulated Transportation

3.7.1 Determination of Physicochemical Quality

Color, hardness, pH, TSS, and TA were measured following Part I instructions.

3.7.2 Determination of Microbial Properties

Microbial analysis was determined followed by Part I.

3.7.3 Determination of Gas Inside Package

The samples (180-200g) were collected with 5 ml of spring with a 27mm needle. This study employed the static method (the closed system method) to analyze the gas composition inside the package. After 20 minutes, a 5ml syringe with needles containing bugs was injected into the Vacuum packaging and taken from each sample. Then, the samples from needles were measured by Gas chromatography (GC) (7890A Manufacturer. Agilent Technologies Inc., city WilminglonD6, country, USA fitted with flame ionization detector (FID) as a capillary column for C_2H_4 and thermal conductivity detector (TCD) fittered with a stainless steel porapakQ column for CO_2. The injector temperature is 250 ̊oven temperature is 60 ℃, and the detector temperatures for FID and TCD were set at 300 ℃ and 200, respectively. Carrier gas is

helium, and the flow rate of carrier gas is 2ml min^{1}. Ethylene retention time is 1.1 minutes. CO_2 retention time is 2.8 minutes and O_2 retention time is 4.57 minutes.

3.7.4 Determination of Volatile Compounds

In an adaptation of the methodology by Steingass et al. (2014), volatile compound profiles of fresh pineapple were obtained with modifications. A 150-gram sample of fresh pineapple was homogenized in a household blender (Philips HR2118/01) at speed level 1 for 1 minute, alongside 10 mL of deionised water and 30 g of sodium chloride to enhance extraction efficiency. Subsequent analysis was performed using a gas chromatography-mass spectrometry (GC-MS) system (Agilent Technologies, GC Model 7890B / MS Model 5977B), operating in an automated mode. Helium served as the carrier gas throughout the procedure. Headspace gas sampling was conducted with a 10 µL syringe, maintaining an oven temperature of 40°C and a loop temperature of 80°C. A 1 µL aliquot was injected into the gas chromatograph for compound separation. The headspace autosampler, designed to be chemically inert, allowed for temperature adjustments across all heated zones, within a range of 20°C to 250°C, maximizing the system's adaptability to a broad array of sample conditions.

3.8 Statistical Analysis

All the data gathered was analyzed using analysis of variance (ANOVA) and Duncan's multiple range test at a 95% ($p< 0.05$) confidence level. IBM SPSS Statistic 26 was used as the software to analyze the data, and all data was presented as means ± standard deviation (SD). For the analysis, all tests were conducted in triplicate. Significant differences were determined for experiment two using the independent t-test.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Effect of UV-C Irradiation Before and After Partial Vacuum Packing on Microbial Reduction and Shelf Life of Fresh-cut 'Phulae' Pineapple

4.1.1 Physical and Chemical Quality in fresh cut 'Phulae' Pineapple

Fruit color plays a significant role in the purchase. The results showed that after storage of fresh-cut pineapple, all treatments' value of L* decreased. A decrease in L* values might be related to the color of the pineapple flesh getting darker. The value of a* decreased (4.7±0.11 to 2.35±0.24) in each treatment. There was no significant difference between L*, a* and b* values. The samples were washed with 2% NaCl which can help to maintain the color of fruits and prevent browning. NaCl has antibacterial and antibranding abilities. It can prevent polyphenol oxidase from encountering polyphenols within the cell and from destroying the cell compartment (Jatturaspaibool et al., 2012).

TSS, TA and pH were not significantly different in all treatments as shown in Table 1. The previous research reported that UV-C has not directly affected the changes in TSS, TA and pH in orange juice (Koutchma, 2009; Tran & Farid, 2004). However, UV-C radiation can result in secondary reactions or have an impact on microbes that over time could indirectly alter TSS, TA and pH.

Table 4.1 Effect of UV-C irradiation on the Physical and Chemical Quality of fresh-cut 'Phulae' Pineapple during storage

Treatment	Days	L*	a*	b*	TSS	TA	pH
T1	0	63.89±0.10*	4.70±0.11*	49.22±0.77*	13.33±2.30*	0.88±0.00*	3.85±0.44*
T2		63.70±0.00*	4.37±0.23*	49.43±0.34*	13.46±2.60*	0.92±0.21*	3.89±0.32*
T3		63.65±0.23*	4.68±0.34*	51.12±0.45*	13.63±3.40*	0.94±0.12*	3.88±0.34*
T4		62.99±0.20*	4.35±0.77*	48.95±0.66*	14.16±3.30*	1.01±0.33*	3.86±0.33*
T5		60.44±0.30*	3.61±0.56*	44.9±0.57*	13.93±2.90*	0.97±0.33*	3.82±0.22*
T1	2	59.59±0.44*	3.79±0.55*	43.24±0.55*	13.96±2.70*	0.86±0.11*	2.64±0.22*
T2		56.00±0.09*	3.90±0.78*	41.00±0.78*	12.76±1.20*	0.84±0.00*	3.56±0.33*
T3		56.09±0.30*	3.90±0.44*	41.43±0.76*	12.90±1.30*	0.88±0.00*	3.67±0.31*
T4		57.38±0.20*	4.45±0.55*	42.12±0.44*	12.90±1.90*	0.93±0.08*	2.66±0.11*
T5		56.72±0.12*	3.88±0.23*	41.13±0.55*	13.40±3.20*	0.92±0.12*	2.60±0.00*
T1	4	59.37±0.23*	3.01±0.34*	41.48±0.54*	12.63±3.60*	0.96±0.11*	3.58±0.23*
T2		59.89±0.21*	3.01±0.33*	46.84±0.77*	12.36±2.80*	1.14±0.32*	3.50±0.22*
T3		59.67±0.98*	3.78±0.45*	40.98±0.98*	12.30±1.40*	1.16±0.33*	3.46±0.23*
T4		55.48±0.12*	3.02±0.44*	40.82±0.01*	12.90±2.10*	1.12±0.34*	3.65±0.34*
T5		59.6±0.09*	2.31±0.55*	40.82±0.31*	13.00±2.90*	1.04±0.33*	3.43±0.55*
T1	6	56.07±0.12*	3.46±0.11*	42.43±0.66*	12.53±0.77*	0.95±0.33*	3.55±0.65*
T2		61.09±0.23*	3.66±0.21*	45.66±0.34*	12.86±1.20*	0.84±0.21*	3.73±0.34*
T3		58.00±0.78*	4.51±0.33*	44.29±0.77*	12.50±0.55*	0.80±0.22*	3.27±0.55*
T4		56.02±0.45*	4.51±0.45*	42.00±0.67*	12.40±1.22*	0.94±0.20*	3.57±0.77*
T5		53.32±0.12*	2.29±0.09*	39.20±0.66*	12.86±2.67*	0.97±0.12*	3.43±0.45*
T1	8	51.06±0.23*	3.60±0.80*	41.26±0.32*	12.60±2.40*	0.87±0.22*	3.73±0.98*

Table 4.1 (continued)

Treatment	Days	L*	a*	b*	TSS	TA	pH
T2		62.09±0.55*	3.74±0.07*	42.29±0.44*	12.50±1.40*	0.89±0.25*	3.57±0.77*
T3		54.85±0.45*	3.75±0.87*	43.53±0.77*	11.53±0.88*	0.98±0.00*	3.70±0.34*
T4		52.29±0.34*	3.15±0.66*	38.60±0.34*	12.80±0.9*	0.83±0.22*	3.81±0.44*
T5		52.04±0.33*	2.79±0.98*	38.58±0.33*	12.26±1.60*	0.91±0.00*	3.53±0.34*
T1	10	50.20±0.34*	2.74±0.56*	44.08±0.34*	10.93±2.30*	0.89±0.23*	3.86±0.33*
T2		56.63±0.23*	3.01±0.23*	43.06±0.45*	10.50±1.40*	0.88±0.22*	3.37±0.34*
T3		54.74±0.22*	2.64±0.55*	43.89±0.65*	10.63±1.56*	0.81±0.00*	3.43±0.66*
T4		52.56±0.25*	2.74±0.98*	42.74±0.77*	10.73±1.20*	0.82±0.21*	3.42±0.59*
T5		50.12±0.34*	2.15±0.34*	38.43±0.55*	11.50±0.55*	0.92±0.00*	3.33±0.33*
T1	12	48.23±0.23*	2.58±0.33*	45.63±0.02*	10.96±0.66*	0.82±0.10*	3.46±0.21*
T2		54.54±0.32*	3.08±0.65*	43.82±0.00*	9.96±0.90*	0.83±0.00*	3.37±0.12*
T3		52.21±0.32*	2.64±0.25*	44.17±0.21*	10.93±1.20*	0.72±0.22*	3.46±0.88*
T4		52.41±0.33*	2.34±0.00*	45.48±0.11*	11.03±0.67*	0.76±0.00*	3.55±0.10*
T5		50.02±0.32*	2.25±0.34*	40.53±0.33	10.20±0.45*	0.88±0.00*	2.67±0.23*
T1	14	45.96±0.33*	2.35±0.24*	50.17±0.34*	10.50±1.3*	0.90±0.0*	3.33±0.45*
T2		50.20±0.23*	2.71±0.33*	44.23±0.33*	9.86±0.89*	0.80±0.0*	3.25±0.20*
T3		50.42±0.33*	2.56±0.23*	45.92±0.60*	10.40±0.88*	0.79±0.01*	3.23±0.12*
T4		50.00±0.56*	2.49±0.87*	46.6±0.66*	11.06±0.9*	0.84±0.01*	3.56±0.21*
T5		50.12±0.39*	2.06±0.08*	43.03±0.76*	11.6±0.44*	0.80±0.00*	3.33±0.00*

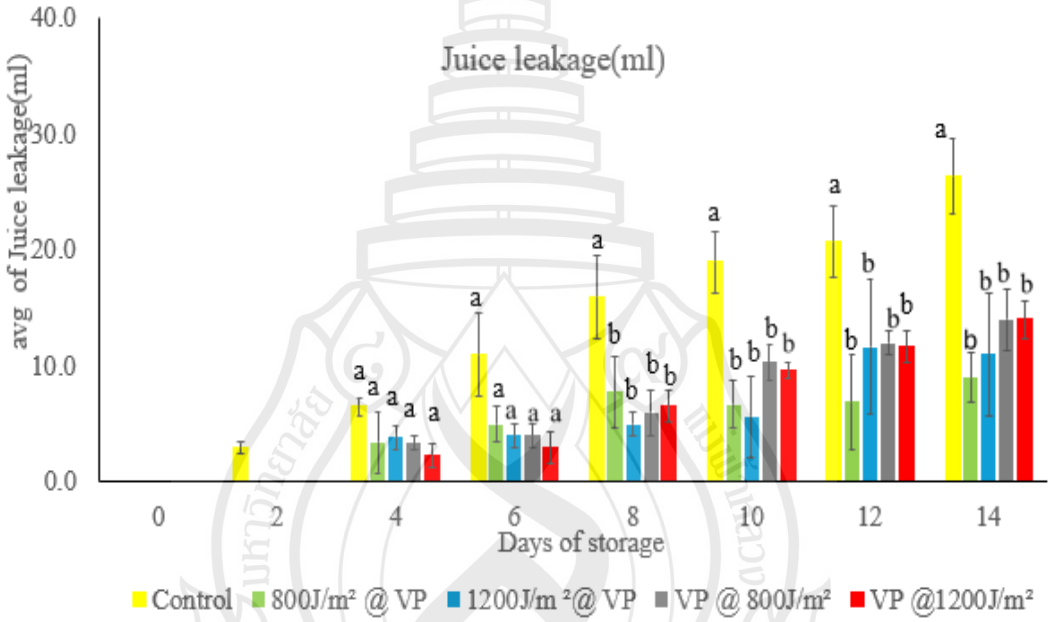
Note (*) meant non-significant and ±represented the Standard Deviation SD. T1=control, T2=UV-C(800J/m²) VP, T3=UV-C (1200J/m²) VP, T4=VP, UV-C (800J/m²), T5=VP, UV-C (1200J/m²)

In the control sample, it was observed that there was a slight increase in juice leakage during storage, from 0 mL to 26.33±3.21 mL per bag. According to Figure 4.1, all treatments showed significant differences from the untreated control. The data indicated that high irradiated samples (1200 J/m²) might offer better preservation over extended periods, though both treatments (800 J/m² and 1200 J/m²) were beneficial. Juice leakage became especially apparent over time in all groups, however, the treated group especially the high dosage of UV-C combined with the Vacuum package was better able to contain this leaking than the control group.

Firmness reduction may be attributed to the significant amount of juice leakage, especially in the control sample shown in Figure 4.2. During the 14 days of storage, the firmness of the control samples decreased significantly, from about 55 N to nearly zero. Firmness declines progressively in all groups as the storage period increases. The untreated control shows a more significant drop in firmness, possibly due to more rapid degradation processes such as moisture loss or enzymatic activity (Bu et al., 2013). In fresh-cut potatoes, Pelaić et al. found that higher UV-C dosages increased firmness, which they attributed to decreased activity of enzymes that break down cell walls. Maintaining fruit firmness and minimizing solution leakage are two important benefits of applying UV-C light. To maintain the fruit's structural integrity, the technique mainly entails inhibiting enzymes that break down cell walls. This promotes firmness and reduces cellular content loss, extending the fruit's shelf life and general quality while it is being stored.

