Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Application of UV-C and Modified Atmosphere Packaging to Prolong the Shelf Life of Parboiled Hokkien Noodles

A thesis presented in partial fulfilment of the requirements for the degree of Master of Food Technology

Massey University

Manawatu, New Zealand

Yiyun Xu

2026

Abstract

Hokkien noodles is a popular pre-cooked alkaline noodle product that is widely consumed in Asia. Despite their nutritional and sensory appeal, the high moisture content limits shelf life to 1–1.5 days at room temperature. The main challenge affecting the shelf life of pre-cooked noodles is microbial spoilage. Nowadays, traditional chemical preservatives raise health and sensory concerns, driving demand for clean-label alternatives. Ultraviolet-C (UV-C) light treatment is an eco-friendly, non-chemical disinfection method, that has shown promise in inactivating microorganisms on food surfaces. However, UV-C treatment alone does not prevent recontamination.

This study explores the synergistic effects of UV-C treatment and modified atmosphere packaging (MAP) in extending the shelf life of Hokkien noodles. UV-C effectively reduces surface microbial load, while MAP maintains a minimum oxygen level to inhibit microbial growth, particularly anaerobic and spoilage bacteria. Together, these technologies may ensure microbial safety and maintain the sensory quality of fresh noodles. By combining UV-C light and MAP, this research highlights the potential of this multi-hurdle method to meet modern consumer demands and improve the shelf life of commercial noodles.

The current study was carried out in two stages to evaluate the effects of UV-C treatment and MAP on the shelf life and quality of pre-cooked Hokkien noodles. Phase one identified the optimal UV-C dosage with MAP to extend the shelf life of Hokkien noodles stored at 4 °C for 14 days. The pre-cooked Hokkien noodles were subjected to four different UV-C doses (50, 110, 126, and 220 mJ/cm²). Half of the samples were packaged under modified atmosphere packaging (MAP) conditions, while the remaining samples were not packaged under MAP. Standard plate count (SPC), yeast and moulds (Y&M), pH, and water activity were analysed for each dosage. Based on the findings in stage one, a UV-C dosage of 110 mJ/cm² combined with modified atmosphere packaging was selected for phase two experiments. This combination provided sufficient germicidal efficacy while preserving the texture (preventing breakage) of the Hokkien noodle product.

In phase two, noodles were treated with the optimal UV-C dosage identified in phase one and stored under modified-atmosphere packaging conditions. Control samples were maintained as a baseline for comparison to evaluate the effects of the tested parameters on the treated samples. Their shelf life was evaluated over a 42-day storage period at 4°C. Physicochemical attributes and food quality changes of the noodle products were analysed for both UV-C-treated and control samples by assessing SPC, Y&M, EB, pH, colour, texture (springiness), and water activity. ANOVA revealed no significant differences in pH and water activity between control and UV-C-treated samples ($p > 0.05$). However, notable colour changes were observed due to non-enzymatic browning reactions, pigment degradation, and microbial activity, which stabilised over storage. Texture analysis showed a reduction in springiness throughout storage. The combined UV-C and MAP approach significantly enhanced microbial stability and extended shelf life. The combined application of UV-C treatment and MAP showed potential for improving the microbiological stability of Hokkien noodles during chilled storage. UV-C treatment effectively reduced surface microbial loads, while MAP suppressed oxygen-sensitive bacteria growth and preserved product texture. Chilled storage at 4 °C combined with lactic acidification to a pH of approximately 4.6 provided an additional hurdle to inhibit bacterial and fungal growth. Microbial analysis demonstrated the efficacy of the multi-barrier method in delaying the spoilage of commercial Hokkien noodles. However, the differences between the treated and control samples were relatively small. UV-C treatment did not substantially reduce microbial counts compared with the control under the conditions investigated. Furthermore, although MAP may influence microbial growth by modifying the package atmosphere, the standard plate count (SPC) method was conducted under aerobic conditions; therefore, the present study did not specifically assess strictly anaerobic bacteria.

Overall, this study shows that integrating UV-C treatment and MAP is an effective multi-hurdle preservation strategy for pre-cooked Hokkien noodles. The findings provide practical guidance for manufacturers seeking clean-label solutions to extend shelf life, enhance microbial safety, and maintain product quality within the fresh noodle product category. Further studies using anaerobic microbiological methods and longer storage periods are recommended to

determine the potential contribution of MAP to controlling anaerobic bacteria and to confirm any shelf life extension.

Acknowledgements

It has been a gratifying and memorable experience to participate in the postgraduate program in Food Technology at Massey University, Auckland.