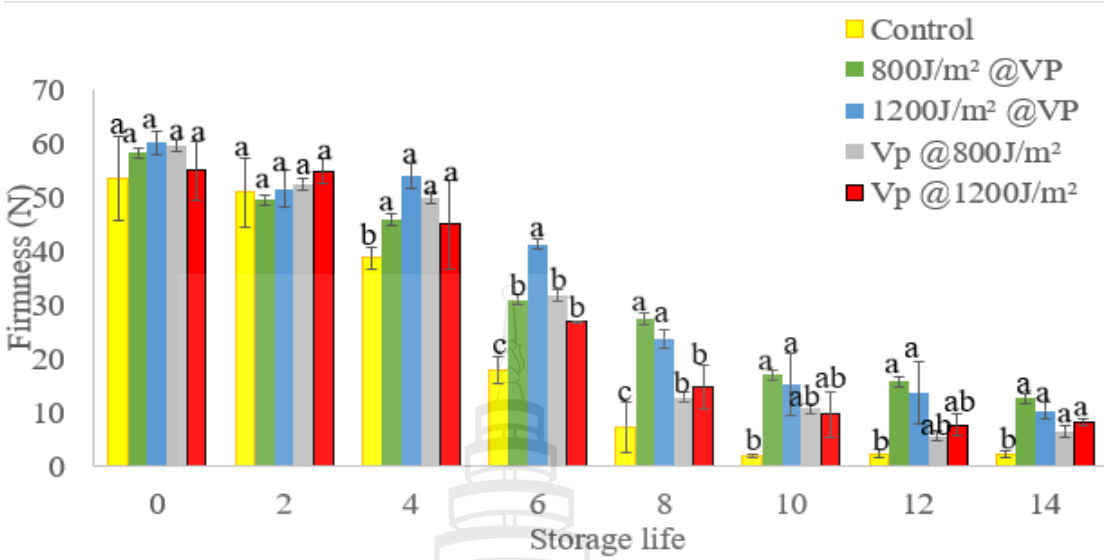
This study found that fresh-cut pineapples treated with UV-C maintained their firmness throughout storage than the untreated fruit. Early in the storage period, there was less of a difference in the firmness of the fresh-cut pineapples with radiation. The 800J/m² dosage before and after packaging treatment showed comparable changes, indicating that vacuum packing, combined with 800J/m² exposures, is useful for maintaining firmness. A dosage of 1200J/m² before packing treatment was superior to the control, indicating that increased radiation exposure helps preserve firmness, possibly by improving cellular structures or lowering microorganisms (Baligad et al., 2023). Because of the combined benefits of vacuum packaging and high UV-C dosage exposure, 1200J/m² before and after treatment showed the best results, keeping the most excellent firmness levels. Similar findings related to firmness in tomatoes have been

reported by (Liu et al., 1993). The decrease in enzyme activity associated with cell wall breakdown is one of the main ways that UV-C preserves firmness. Other studies supported these findings, showing that vacuum packaging greatly increases the shelf life and quality of foods stored by preventing microbial development and oxidation and maintaining the food's texture and firmness (Moradinezhad and Dorostkar, 2021). Similarly, fresh-cut potatoes treated with UV-C exhibited varying firmness retention depending on the irradiation dose, with higher doses correlating with increased firmness due to reduced enzyme activity (Ng et al., 2022; Pelaić et al., 2022).



Note Different letters represented significant differences (P< 0.05). The vertical bars means the Standard Deviation (SD).

Figure 4.1 Effect of UV-C Irradiation on Juice Leakage (mL) of Fresh-cut 'Phuale' Pineapple



Note Different letters represented significant differences (P< 0.05)

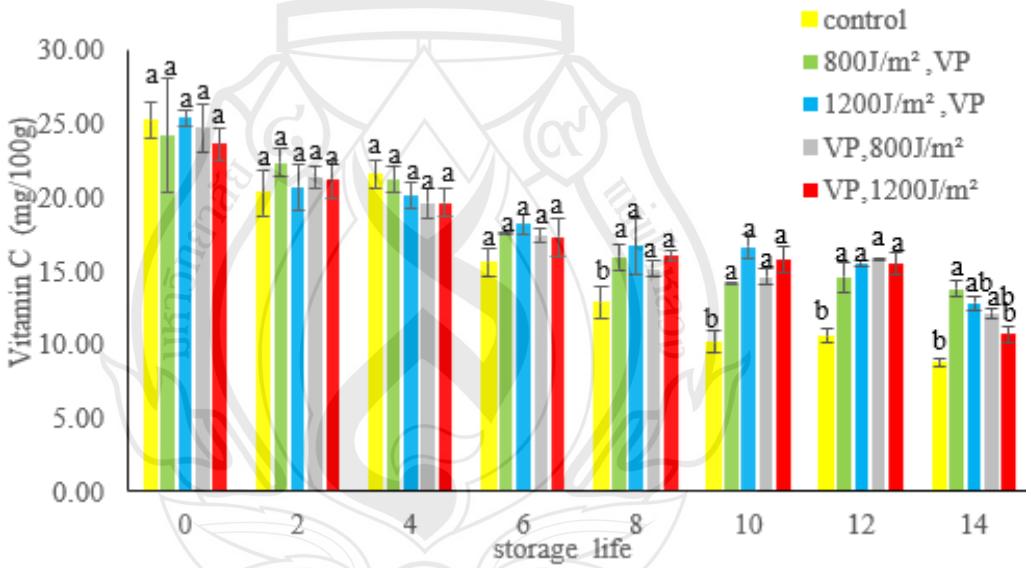
Figure 4.2 Effect of UV-C Irradiation on Firmness of Fresh-cut 'Phulae' Pineapples

4.1.2 Vitamin C Content of Fresh-cut 'Phulae' Pineapple

The level of Vitamin C in all treatments showed a slight decrease during the 14 days of the storage period observed in Figure 4.3. The control decreased from 30 mg/100g to 10.33 mg/100g during 14 days of storage. In comparison to the control group, the 800 J/m² and 1200 J/m² treatment groups exhibit better vitamin C retention at specific periods. The reduction of Vitamin C might be due to the cutting effect or temperature changes. Similar results were observed by Moradinezhad and Dorostkar (2021), Pan and Zu (2012). It showed that the level of vitamin C decreased as the storage period increased. The light exposure caused a slight decrease in the level of vitamin C within four days after the treatments were exposed to the sample. The reduction in Vitamin C may be due to a breakdown in light, temperature, and cutting or blending.

Moreover, the minimal process could induce nutrient loss, especially vitamins (Gil et al., 2006). High UV-C doses (1200 J/m²) appear to retain more vitamin C than lower doses (800 J/m²) over time. That means UV-C cannot significantly affect vitamin C levels during the long storage period. After 14 days of storage, the control declined below 10% Vitamin C level from the initial day of storage. However, the combined treatments provided the most effective preservation, maintaining Vitamin C levels

above 25 mg/100 g even by Day 14. Other research showed that the fresh-cut pineapples treated with UV-C only maintained 25% of their vitamin C level (Pan and Zu, 2012) during 12 days of storage. The storage temperature is critical for maintaining vitamin - C levels in fresh-cut pineapples. Supapvanich and Techavuthiporn 2022 observed that ascorbic acid content is greatly preserved during short-term storage when cold storage is kept at 4 ° in pineapple. The longer the storage time, the more vitamin C levels decline. The oxidative stress caused by UV-C treatment, which is useful in lowering microbial burdens but may also hasten the breakdown of delicate substances like ascorbic acid, is responsible for reduced vitamin C levels (George et al., 2015). Liao et al. (2023) suggested that the combination of UV-C treatment and modified atmosphere packaging could help maintain quality but still observed a decline in vitamin C levels during storage.



Note Different letters represented significant differences (P< 0.05).

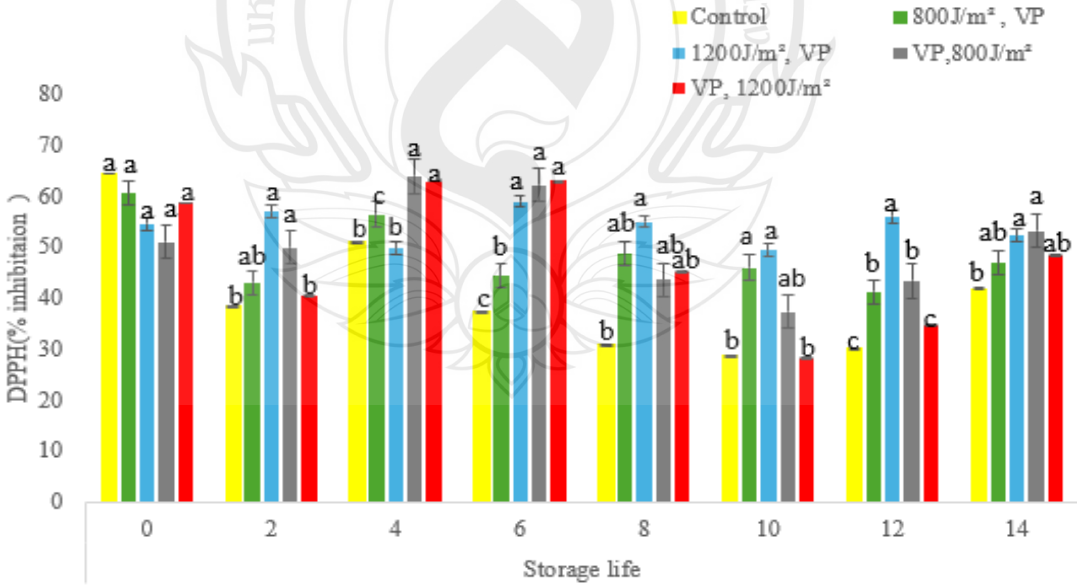
Figure 4.3 Effect of UV-C Irradiation on Vitamin C Content of Fresh-cut 'Phulae' Pineapple

4.1.3 Antioxidant Activity in Fresh cut 'Phulae' Pineapples

The percentage of DPPH inhibition in control decreased over time, from 64.34% on day 0 to 45.88% on day 14. These results showed antioxidant activity is gradually declining, as can be expected when fruit spoils and loses its nutritional value. In addition, the antioxidant activity of UV-C (800J/m^2 and 1200J/m^2) treated sample

before and after packing was significantly (P< 0.05) different from the control, and it exhibited a slower rate of decline in DPPH activity.

The 1200J/m², VP first exhibited a slight increase in DPPH inhibition (54.14%). However, it is still less than the 800 J/m² treatment on the first day of storage. Moreover, the antioxidant activity remains more stable over the 14-day storage period, ending with a higher inhibition percentage than the control or 800 J/m². High doses tended to result in greater antioxidant activity, although there were some exceptions. Conversely, the combination of vacuum packaging with UV-C at 800 J/m² and 1200 J/m² produced the highest initial values of antioxidant activity and more consistent inhibition percentages. This suggests that vacuum packing and UV-C irradiation combined can greatly extend the antioxidant qualities of fresh-cut pineapple's shelf life. The method most likely involves blocking oxidative reactions that cause the fruit's antioxidant chemicals to deteriorate. Previous research has shown a similar effect in fruits like strawberries and blueberries, where UV-C treatment can maintain antioxidant properties.(Li MeiLin et al., 2019; Pérez-Lavalle et al., 2020).Rivera-Pastrana et al. observed that UV-C irradiation led to an increase in bioactive compounds and radical scavenging activity in papaya fruit, reinforcing the idea that UV-C can stimulate the production of antioxidants that effectively neutralize DPPH radical (Rivera-Pastrana et al., 2014).



Note Different letters represented Significant differences (P < 0.05)

Figure 4.4 Effect of UV-C Irradiation on Antioxidant Activity (DPPH) Inhibition of Fresh-cut ‘Phulae’ Pineapple

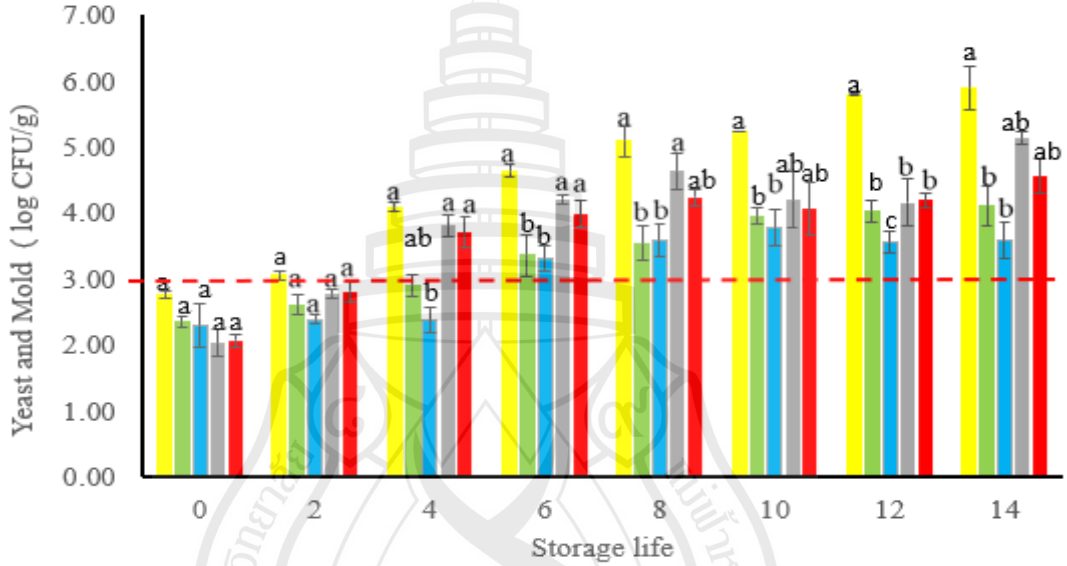
4.1.4 UV-C Irradiation on Microbial Quality of Fresh-cut 'Phulae' Pineapple

One major issue with food safety and quality is the microbiological deterioration of fresh-cut pineapple, especially concerning yeast and mold. The yeast and mold count in both the treated and control samples were relatively comparable, indicating a similar baseline of microbial growth across all treatments on the first day of storage. The yeast and mold levels increased consistently across all treatments, reaching around day 10. The yeast and mold count in the control group was 5.90 ± 0.01 log CFU/g, while the other treatments (800 J/m² and 1200 J/m^2) recorded approximately 4 log CFU/g both before and after vacuum packaging over a 14-day storage period. All treatments conformed to the standard, despite the controls exceeding it.

Due to their high moisture content and nutrient-rich environment, which provides the ideal conditions for microbial development, fresh-cut pineapples are extremely highly susceptible to microbial contamination. Applying a high dosage of UV-C treatment (1200 J/m²) before and after packaging resulted in the most substantial reductions in microbial growth relative to the control by day 14. The direct exposure of fruit enhances the irradiation effect on surfaces where microbial contamination frequently occurs, thereby increasing the efficiency of UV-C treatment (George et al.,2015, Suthiluk et al., 2023). Intensive calibration of UV-C dosage and exposure time is essential to optimize benefits and reduce adverse effects on the fruit.

The Total Plate Count (TPC) of fresh-cut pineapple in the control sample was 5.70±0.33 log CFU/g, while it was 4.57±0.26 log CFU/g in the 800 J/m² irradiated sample before it was packed. Samples treated with 1200 J/m² before packing demonstrated lower TPC values, particularly at early time points (Days 2, 4, and 6). This indicates that the higher intensity treatment (1200 J/m², VP) consistently exhibits a more indicated inhibitory effect on microbial growth than the lower intensity treatment (800 J/m², VP). Direct exposure to UV-C treatment demonstrated greater efficacy compared to the treatment applied post-packaging, as observed in Figure 4.6. For microbial quality, after 14 days of storage, the higher dosage of UV-C treatment (1200 J/m²) before packing resulted in the lowest count among the treatments 4.10 Log CFU/g which was below the National Department of Medical Sciences' microbial count safety. According to the result,1200J/m² before packaging was used in

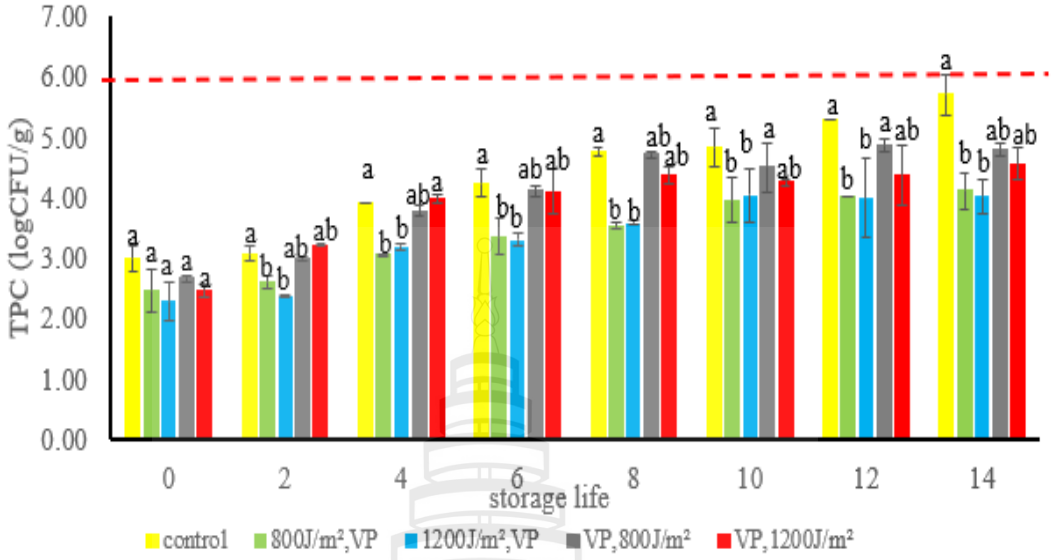
the transportation conditions and the 1200 J/m^2 before packaging was by 2 log CFU/g microbial reduction to the control. The reduction is caused by the fact that UV-C light can damage microbial DNA, causing cell death and inhibiting replication (Mansor et al., 2014). Similar results suggested that, depending on the fruit variety and treatment conditions, UV-C treatment had been able to achieve reductions in microbial counts ranging from 1 to 2 logs (90% to 99% reduction (Baligad et al., 2023; Collado et al., 2020; Lv et al., 2023).



Note Different letters at each storage period showed differences at P< 0.05

(---) represented the standard of Safety level (< 3 log CFU/g).

Figure 4.5 Yeast and Mold (log CFU/g) in Fresh-cut 'Phulae' Pineapple for 14 Days



Note Different letters at each storage period showed differences at $P < 0.05$

(---) represented the Standard of Safety level (< 3 log CFU/g)

Figure 4.6 Total Plate Count (log CFU/g) in Fresh-cut 'Phulae' Pineapple for 14 Days

4.2 Quality Changes of UV-C Treated Sample with a Partial Vacuum Package during Simulated Domestic Transportation

4.2.1 Physical and Chemical Quality Changes of UV- C Treated Sample with Partial Vacuum Packing during Simulate Domestic Transportation

One key factor to consider when analyzing quality is the consumer's desire, particularly when analyzing the appearance of ready-to-eat fruits. All samples were kept at 0-4°C for 24 hours, then packed in an ice foam box and kept at ambient temperature as a loading process. After loading, the samples were stored at 10-15°C. Sampling was done for quality determination at each step. For both early steps, the samples did not change because of the low temperature.

According to Figure 4.7, the differences between the control and the treated samples were observed clearly during 14 days of storage. The deterioration is more obvious, with additional color and vibrancy loss. At 14 days of storage, the control exhibits some visible browning, potentially indicating oxidation or microbial

multiplication. These enzymes cause phenolic compounds to oxidize, which creates brown pigments (Thu et al., 2017). After 6 days of storage, the control released gas inside the vacuum package and showed a pillowing appearance. Various factors, such as microorganism growth, gas production, fermentation, etc. can cause this phenomenon. However, samples that received UV-C treatment maintained good quality and still maintained vacuum conditions. UV-C treatment can maintain fruit quality.

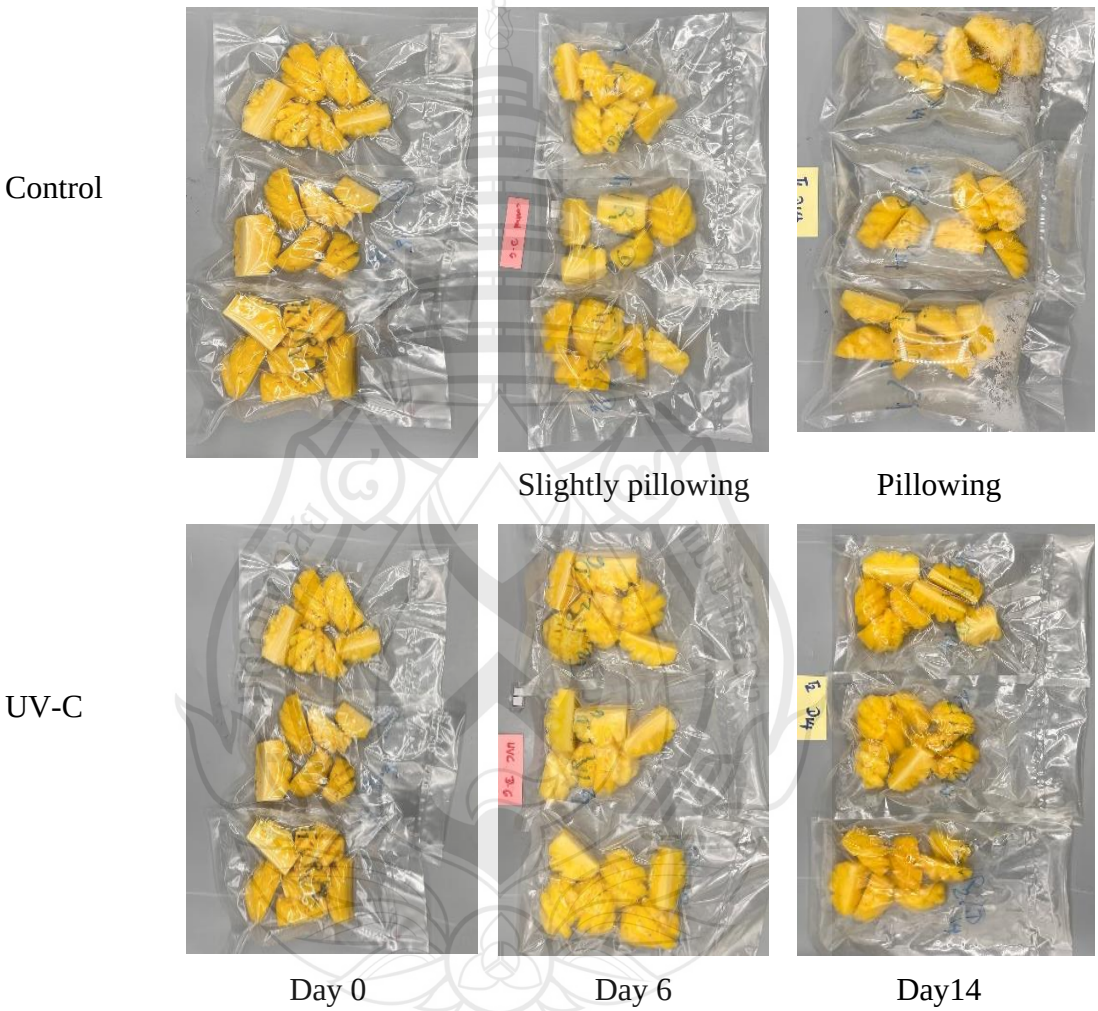


Figure 4.7 The Visual Appearances between Control and UV-C (1200J/m², VP) during Domestic Simulated Transportation

The L* value for the control group remained relatively stable throughout the storage duration, with only slight fluctuations. However, the samples exposed to 1200 J/m² generally maintained higher L* values than the control group, especially at the beginning and middle of the storage period. The decrease in L* value had a relationship

to carotenoid accumulation (Ali et al., 2011). Several studies have shown that applying UV-C treatment can prevent browning reactions and maintain the fresh-cut fruits' appeal. Fresh-cut 'Tommy Atkins' mangoes treated with UV-C had a more stable L* value in storage than untreated samples. The study indicated that UV-C irradiation inhibited the activity of polyphenol oxidase (PPO), an enzyme responsible for browning, thereby helping to maintain the brightness of the fruit (Garzón-García et al., 2023).

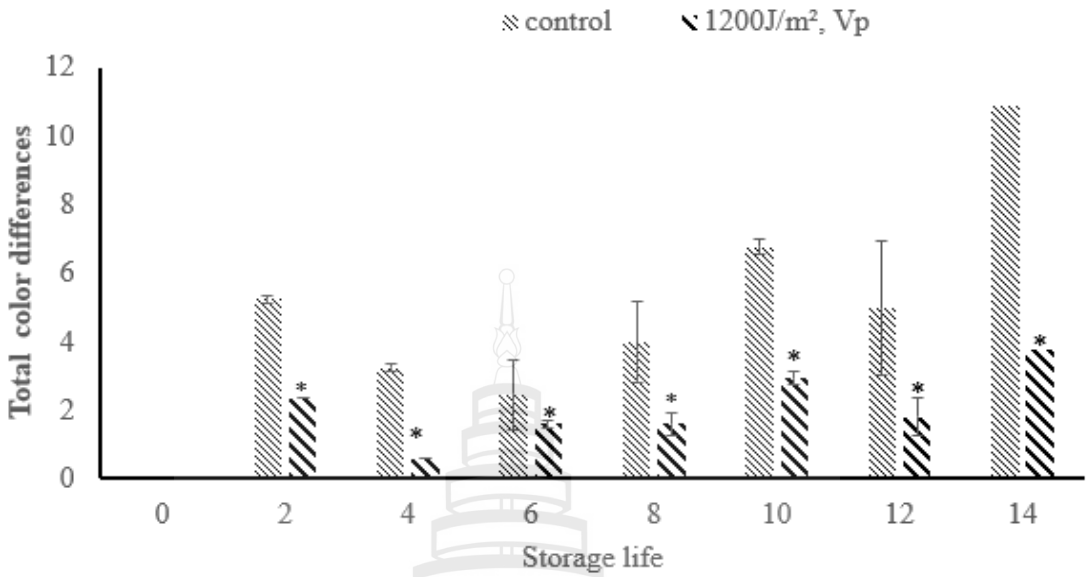
Nevertheless, both treatments in a* showed a significant decline towards the end of the storage duration. The value of a* in control was higher than in the treatments and for both control and treated samples, a* values decreased significantly during the storage period. Initially, the control group had higher a* values, but the result had changed by day 6, with the treated samples showing slightly higher a* values than the control. The b* values (44.8 to 29.88) in the control group decreased over time, with a substantial decrease occurring after 12 days of storage at 15 °C. Araújo et. al. suggest that storage conditions, including temperature, can influence the color attributes of fruits, even when treated with UV-C (Araujo et al., 2017).The relationship between temperature and duration of storage is important because it can make fruits that have been exposed to UV-C subsequently decrease in color. As a result, the treated samples exhibited more consistent b* values throughout time, with only slight changes. The decrease of a* and b* can lead to over-ripening, which can be caused by environmental factors such as temperature changes that may deteriorate the pigments on the fruit's surface.

Table 4.2 UV-C Irradiation on the Color (L*, a*, b*) of Fresh-cut 'Phulae' Pineapple During simulated Domestic Transportation

Treatment	Step	Days	L*	a*	b*
control	0-4°C	0	61.7 0±2.33	3.16±0.51	44.80±2.92
1200J/m², Vp			63.84±1.79	2.77±0.55	42.67±0.65
control	Ice	2	62.73±1.44	2.28±0.29	33.91±1.22
1200J/m², VP			62.89±1.49	2.65±0.38	37.38±1.74
control	10-15°C	4	61.38±2.05	2.06±0.76	36.85±2.15
1200J/m², VP			64.22±0.20	2.19±0.08	36.95±0.42
control		6	63.64±1.33	1.37±0.17	35.80±2.28
1200J/m², VP			64.1±1.16	1.89±0.50	37.82±0.88
control		8	52.40±2.54	1.36±0.57	30.01±2.74*
1200J/m², VP			61.22±1.63*	1.67±0.25	36.25±1.73
control		10	50.18±4.74	1.39±0.44	30.77±1.44*
1200J/m², VP			60.32±0.43*	1.58±0.00b	38.51±2.73
control		12	50.34±0.34	0.65±0.00	27.18±3.97
1200J/m², VP			60.41±1.96*	1.48±0.18*	36.39±2.09*
control		14	48.45±1.39	0.34±0.01	29.88±1.88
1200J/m², VP			57.70±2.84*	1.56±0.08*	37.90±0.28*

Note (*) mean significant difference P <0.05. Means ± Standard deviation (SD)

When determining the quality of fruits, particularly fresh-cut fruits, the consumer primarily focused on their color. The total differences Δ E showed that the control group had a significantly greater color difference than the treatment group in Figure 4.8. The results indicated that this treatment is beneficial in maintaining the color quality of the product. On 2 days, the control and 1200 J/m² with vacuum packing treatment were observed to have the most significant differences, and color differences in both groups decreased regarding time, but the treatment group continuously maintained a smaller difference, indicating a longer-lasting effect. Throughout the storage period, the 1200J/m^2 VP treatment consistently maintained a lower total color difference than the control group. The fact that the treated samples showed fewer color differences suggests that vacuum packaging is an effective method of preventing the oxidation and enzymatic browning processes that lead to discoloration (Denoya et al., 2015).



Note (*) indicated statistically significant changes between treatments at each storage time. Means ± Standard deviation (SD) n= (3)

Figure 4.8 Total Color Difference (ΔE) between Control and UV-C (1200J/m², VP) in Fresh-cut 'Phulae' Pineapple under Simulated Transportation

The value of TSS was not significantly different between the treatments and control in the initial days of storage. However, on the longer days of storage (12, 14), the data demonstrated significant changes, with the level of TSS in the control decreasing by 9.43% after 14 days of storage. UV-C may have secondary effects on ripening or fruit metabolism, potentially leading to changes in sugar concentration over time (Lingegowdaru, 2007). The titratable acid (TA) increased in both treatments along the long storage duration. The level of TA in the control increased by almost 2% during the 14 days of storage, and in the treated sample was lower than in the control. A similar result showed that TA always increased, accompanied by an ascending trend of the microbe by Zu et al., 2009.

In the first stage of transportation, the pH of the control and 1200 J/m², VP treated samples was similar, at about 4.0 – 4.2. There was no significant difference between them; both treatments showed a consistent pH during ice storage. Both treatments in pH levels remain constant, showing no significant drop or rise. After transferring the samples from ice boxes to high temperatures between 10 - 15 °C, the

pH of the control group gradually decreased, especially starting on day 8. By day 14, the control samples had a significant pH decrease. The decrease in the pH level in the control group demonstrated that microorganisms converted the fruit's sugar level into organic acids like lactic or acetic acid through the fermentation process. Changes in the pH value throughout the time of storage could be associated with the development of microorganisms and the consequent production of organic acids (Heard, 2002).

On the other hand, in 1200 J/m², VP-treated samples, the pH decreased less gradually by day 10, indicating a more stable pH over time. Nevertheless, the pH was still higher than the control by days 12 and 14, and the difference was still substantial. The control group of pH decreased more quickly after shifting from ice boxes to 10 - 15°C, likely due to increased microbial activity or enzymatic processes. Greater resistance to this pH change is demonstrated by the treatment group, suggesting that the applied treatment decreases the negative effects of higher storage temperatures on product stability According to the pH data, the fermentation process started after one week of storage time. These results are consistent with previous studies, which have demonstrated that UV-C irradiation impacts the physicochemical properties of food products, possibly due to its effects on metabolic pathways and enzyme activity. The observed changes in these quality attributes have important implications for applying UV-C therapy in food processing, particularly in increasing sensory aspects or extending the shelf life for certain product

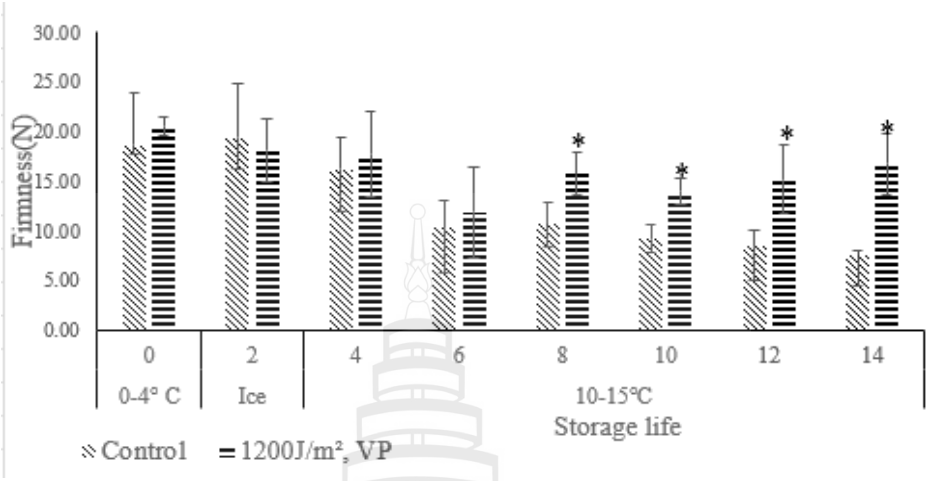
Table 4.3 Effect of UV-C irradiation on TSS, TA and pH under Simulated Transport Conditions

Treat	parameter	0-4 °C	Ice	10-15°C					
		0	2	4	6	8	10	12	14
Control	TSS(Brix°)	15.03±0.50	14.2±0.24	13.50±0.57	14.03±0.65	14.50±0.37	10.07±0.50*	8.23±0.56*	9.43±0.65*
1200Jm², VP		14.76±0.25	14.2±0.17	13.66±0.98	14.40±0.31	13.73±0.45	13.03±0.45	12.26±0.85	12.93±0.42
Control	TA (%)	1.23±0.49	1.46±0.56	1.20±0.15	1.35±0.44	1.20±0.20	1.35±0.59*	1.74±0.11*	1.83±0.20*
1200Jm², VP		1.05±0.17	1.02±0.24	1.15±0.22	1.05±0.20	1.16±0.11	1.02±0.01	1.09±0.06	1.13±0.12
Control	pH	4.03±0.10	4.04±0.30	3.89±0.24	4.02±0.21	3.94±0.23	3.14±0.33*	2.50±0.23*	2.10±0.32*
1200Jm², VP		4.05±1.23	3.96±0.18	4.12±0.50	4.17±0.28	4.19±0.19	4.03±0.15	3.98±0.10	4.26±0.12

Note Means ± Standard deviation (SD) n= (3). (*) represented significantly at $P < 0.05$.

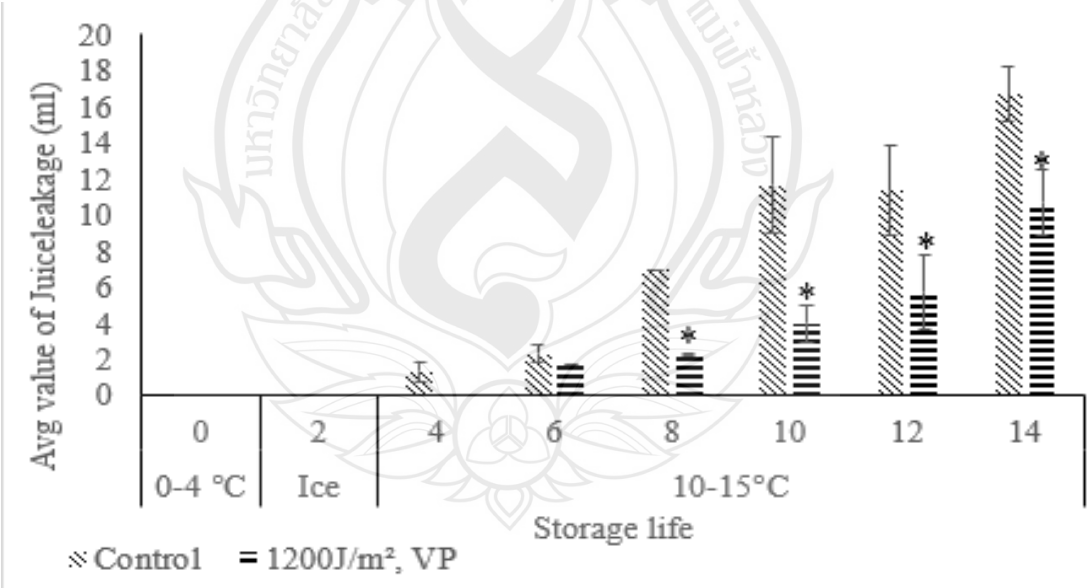
According to Figure 4.9, Firmness decreased along the storage during the transportation step. For the first step of transportation at 0 - 4 °C, both treatments did not show significant differences in firmness. In fruits, vegetables, and other perishable foods, lower temperatures can slow down biological reactions including enzyme activities and respiration rates (Quyen et al., 2013). However, when the temperature shifted (10-15° C), the firmness in the control samples started to decline, whereas the treated samples maintained higher firmness levels, showing that the treatment likely offers protection or delay against the loss of firmness at higher temperatures. By day 14, the firmness of the treated group is significantly higher than that of the control group, with the control group showing the most degradation. In the control samples, faster firmness loss can be attributed to higher microbial activity, which accelerates enzymatic degradation of cell wall components. Anaerobic conditions may have further favored spoilage microorganisms, hastening tissue softening.

Juice leakage is a crucial indicator of food products' freshness and quality, especially in fruits, vegetables, and meats. Excessive JL is often associated with texture loss and microbial spoilage, negatively affecting consumer perception and product marketability. There was no JL for both treatments in the early step. During the initial steps (0-4°C), the cold temperature alone had to be sufficient to prevent significant JL. Lower temperatures (0–4°C) suggest that temperature is an important element in delaying the breakdown of cell walls. JL began after 4 days of storage at the high temperature observed in Figure 4.10. JL in the control samples increased rapidly beginning on day 10, reaching its maximum levels every day. On the other hand, the treated samples exhibited less juice loss; the differences were statistically significant starting on day 8. On day 14, there was around 18 mL of JL in the control, but only about 10 mL in the treatment, a considerable drop. In the control group tissue softness probably resulted in more cell wall disintegration, which enhanced liquid release.



Note * represented significant differences ($P < 0.05$). The data means n= (3) replication and the vertical bars represent a Standard Deviation (SD).

Figure 4.9 Effect of UV-C radiation on Firmness in Fresh-cut 'Phulae' Pineapple under Simulated Domestic Transportation



Note * represented significant differences ($P< 0.05$). The vertical bars represented a Standard deviation (SD).

Figure 4.10 Effect of UV-C Irradiation on Juice Leakage (mL) in Fresh-cut 'Phulae' Pineapple under Simulated Domestic Transportation

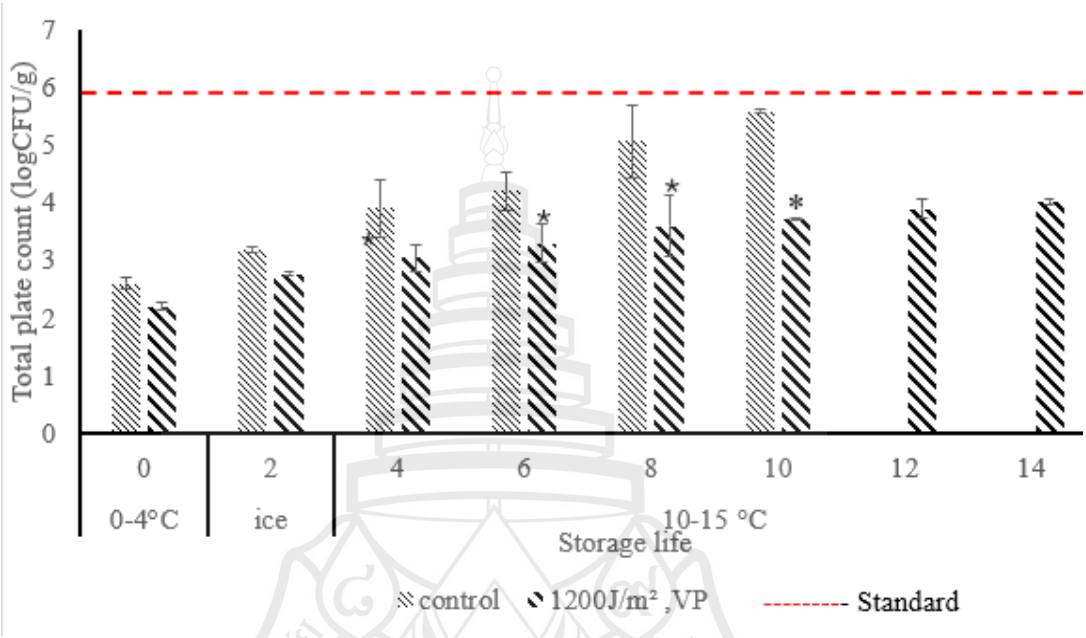
4.2.2 Effect of UV-C Irradiation on the Microbial Population under Simulated Domestic Transportation

Similar microbial counts are seen in both the control and treated samples, suggesting that the starting count of bacteria remains consistent during treatments. The microbial growth is slightly higher in the control samples compared to UV-treated samples, showing a potential inhibitory effect of UV treatment. After 6 days of storage at 10-15 ℃, statistical analysis under transportation conditions showed a significant difference in the microbial populations on 1200J/m² before packaging the UV-C-treated sample and controls shown in Figure 4.11. The control samples show a steeper increase in microbial load at high storage temperatures (10–15°C), emphasizing the importance of maintaining lower temperatures during storage to inhibit spoilage. After 10 days of storage, the control reached the standard level of safety and the results showed that the control had gas inside the package, and a fermented odor was observed. However, the treated sample was still under the safety level, reaching 4.4 log CFU/g during 14 days of storage. The TPC was higher than the irradiated sample with 2 log CFU/g. Other Studies have demonstrated that UV-C irradiation can achieve a 2-log reduction in total viable counts of microorganisms, including bacteria, yeasts and molds, during storage (George et al., 2015; Hinojosa et al., 2013).

Under cold storage conditions (0–4°C and ice boxes), the treatment had no apparent effect on microbial counts in days (0, 2, 4). However, the treatment's ability to inhibit microbial growth increases as storage conditions rise to higher temperatures (10–15 °C). Other research showed that the microbial population developed with temperature and that 5°C was the national acceptance threshold level above other temperatures (Quyen et al., 2013; Sari et al., 2016).

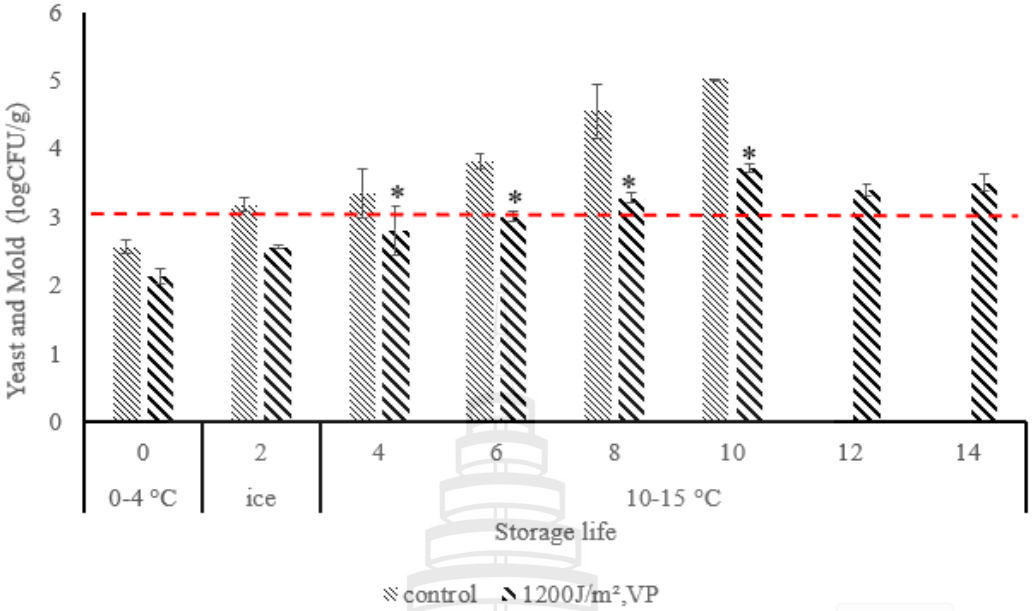
The control and treated samples had relatively low starting yeast and mold counts (around 2–3 log CFU/g) throughout storage (0–4°C). However, the temperature shift to 10-15°C likely accelerated microbial growth, with the control group showing higher counts, reaching nearly 5 log CFU/g on day 8. The relationship between temperature and UV-C treatment is curious. UV-C, while effective at low temperatures, enhances microbial inactivation when combined with other preservation techniques

such as low heat or high-pressure processing. The control group experienced a sharp increase in microbial counts after day 8, reaching a peak of nearly 5 CFU/g by day 10, and continuing to maintain higher levels until day 14. The high amount of yeast and mold can cause off-odor and fermentation in samples. Thu et al., 2017).



Note *showed differences at P<0.05. The vertical bars mean standard deviation (SD). (---) represented the Standard of Safety level (< 3 log CFU/g).

Figure 4.11 Total Plate Count (log CFU/g) in Fresh-cut 'Phulae' Pineapple under the Simulated Domestic Transportation



Note *showed significant differences at P<0.05. The vertical bars mean the Standard deviation (SD).

(---) represented the Standard of Safety level (< 3 log CFU/g).

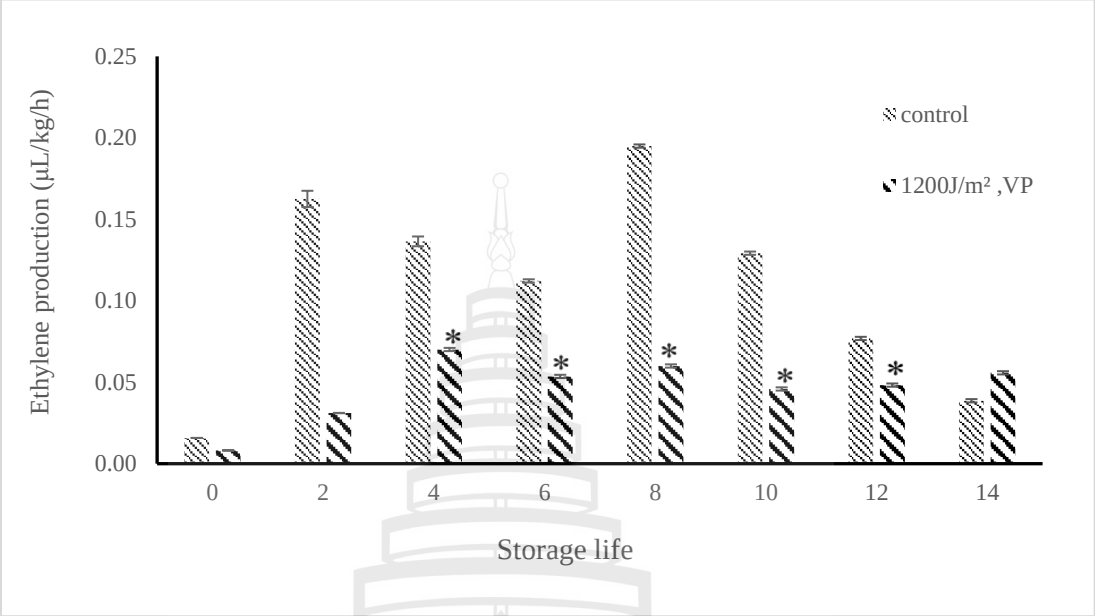
Figure 4.12 Yeast and Mold (log CFU/g) of Fresh-cut 'Phulae' Pineapple under the Simulated Domestic Transportation

4.2.3 Gas Composition in Package

Ethylene is a gaseous plant hormone that is crucial in regulating processes such as fruit ripening, leaf senescence, and abscission. On day 0, both treatments have negligible ethylene production, with no significant difference. Compared to the 1200 J/m², VP treated samples, the control consistently shows higher ethylene production from day 2 to day 8. On day 2, the increase in the production of ethylene for control most likely represented a physiological reaction to stress, damage, or metabolic adjustment that occurs immediately, however, was gradually minimized in treated samples by the inhibitory effects of VP and UV-C. The treated samples indicate significantly reduced ethylene production than the control, which peaks around day 8. This suggests that the treatments effectively suppressed ethylene biosynthesis mechanisms by reducing stress signaling or modulating enzymatic activity. Day 8 ethylene production in control samples corresponds with rapid ripening and possible senescence, which results in a decline in quality. This corresponds with the established trend of climacteric fruits when ethylene levels increased with the ripening process (Chen et al., 2007; Saltveit, 1999).

After day 8 of both treatments' ethylene production began to decrease, suggesting that the ripening process was close to completion. However, on days 10, 12, and 14, the control group still exhibits significantly higher ethylene levels than the treated samples shown in Figure 4.13. The 1200 J/m², VP treatment has been shown to delay the ripening process and extend the product's shelf life by decreasing ethylene production. Other studies observed that UV-C treatment can slow down the production of ethylene, a plant hormone that regulates fruit ripening (Bu et al., 2013; Tiecher et al., 2013). By slowing down ethylene production, UV-C helps delay ripening, which helps keep the fruit firm and fresh for a longer time (Cote et al., 2013; East et al., 2009). The increase of ethylene can be slowed down by low temperatures. Fruit storage at a lower temperature causes a slowdown in the enzymatic processes that lead to the synthesis of ethylene (Bu et al., 2013). The accumulation of ethylene response factor (ERF) transcripts in tomato fruits is altered by UV-C radiation, indicating that UV-C may modify the ethylene signalling pathways and perhaps impact ethylene output (Severo et al., 2015). UV-C treatment has a significant impact on ethylene production in fresh-cut fruits, generally leading to a reduction in ethylene levels, which is beneficial for

extending shelf life and maintaining quality (Kaya & Unluturk, 2019; Pristijono et al., 2017).



Note * showed a significant difference at $P < 0.05$ and the vertical bar represented the Standard deviation (SD).

Figure 4.13 Ethylene Production (µL/kg/h) for both control and UV-C (1200J/m², for 14 Days

Under closed-system conditions, changes in concentration cause the O_2 to decrease and the CO_2 to rise steadily for a certain period. Figures 4.12 a and b present the gas concentrations (%) inside the package for control and treatment during storage. For the control, O_2 levels started around 10 %, then rapidly decreased by the second day and stayed close to 0% afterwards, and then CO_2 (%) gradually increased from day 0 to 14 days, as shown in Figure 4.14.

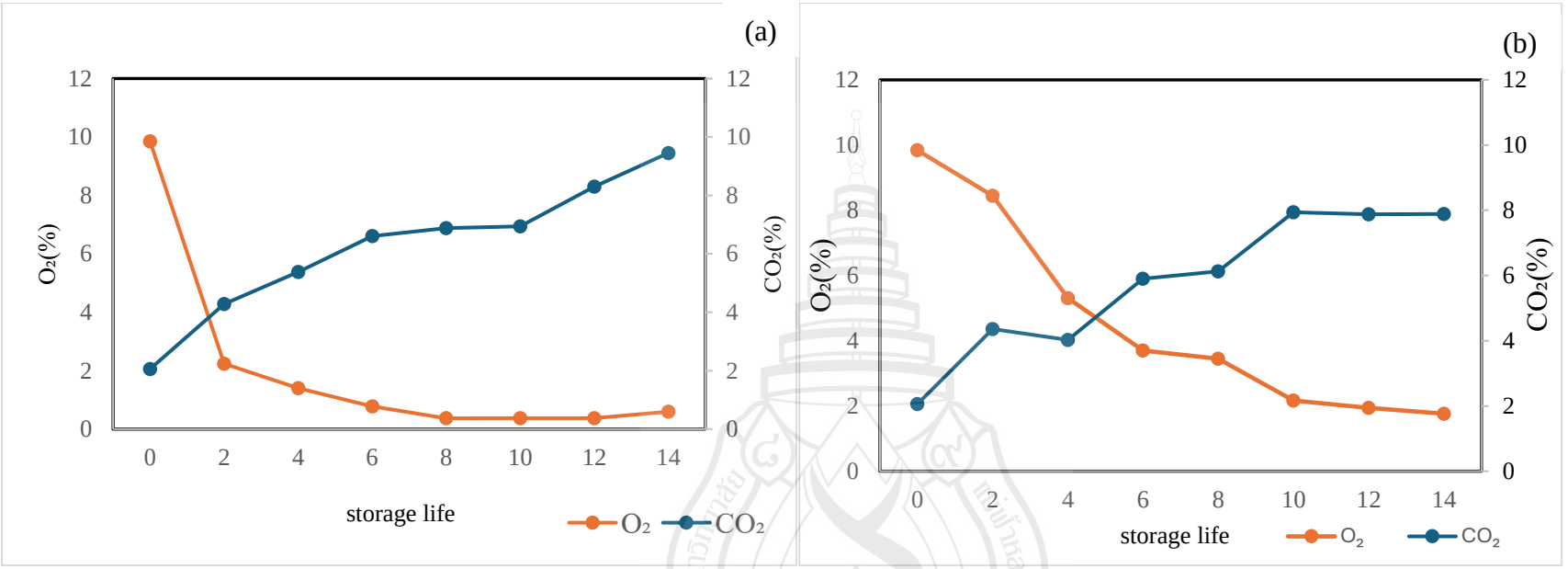
The sharp decline in O_2 levels during the first 4 days indicates high respiratory activity, likely driven by enzymatic reactions and microbial metabolism. This aligns with fresh-cut produce's natural response to wounding during preparation, which often stimulates respiration and ethylene production. The associated increase in CO_2 indicates active respiration, which is the aerobic metabolism of carbohydrates. The increased level of CO_2 for control is due to the metabolic activity of the spoilage bacteria This could indicate a higher level of metabolic activity (either from the product or microbial

growth) in the control condition. The control group showed a faster change to low oxygen levels, which produced an anaerobic or microaerobic environment that was favorable for mold and yeast and other spoiling microbes. The organisms could lead to fermentation, accelerating product degradation and reducing sensory quality (Hansen et al., 2016; Tsironi et al., 2019).

Compared to the control, the CO_2 accumulation decreased by the 1200 J/m², VP treatment, as seen in Figure 4.14 b. The lower CO_2 (%) increase may indicate that the treatment can reduce metabolic respiration or prevent the growth of microorganisms. The difference in CO_2 accumulation(%) may significantly affect the shelf life and the avoidance of spoiling because excessive CO_2 building can affect the quality of the product by causing fresh fruit or vegetables or food products an off-flavor or an unpleasant odor. Techavuthiporn et al.(2017) was suggested that fresh-cut ‘Phulae' pineapples had a 12-day storage life at 5°C in a modified environment of 2% O_2 and up to 17% CO_2. For fresh-cut products, the optimal gas composition typically consists of high CO_2 (5–10%) and low O_2 (about 1-5%). This combination effectively slows respiration, reduces spoilage, and maintains the overall quality of the produce during storage. For fresh-cut peppers, Barth et al. suggest a storage environment of 3% O_2 and 5–10% CO_2, indicating the significance of these levels in preserving quality.

Within the first two days, oxygen levels in the control significantly decreased, indicating that the stored environment quickly became anaerobic, as shown in Figure 4.14 (a). This is typical for situations where respiration uses oxygen or the microbe consumes oxygen. The oxygen level in the control decreased from its initial value of 10% gradually during the storage. Fresh-cut fruits have a high rate of respiration due to their large surface area and the metabolic acidity of an injured cell caused by cutting, which led to these results (Hansen et al., 2016; Waghmare and Annapure, 2013). By day 14, the oxygen content in control is almost zero percent (< 2%), resulting in an anaerobic or microaerobic environment. Fermentative microorganisms, such as molds and yeast, which are known to become successful in low-oxygen environments and produce bad tastes, may benefit from this. However, the slightly lower initial O_2 percentage in the treated condition could suggest an accelerated initial consumption or the need to seal the package to limit oxygen ingress. For treatment, Oxygen levels remained higher (5%) for most of the storage time, dropping more slowly than control.

Compared to the control, oxygen levels decline at a slower rate, indicating reduced metabolic activity potentially due to the inhibitory effects of UV-C on microbial and enzymatic respiration. The delayed respiration indicates that microbial activity has been reduced for a longer amount of time. UV-C helps maintain a higher oxygen environment by minimizing the initial microbial load, which probably delays the first signs of deterioration and improves quality retention.



Note Data represented two measurement values to produce CO_2 and consumption of O_2.

Figure 4.14 Consumption of O_2 (%) and Production of CO_2 (%) in fresh-cut 'Phuale' Pineapple (a) Control and (b) UV-C (1200J/m²), VP for 14 Days

4.2.4 Effect of UV-C Irradiation on Volatile Compound in Fresh-cut 'Phulae' Pineapple

The volatile compounds in fresh-cut pineapple play a crucial role in determining its aroma and overall sensory quality. Researchers have found that about 280 volatile compounds make up the aroma of pineapples, but only a small number of these volatiles primarily contribute to the aroma (Elss et al., 2005; Tokitomo et al., 2005). These are the most important chemicals: ethyl hexanoate, methyl butanoate, and 2,5-dimethyl-4-methoxy-3(2H)-furanone (Lasekan & Hussein, 2018). However, when subjected to improper storage conditions or microbial contamination, the balance of these compounds can shift, leading to the development of off-odors. To analyze volatile compounds, the GCMS, which is an appropriate technique for identifying the active ingredients found in fruits, vegetables, and plants, such as phytochemicals and fatty acids, was used.

The volatile compound in 'Phulae' pineapple' was shown in Table 4 with its retention time (RT), odor description, and area sum (%). The primary components of fragrance in 'Phulae' pineapple were also present, including hexanoic acid methyl ester, hexanoic acid ethyl ester, ocimene, butanoic acid, 2-methyl-, ethyl ester, butanoic acid, methyl ester, butanoic acid, 2-methyl-, methyl ester, octanoic acid, methyl ester, ethyl acetate, acetic acid, 1-Butanol, 3-methyl-, Octanoic acid ethyl ester and acrylic acid isoamyl ester. Fresh-cut 'Phulae' pineapple changed in flavor and odor after storage in relationship with the amount of specific volatile compounds. The high levels of 1,4-Dioxane, 2,3 dimethoxy, and 2-methylpropylacetate suggested more severe fermentation or spoiling during six days of storage for control.

Enzymatic and microbiological activity during fermentation or spoiling can create undesirable volatile compounds, such as certain alcohols and acids, that may impart a disagreeable smell(George et al., 2023; Pino, 2013). Ethanol and acetic acid, frequently linked to unpleasant fermentation aromas, can be produced when yeast or bacteria break down carbohydrates.(Benítez et al., 2014; Pino, 2013). An extremely strong concentration (2-methyl propyl acetate, 38.18) had a relationship to a smell of fermentation. An increase in esters like this after six days of storage can be a sign that fermentation or ripening processes are beginning. Depending on the food, this could result in the development of stronger fermented or overripe fruit characteristics in

samples that are stored, which could signal spoiling or deterioration. The presence of high concentrations of certain esters, such as ethyl acetate, can impart undesirable flavors, potentially spoiling the quality of the fermented product (Nguyen et al., 2019).

Moreover, the fermentation environment, including the composition of the medium, can influence the metabolic pathways of lactic acid bacteria which may switch from homofermentative to mixed-acid fermentation depending on the available nutrients (Alvarenga et al., 2015; Nguyen et al., 2019). The sample showed significant chemical changes after six days of storage, resulting in a rise in esters and other compounds that contribute to off-putting or unpleasant odors.

Ethyle acetate showed an increase (65.31%), which is a clear sign of fermentation. When concentrations become too high, this compound, which has pear-like aromas, takes on a more unpleasant, overripe fruit. The increase in ethyl acetate signifies the product's impending spoilage or exposure to fermentation-promoting conditions like microbial contamination or improper storage temperature (Saltveit, 1999). Trejo Araya et al. (2009) noted that even after 14 days of storage, raw carrots treated with HPP + vacuum packaging can remain free of fermentative metabolites like ethanol and acetic acid.

On day 12, the control treatment still exhibited fruity and sweet odors, along with some indications of fermentation and medicinal notes. Fruity esters like butanoic acid and 2-methyl ethyl ester decrease during UV-C treatment, whereas medicinal and slight chemical smells rise. This suggested that UV-C may amplify unpleasant or spoilage-related smells while decreasing fresh, fruity aromas. Ethyl acetate has a distinct pear-like or overripe fruit odor, and its high concentration (90%) during 14 days of storage indicates fermentation or microbial activity, which is a key factor in the degradation of stored samples. Ethyl acetate is commonly associated with the fermentation process.

The high levels of ethyl acetate and 2-methyl propyl acetate indicated the occurrence of fermentation or microbial spoilage, particularly in the control sample after 14 days of storage. Additionally, undesirable rancid and cheesy odors were caused by oxidative and rancid compounds such as pentatonic acid, 3-methyl-, and ethyl ester, indicating a clear degradation in the product's quality. Moreover, 3-bromo-2-naphthoic acid and oxirane, 3-butenyl, indicated the product had undergone oxidative reactions

during storage, further compromising its freshness. The presence of rancid compounds can also indicate the onset of spoilage, as they are often associated with the degradation of the quality of food products (Baroutian et al., 2012). Furthermore, during storage, the accumulation of volatile compounds like butyric acid and ethyl acetate can increase the rancidity of pineapples. Microbial activity or lipid oxidation typically produces these compounds, which can impart undesirable flavours often described as sour or rancid (Baroutian et al., 2012).

Table 4.4 ‘Phulae’ Pineapple Volatile Compounds and Odor Description

Day	Rt	Compound Name	Treatment		Odor Description
			Control	UV-C, VP	
0	3.89	Ocimene	2.45	3.66	Floral
	3.955	Butanoic acid, 2-methyl-, methyl ester	12.45	7.90	Sharp, sweet, green and apple
	17.017	Octanoic acid, ethyl ester	0.23	ND	Fruity, winey and musty
	6.987	Hexanoic acid, methyl ester	8.99	1.54	Apple peel-like, fruity
	8.567	Hexanoic acid, ethyl ester	0.09	ND	sweet, slightly woody, or chemical odor
2	2.694	3-amino-2,2-dimethyl-3-oxo-propanoic acid	62.51	69.1	sweet, slightly woody, or chemical odor
	3.87	Butanoic acid, 2-methyl-, methyl ester	5.94	6.38	Sharp, sweet, green and apple
	18.017	Octanoic acid, ethyl ester	0.16	ND	Fruit sweet like oranges
	11.03	3-Carene.	2.63	1.26	citrus
	5.575	Acrylic acid isoamyl ester.	0.8	1.91	strong fruity, sweet odor
	19.03	Aristolene	0.22	ND	Woody, sweet
	19.48	alpha. -Cubebene	0.56	0.26	Woody and spicy like herbal
	19.62	Decanoic acid, ethyl ester	0.27	ND	Sweet fruit and citrus
	9.062	Hexanoic acid, ethyl ester;	14.94	9.33	Sweet, alcoholic, fruity, waxy and green

Table 4.4 (continued)

Day	Rt	Compound Name	Treatment		Odor Description
			Control	UV-C, VP	
4	2.682	3-amino-2,2-dimethyl-3-oxo-propanoic acid;	87.86	84.78	slightly medicinal, distinctive
	2.682	3-amino-2,2-dimethyl-3-oxo-propanoic acid;	3.67	0.98	the slightly medicinal, distinctive smell
	4.100	Butanoic acid, 2-methyl-, methyl ester	2.94	2.74	Sharp, sweet, green and apple
	10.73	Bicyclo [3.1.1] hept-2-ene, 3,6,6-trimethyl-	0.33	0.19	pungent, earthy, and herbal odor
	19.47	alpha. -Cubebene	0.12	ND	woody, spicy, and balsamic
	5.053	Acrylic acid isoamyl ester	3.47	2.11	strong fruity, sweet odor
	5.594	Hexanoic acid, ethyl ester	1.47	2.4	Sweet, alcohol, fruity, waxy
	5.603	Acrylic acid isoamyl ester	3.47	2.59	strong fruity, sweet
6	2.144	3-amino-2,2-dimethyl-3-oxo-propanoic acid;	ns	91.15	the slightly medicinal, distinctive smell
	2.661	Butanoic acid,2methylethyl ester	4.53	2.59	Sharp, sweet, green and apple
	4.139	Acrylic acid isoamyl ester	3.4	2.36	strong fruity, sweet odor
	5.038	Hexanoic acid, ethyl ester	2.33	0.51	Sweet, alcoholic, fruity, waxy and green
	2.132	2-methyl propyl acetate -	38.18	ND	fermented
	2.691	1,4-Dioxane,	90.88	ND	sweet, ether-like odor
	21.64	Ethyl acetate	46.89	0.93	Pear or overripe fruit
	4.139	Methyl 1-Dideuterio-2-butenyl Ether	ND	2.43	sweet, fruity, and slightly herbal or spicy scent

Table 4.4 (continued)

Day	Rt	Compound Name	Treatment		Ord description
			Control	UV-C, VP	
8	2.150	4-Cyclopentene-1,3-diol	ns	95.16	slightly medicinal scent
	2.682	Hexanoic acid, ethyl ester	0.41	ND	slightly sweet, floral, or woody odor. Silicone-like
	2.132	Oxirane, 3-butenyl	ns	89.03	mild, slightly sweet, or chemical odor
	2.098	Ethyle acetate	65.31	2.39	Pear or overripe fruit
	2.336	Cycloheptane, methyl-	ND	2.15	slightly sweet, waxy, or chemical odor
	2.676	2-methyl propyl acetate	45.6	ND	fermented
	2.120	3-Bromo-2-naphthoic Acid	0.50	ND	mild, somewhat chemical or aromatic scent
	4.812	Butanoic acid, 2-methyl-, ethyl ester	4.57	ND	Sharp, sweet, green and apple
	5.41	Acrylic acid isoamyl ester	3.22	ND	strong fruity, sweet odour
10	2.676	3-amino-2,2-dimethyl-3-oxo-propanoic acid	92.17	ND	the slightly medicinal, distinctive smell
	4.142	Butanoic acid, butyl ester.	2.63	3.04	Sharp, sweet, green and apple
	5.578	Acrylic acid isoamyl ester.	3.19	3.27	fruity, sweet odor, banana or pear
	2.657	1,4-Dioxane, 2,3-dimethoxy-.	3.48	ND	sweet, slightly woody, or chemical odor
	22.196	. Ethyl acetate	92.02	0.6	Pear or overripe fruit
	2.162	2-methyl propyl acetate	4.89	ND	fermented
	9.077	Hexanoic acid, ethyl ester	ND	0.15	Sweet, alcoholic, fruity, waxy and green

Table 4.4 (continued)

Day	Rt	Compound Name	Treatment		Order description
			Control	UV-C, VP	
12	2.670	3-amino-2,2-dimethyl-3-oxo-propanoic acid	89.89	90.51	slightly medicinal, distinctive smell
	4.161	Methyl 1-Dideuterio-2-butenyl Ethe	0.11	ND	Slightly sweet, fruity, or chemical odor.
	5.044	Butanoic acid, 2-methyl-, ethyl ester	3.79	1.25	Sharp, sweet, green and apple
	5.374	Acrylic acid isoamyl ester	3.08	2.18	strong fruity, sweet odor
	9.083	Hexanoic acid, ethyl ester	0.16	0.47	Sweet, alcoholic, fruity, waxy and green
	23.16	2-methyl propyl acetate	0.11	ND	fermented
	16.93	Octanoic acid, ethyl ester;	0.15	ND	-
	2.129	3-Bromo-2-naphthoic Acid.	ND	1.14	medicinal, distinctive smell.
	2.657	1,4-Dioxane, 2,3dimethoxy	90.76	ND	sweet, slightly woody, or chemical odor
14	1.973	3-Bromo-2-naphthoic acid.	0.93	0.63	mild, aromatic, or slightly medicinal odors
	2.315	3-amino-2,2-dimethyl-3-oxo-propanoic acid	87.08	89.51	slightly medicinal, distinctive smell.
	3.733	Methyl 2-Methyl-2-propenyl-1-d2 Ether.	ND	2.73	mild, slightly sweet, or fruity odor,
	4.821	Butanoic acid, 2-methyl-, ethyl ester	1.86	3.58	Sharp, sweet, green and apple

Table 4.4 (continued)

Day	Rt	Compound Name	Treatment		Order description
			Control	UV-C, VP	
14	5.38	Acrylic acid isoamyl ester	2.33	3.43	fruity, sweet odor, banana or pear
	9.077	Pentatonic acid, 3-methyl-, ethyl ester	ns	0.13	rancid, sweaty, or cheesy
	2.107	Oxirane, 3-butenyl-	ns	10	mild, sweet, ether-like odor
	2.129	1,2-Dimethoxy-5,10-dihydroindeno[1,2-b] indole	0.81	ND	musty or slightly medicinal
	3.336	Formic acid, 2-methyl butyl ester.	7.4	ND	fruity, pleasant odor apple or pear-like scents
	9.031	2-methyl propyl acetate	0.12	ND	fermented
	16.935	Octanoic acid, ethyl ester	0.21	ND	Fruity, citrus-like
	2.67	Ethyl acetate	94.42	ND	Pear or over-ripe fruit
	2098	3-Bromo-2-naphthoic Acid	0.93	ND	slightly medicinal, distinctive smell.

Note ND means absent, and RT means retention time.

CHAPTER 5

CONCLUSIONS

The results demonstrate that UV-C treatment effectively delays fruit ripening and maintains the freshness of fresh-cut ‘Phulae’ pineapples over prolonged storage. UV-C light markedly diminished firmness loss and juice leakage while also lowering microbial populations, including bacteria, yeast, and mold. A dosage of 1200 J/m² applied before packaging showed the most pronounced impact on microbial reduction, fruit firmness, and enhancement of antioxidant activity. Significantly, elevated UV-C exposures (1200 J/m²) before packaging were associated with enhanced fruit quality. Furthermore, direct exposure to UV-C at 800 and 1200 J/m² before packaging showed greater efficacy than UV-C treatment administered post-packaging.

During the stimulation for domestic transportation, the UV-C treatment at 1200 J/m² before vacuum packaging significantly reduced microbial populations while maintaining fruit firmness, minimizing juice leakage, color difference, TSS, TA, and pH. Moreover, UV-C treatment can maintain the vacuum condition due to the reduction of microorganisms. Furthermore, the UV-C-treated pineapples exhibited reduced spoilage indicators, such as volatile compounds associated with fermentation, compared to untreated controls. The optimal temperature for transporting fresh-cut ‘Phulae’ pineapple, to maintain its quality and microbiological integrity, was recommended between 0 and 5°C. The results indicate that UV-C treatment can prolong the storage of fresh-cut 'Phulae' pineapple by up to 14 days during simulated transportation.

CHAPTER 6

SUGGESTIONS

Based on the yeast and mold data, it was recommended that the relationship between yeast and mold count be classified at the ‘Phulae’ pineapple safety level instead of following the Thailand National Standard.

REFERENCES

Achen, M., & Yousefa, A. (2001).Efficacy of ozone against *Escherichia coli* O157:H7 on apples. *Journal of Food Science*, *66*(9), 1380–1384.

Ali, S., Masud, T., & Abbasi, K. S. (2011). Physico-chemical characteristics of apricot (*Prunus armeniaca L*.) grown in Northern Areas of Pakistan. *Scientia Horticulturae*, *130*(2), 386-392. https://doi.org/10.1016/j.scienta.2011.05.040

Alvarenga, L., Dutra, M., Alvarenga, R., Lacerda, I., Yoshida, M., & Oliveira, E. (2015). Analysis of alcoholic fermentation of pulp and residues from pineapple processing. *CyTA-Journal of Food*, *13*(1), 10-16.

Araujo, L. d. S., Costa, E. M. R., Soares, T. L., Santos, I. S. d., & Jesus, O. N. d. (2017). Effect of time and storage conditions on the physical and physico chemical characteristics of the pulp of yellow and purple passion fruit. *Food Science and Technology*, *37*(3), 500-506.

Asim, M., Abdan, K., Jawaid, M., Nasir, M., Dashtizadeh, Z., Ishak, M., & Hoque, M. E. (2015). A review on pineapple leaves fibre and its composites. *International Journal of Polymer Science*, *2015*.

Baligad, J. L., Huang, P.-L., & Do, Y.-Y. (2023). The Effects of UV-C Irradiation and Low Temperature Treatment on Microbial Growth and Oxidative Damage in Fresh-Cut Bitter Gourd (*Momordica charantia* L.) Horticulturae, *9*(10), 1068; https://doi.org/10.3390/horticulturae9101068

Barbosa-Cánovas, G., Pothakamury, U., Palou, E., & Swanson, B. (1998). *Nonthermal preservation of foods*(p.354). Macel Dekker.

Barth, M., Hankinson, T. R., Zhuang, H., & Breidt, F. (2009). Microbiological spoilage of fruits and vegetables. *Compendium of the Microbiological Spoilage of Foods and Beverages*, 135-183.

Benítez, S., Soro, L., Achaerandio, I., Sepulcre, F., & Pujolá, M. (2014). Combined effect of a low permeable film and edible coatings or calcium dips on the quality of fresh-cut pineapple. *Journal of Food Process Engineering*, *37*(2), 91-99.

Bu, J., Yu, Y., Aisikaer, G., & Ying, T. (2013). Postharvest UV-C irradiation inhibits the production of ethylene and the activity of cell wall-degrading enzymes during softening of tomato (*Lycopersicon esculentum* L.) fruit. *Postharvest Biology and Technology*, *86*, 337-345.

Campero, E. V., Barrionuevo, M. J., & Marigliano, A. C. G. (2023). Effect of UV Radiation on Postharvest Conservation of Blueberries. *European Journal of Chemistry*, *14*(4), 477.2473

Casas-Junco, P. P., Balois-Morales, R., Ochoa-Jiménez, V. A., Berumen-Varela, G., & Bautista-Rosales, P. U. (2024). The toxigenic potential of phytopathogenic fungi isolated from pineapple *Ananas comosus* (L.) Merr. var MD-2 associated with postharvest rot disease. *Archives of Phytopathology and Plant Protection*, *57*(10), 722-735.

Chen, N., Paull, R., Chen, C., & Saradhuldhat, P. (2007). Pineapple production for quality and postharvest handling. In *Proceedings of the VI International Pineapple Symposium* (Vol. 822, pp. 253-260). ISHS.

Collado, E., Venzke Klug, T., Martínez-Hernández, G. B., Artés-Hernández, F., Martínez-Sánchez, A., Aguayo, E., Artés, F., (2020). UV-C pretreatment of fresh-cut faba beans (*Vicia faba*) for shelf life extension: Effects of domestic microwaving for consumption. *Food Science and Technology International*, *26*(2), 140-150.

Cote, S., Rodoni, L., Miceli, E., Concellón, A., Civello, P. M., & Vicente, A. R. (2013). Effect of radiation intensity on the outcome of postharvest UV-C treatments. *Postharvest Biology and Technology*, *83*,83-89, https://doi.org/10.1016/j.postharvbio.2013.03.009

Damdam, A., Al-Zahrani, A., Salah, L., & Salama, K. N. (2023a). Effect of combining UV-C irradiation and vacuum sealing on the shelf life of fresh strawberries and tomatoes. *Journal of Food Science*, *88*(2), 595-607.

Damdam, A. N., Al-Zahrani, A., Salah, L., & Salama, K. N. (2023). Effects of UV-C Irradiation and Vacuum Sealing on the Shelf-Life of Beef, Chicken and Salmon Fillets. *Foods*, *12*(3), 606. https://www.mdpi.com/2304-8158/12/3/606

de Ancos, B., Sánchez-Moreno, C., & González-Aguilar, G. A. (2017). Pineapple composition and nutrition. *Handbook of Pineapple Technology: Production, Postharvest Science, Processing and Nutrition*, 221-239.

Denoya, G. I., Vaudagna, S. R., & Polenta, G. (2015). Effect of high pressure processing and vacuum packaging on the preservation of fresh-cut peaches. *LWT - Food Science and Technology*, *62*(1, Part 2), 801-806

Domestic Office of Agricultural Economics (DOAE). (2022). *'Phulae' and 'Nanglae' pineapple*. http://mueang.chiangrai.doae.go.th/

East, A., Araya, X. T., Hertog, M., Nicholson, S., & Mawson, A. (2009). The effect of controlled atmospheres on respiration and rate of quality change in 'Unique'feijoa fruit. *Postharvest Biology and Technology*, *53*(1-2), 66-71.

FAOSTAT. (2022). *FAOSTAT, Pineapple production countries*. FAOSTAT. https://www.fao.org/faostat/en/#rankings/countries_by_commodity

Food and Agriculture Organization of the United Nations (FAO). (2022). *Production quantities of pineapple (Ananas comosus)*. https://www.fao.org/markets-and-trade/publications/detail/en/c/1622091/

Food and Drug Administration (FDA). (2002). *CFR - Code of Federal Regulations Title 21*. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=179.39

Garzón-García, A. M., Ruiz-Cruz, S., Dussán-Sarria, S., Hleap-Zapata, J. I., Márquez Ríos, E., Del-Toro-Sánchez, C. L., Tapia-Hernández, J.A.,Canizales Rodríguez, D. F., & Ocaño-Higuera, V. M. (2023). Effect of UV-C Postharvest Disinfection on the Quality of Fresh-Cut'Tommy Atkins' Mango. *Polish Journal of Food and Nutrition Sciences*, *73*(1), 39-49.

George, D. S., Razali, Z., Santhirasegaram, V., & Somasundram, C. (2015). Effects of ultraviolet light (UV-C) and heat treatment on the quality of fresh-cut Chokanan mango and Josephine pineapple. *Journal of Food Science*, *80*(2), S426-S434.

George, J., Nguyen, T., Williams, D., Hardner, C., Sanewski, G., & Smyth, H. E. (2023). Review of the aroma chemistry of pineapple (*Ananas comosus*). *Journal of Agricultural and Food chemistry*, *71*(9), 4069-4082.

Gil, M. I., Aguayo, E., & Kader, A. A. (2006). Quality changes and nutrient retention in fresh-cut versus whole fruits during storage. *Journal of Agricultural and Food chemistry*, *54*(12), 4284-4296.

Gimeno, D., Gonzalez-Buesa, J., Oria, R., Venturini, M. E., & Arias, E. (2022). Effect of Modified Atmosphere Packaging (MAP) and UV-C Irradiation on Postharvest Quality of Red Raspberries. *Agriculture*, *12*(1), 29.

Guerrero-Beltr· n, J., & Barbosa-C· novas, G. (2004). Advantages and limitations on processing foods by UV light. *Food Science and Technology International*, *10*(3), 137-147.

Hansen, A. Å., Moen, B., Rødbotten, M., Berget, I., & Pettersen, M. K. (2016). Effect of vacuum or modified atmosphere packaging (MAP) in combination with a CO2 emitter on quality parameters of cod loins (*Gadus morhua). Food Packaging and Shelf Life*, *9*,29-37.

Hinojosa, A., Silveira, A. C., Ospina, M., Char, C., Sáenz, C., & Escalona, V. H. (2013). Safety of ready-to-eat watercress using environmentally friendly sanitization methods. *Journal of Food Quality*, *36*(1), 66-76.

Huang, Y., Sido, R., Huang, R., & Chen, H. (2015). Application of water-assisted pulsed light treatment to decontaminate raspberries and blueberries from Salmonella. *International Journal of Food Microbiology*, *208*, 43-50.

Jemni, M., Chniti, S., Harbaoui, K., Ferchichi, A., & Artés, F. (2016). Partial vacuum and active modified atmosphere packaging for keeping overall quality of dates. *J New Sci Agric Biotechnol*, *29*(1), 1656-1665.

Jobling, J. (2000). Temperature management is essential for maintaining produce quality. *Good Fruit and Vegetables Magazine*, 30–31.

Kaya, Z., & Unluturk, S. (2019). Pasteurization of verjuice by UV-C irradiation and mild heat treatment. *Journal of Food Process Engineering*, *42*(5), e13131.

Kim, H.-J., Lee, C.-L., Yoon, K.-S., & Rhim, J.-W. (2022). Synergistic effect of UV-C LED irradiation and PLA/PBAT-based antimicrobial packaging film on fresh-cut vegetables. *Food Control*, *138*, 109027.

Kim, Y.-H., Jeong, S.-G., Back, K.-H., Park, K.-H., Chung, M.-S., & Kang, D.-H. (2013). Effect of various conditions on inactivation of *Escherichia coli* O157: H7, *Salmonella Typhimurium*, and *Listeria monocytogenes* in fresh-cut lettuce using ultraviolet radiation. *International Journal of Food Microbiology, 166*(3), 349–355.

Kongsuwan, A., Suthiluk, P., Theppakorn, T., Srilaong, V., & Setha, S. (2009). Bioactive compounds and antioxidant capacities of Phulae and Nanglae pineapple. *Asian Journal of Food and Agro-Industry, 2*, 44–50.

Koutchma, T. (2009). Advances in ultraviolet light technology for non-thermal processing of liquid foods. *Food and Bioprocess Technology*, 2, 138-155.

Kramer, B., Wunderlich, J., & Muranyi, P. (2017). Recent findings in pulsed light disinfection. *Journal of Applied Microbiology, 122*(4), 830-856.

Li, M., Li, X., Han, C., Ji, N., Jin, P., & Zheng, Y. (2019). UV-C treatment maintains quality and enhances antioxidant capacity of fresh-cut strawberries. *Postharvest Biology and Technology, 156, 11091*.

Liao, X., Xing, Y., Fan, X., Qiu, Y., Xu, Q., & Liu, X. (2023). Effect of composite edible coatings combined with modified atmosphere packaging on the storage quality and microbiological properties of fresh-cut pineapple. *Foods, 12*(6), 1344.

Liu, J., Stevens, C., Khan, V., Lu, J., Wilson, C., Adeyeye, O., Kabwe, M., Pusey, P., Chalutz, E., & Sultana, T. (1993). Application of ultraviolet-C light on storage rots and ripening of tomatoes. *Journal of Food Protection, 56*(10), 868–873.

Lv, Y., Fu, A., Song, X., Wang, Y., Chen, G., & Jiang, Y. (2023). 1-Methylcyclopropene and UV-C treatment effect on storage quality and antioxidant activity of ‘Xiaobai’ apricot fruit. *Foods, 12*(6), 1296.

Mansor, A., Shamsudin, R., Adzahan, N. M., & Hamidon, M. N. (2014). Efficacy of ultraviolet radiation as a non-thermal treatment for the inactivation of Salmonella typhimurium TISTR 292 in pineapple fruit juice. *Agriculture and Agricultural Science Procedia, 2*, 173–180.

Manthou, E., Coeuret, G., Chaillou, S., & Nychas, G.-J. E. (2021). Evolution of fungal community associated with ready-to-eat pineapple during storage under different temperature conditions. *Food Microbiology, 97,* 103736.

Manzocco, L., Plazzotta, S., Maifreni, M., Calligaris, S., Anese, M., & Nicoli, M. C. (2016). Impact of UV-C light on storage quality of fresh-cut pineapple in two different packages. *LWT - Food Science and Technology, 65,* 1138–1143

Mohd Ali, M., Hashim, N., Abd Aziz, S., & Lasekan, O. (2020). Pineapple (*Ananas comosus*): A comprehensive review of nutritional values, volatile compounds, health benefits, and potential food products. *Food Research International, 137*, 109675. https://doi.org/10.1016/j.foodres.2020.109675

Moradinezhad, F., & Dorostkar, M. (2021). Effect of vacuum and modified atmosphere packaging on the quality attributes and sensory evaluation of fresh jujube fruit. *International Journal of Fruit Science*, *21*(1), 82–94

Moreira, R. V., Costa, M. P., Lima, R. S., Castro, V. S., Mutz, Y. S., Rosario, A. I. L., Delgado, K. F., Mano, S. B., & Conte-Junior, C. A. (2021). Synergistic effect of pequi waste extract, UV-C radiation, and vacuum packaging on the quality characteristics of goat Minas Frescal cheese with sodium reduction. *LWT, 147,* 111523.

Ng, L. C., Tan, J. S., & Fauziah, T. A. (2022). Efficacy of ultraviolet-C irradiation to suppress fruit decay and retain the postharvest quality of dragon fruit (Hylocereus polyrhizus). *Malaysian Applied Biology*, *51*(1), 119-128.

Nguyen, B. T., Bujna, E., Fekete, N., Tran, A. T., Rezessy-Szabo, J. M., Prasad, R., & Nguyen, Q. D. (2019). Probiotic beverage from pineapple juice fermented with Lactobacillus and Bifidobacterium strains. *Frontiers in Nutrition, 6,* 54.

Pan, Y.-G., & Zu, H. (2012). Effect of UV-C radiation on the quality of fresh-cut pineapples. *Procedia Engineering, 37,* 113–119.

Pelaić, Z., Čošić, Z., Repajić, M., Pedisić, S., Zorić, Z., Ščetar, M., & Levaj, B. (2022). Effect of UV-C irradiation on the shelf life of fresh-cut potato and its sensory properties after cooking. *Food Technology and Biotechnology, 60*(2), 166–177.

Pérez-Lavalle, L., Carrasco, E., & Valero, A. (2020). Strategies for microbial decontamination of fresh blueberries and derived products. *Foods,9*(11), 1558.

Pino, J. A. (2013). Odour-active compounds in pineapple (*Ananas comosus* [L.] Merril cv. Red Spanish). *International Journal of Food Science & Technology, 48*(3), 564–570.

Prado, K. S., & Spinacé, M. A. S. (2019). Isolation and characterization of cellulose nanocrystals from pineapple crown waste and their potential uses *International Journal of Biological Macromolecules, 122*, 410-416. https://doi.org/10.1016/j.ijbiomac.2018.10.187

Pristijono, P., Papoutsis, K., Scarlett, C. J., Bowyer, M. C., Vuong, Q. V., Stathopoulos, C. E., & Golding, J. B. (2017). Postharvest UV-C treatment combined with 1-methylcyclopropene (1-MCP), followed by storage in continuous low-level ethylene atmosphere, improves the quality of tomatoes. *The Journal of Horticultural Science and Biotechnology, 92*(5), 521–529.

Rivera-Pastrana, D. M., Gardea, A. A., Yahia, E. M., Martínez-Téllez, M. A., & González-Aguilar, G. A. (2014). Effect of UV-C irradiation and low temperature storage on bioactive compounds, antioxidant enzymes, and radical scavenging activity of papaya fruit. *Journal of Food Science and Technology, 51*, 3821–3829.

Rodoni, L. M., Concellón, A., Chaves, A. R., & Vicente, A. R. (2012). Use of UV-C treatments to maintain quality and extend the shelf life of green fresh-cut bell pepper (*Capsicum annuum* L.). *Journal of Food Science, 77*(6), C632–C639.

Romli, S. R., & Murad, M. (2022). Influence of fresh pineapple intake on human taste detection and recognition thresholds of basic taste stimulants. *Journal of Sensory Studies, 37*(2), e12729.

Saltveit, M. E. (1999). Effect of ethylene on quality of fresh fruits and vegetables. *Postharvest Biology and Technology, 15*(3), 279–292. https://doi.org/10.1016/S0925-5214(98)00091-X

Sari, L. K., Setha, S., & Naradisorn, M. (2016). Effect of UV-C irradiation on postharvest quality of ‘Phulae’ pineapple. *Scientia Horticulturae, 213*, 314-320. https://doi.org/10.1016/j.scienta.2016.09.049

Severo, J., Tiecher, A., Pirrello, J., Regad, F., Latché, A., Pech, J.-C., Bouzayen, M., & Rombaldi, C.V. (2015). UV-C radiation modifies the ripening and accumulation of ethylene response factor (ERF) transcripts in tomato fruit. *Postharvest Biology and Technology, 102*, 9–16.

Siroli, L., Patrignani, F., Serrazanetti, D. I., Chiavari, C., Benevelli, M., Grazia, L., & Lanciotti, R. (2017). Survival of spoilage and pathogenic microorganisms on cardboard and plastic packaging materials. *Frontiers in Microbiology*, 2606.

Techavuthiporn, C., Boonyaritthongchai, P., & Supabvanich, S. (2017). Physicochemical changes of 'Phulae' pineapple fruit treated with short-term anoxia during ambient storage. *Food Chemistry, 228*, 388-393. https://doi.org/10.1016/j.foodchem.2017.02.028

Tiecher, A., de Paula, L. A., Chaves, F. C., & Rombaldi, C. V. (2013). UV-C effect on ethylene, polyamines, and the regulation of tomato fruit ripening. *Postharvest Biology and Technology, 86, 230-239.*

Tran, M. T. T., & Farid, M. (2004). Ultraviolet treatment of orange juice. *Innovative Food Science & Emerging Technologies, 5*(4), 495–502.

Tsironi, T., Ntzimani, A., Gogou, E., Tsevdou, M., Semenoglou, I., Dermesonlouoglou, E., & Taoukis, P. (2019). Modeling the effect of active modified atmosphere packaging on the microbial stability and shelf life of gutted sea bass. *Applied Sciences, 9*(23), 5019.

Umagiliyage, A. L., & Choudhary, R. (2018). Postharvest ultraviolet light treatment of fresh berries for improving quality and safety. *International Journal of Food Science & Nutrition Engineering, 8*(3), 60-71.

Velderrain-Rodríguez, G., Quiros, A., Aguilar, G., Siddiqui, M., & Ayala-Zavala, J. F. (2015). *Technologies in Fresh-Cut Fruit and Vegetables*. (pp. 79-103). https://doi.org/10.1007/978-3-319-10677-9_5

Watts, E. (2022). Seafood handling, processing, and packaging. In *Reference Module in Food Science*. Elsevier. https://doi.org/10.1016/B978-0-323-85125-1.00102-2

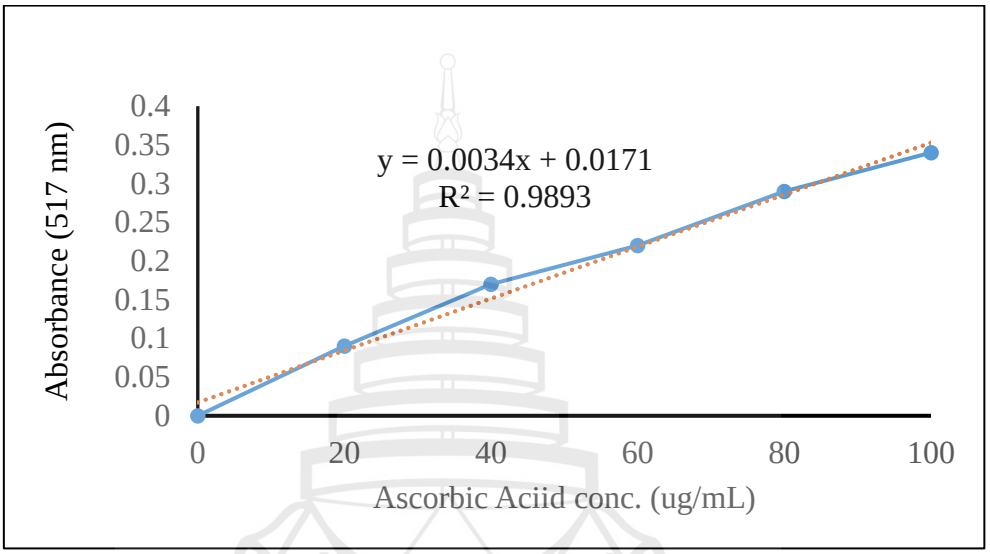
Xin, Z., Qianqian, L., Cong, H., Qingmin, C., Wenxiao, J., & Maorun, F. (2024). Combined treatment of ε-polylysine and UV-C inhibited aerobic bacteria growth and maintained the color, texture, and flavor of vacuum-packed fresh-cut lettuce slices. *Postharvest Biology and Technology, 218*, 113156.

Zdrojewicz, Z., Chorbińska, J., Bieżyński, B., & Krajewski, P. (2018). Health-promoting properties of pineapple. *Paediatrics and Family Medicine, 14*(2), 133.

Zu, H., Pan, Y., Chen, W., Liu, X., & Shao, Y. (2009). Effect of UV-C radiation on microbial indexes of fresh-cut pineapples. *Food Science, 30*, 67-69.

APPENDIX

STANDARD CURVE



FigureA1 Linearity between Absorbance at 517 nm of Ascorbic Acid Concentration for Antioxidant Assay (measured by DPPH Assay)