First and foremost, I would like to express my heartfelt gratitude to my main supervisor, Dr. Tony Mutukumira and my relay supervisor, Dr. Charles Diako, for their invaluable guidance, encouragement, and insightful feedback throughout this journey. Their support has been instrumental in shaping the direction and success of this thesis.

I am deeply thankful to Rachel Liu, the manager of the microbiological laboratory, for her thoughtful advice and unwavering support, which have enriched the quality of my work.

I extend my deepest appreciation to my family and friends, whose support, patience, and understanding have been a constant source of strength and inspiration during this challenging yet rewarding journey.

Furthermore, I sincerely thank Negah Nikanjam and Arthur Xu for providing training on laboratory equipment.

Finally, I wish to acknowledge Massey University for the financial support which made this research possible.

Table of Contents

Abstract I

Acknowledgements IV

List of Figures VIII

List of Tables X

List of Abbreviations and Symbols XI

Chapter 1 Introduction 1

Aim 2

Objectives 2

Chapter 2 Literature Review 4

2.1 Introduction 4

2.2 Noodles 5

2.3.1 Factors Affecting Microbial Reproduction 7

2.3.2 Microbes Spoilage 10

2.4 Food Preservation Technologies 11

2.5 Ultraviolet 12

2.5.1 Ultraviolet (UV)-C 13

2.5.2 Source of Ultraviolet Lights 17

2.5.3 The Effect of UV-C Treatment on Food Quality 20

2.5.4 UV-C Treatment of Microorganisms 21

2.5.4.1 UV-C Treatment of Bacteria 22

2.5.4.2 UV-C Treatment of Spore Formers 22

2.5.4.3 UV-C Treatment of Yeasts and Moulds 23

2.5.5 Application of UV-C Light in the Food Industry 23

2.5.5.1 Application of UV-C Light in Meat and Poultry Processing 25
2.5.5.2 Application of UV Treatment on Grains 26
2.5.6 Compliance to Food Standards 26
2.5.7 Compliance to UV-C Technology Regulations 27
2.6 Modified Atmosphere Packaging 29
2.7 Summary 32
Chapter 3 Preliminary Experiment 33
3.1 Overview 33
3.2 Materials and Methods 33
3.2.1 Formulation Development 33
3.2.2 Dosage Selection 34
3.2.3. Gas selection for modified atmosphere packaging 36
3.2.4. Water activity and pH measurements 37
3.2.5. Microbiological tests 37
3.2.6. Statistical Analysis 37
3.3 Results and Discussion of the Preliminary Experiment 38
3.3.1 pH of samples 38
3.3.2 Water Activity of samples 41
3.3.3 Standard Plate Count Enumeration for the Preliminary Experiment 43
3.3.4 Yeasts and Moulds Enumeration for the Preliminary Experiment 44
3.3.5 Conclusion of the Preliminary Experiment 47
Chapter 4. Characterization of Hokkien Noodle Packaging Using Modified Atmosphere Packaging and UV-C Treatment at a Dosage of 110 mJ/cm² 50
4.1 Introduction 50

4.2 Materials and Methods for Phase Two Experiment 51
4.2.1 Preparation of UV-C Treated Hokkien Noodle Sample for Phase Two 51
4.2.2 Enterobacteriaceae 52
4.2.3 Colour Measurement 52
4.2.4 Texture (Springiness) Measurement 53
4.2.5 Microbiological testing 55
4.3 Results and Discussion for Phase Two Experiment 56
4.3.1 pH of samples 56
4.3.2 Water Activity Measurement Results 58
4.3.3 Colour Measurement Results 60
4.3.4 Texture (Springiness) Measurement Results 66
4.3.5 Standard Plate Count Enumeration for Phase Two Experiment 69
4.3.6 Yeasts and Moulds Enumeration for Phase Two Experiment 72
4.3.7 *Enterobacteriaceae* Enumeration for Phase Two Experiment 74
4.3.8 Conclusion for Microbial Enumeration for Phase Two Experiment 77
4.4 Overall Conclusion 78
References 81
Appendixes 100

List of Figures

Figure 2.1: Bacterial growth curve (Jay et al., 2005). 8
Figure 2.2: UV Spectrum (Universal Lab, 2024). 13
Figure 2.3: Significant factors influencing the UV-light treatment of food products (Singh et al., 2021) 14
Figure 2.4: Death rate curve (Jay, et al., 2005). 14
Figure 2.5: Inactivation of E. coli of LMP lamp - exposure wavelength of UV light vs. operating wavelength (Sharma and Demirci, 2003). 18
Figure 2. 6: Comparison within UV-C wavelengths and the efficiency: mercury emission lamps vs. PUV lamps (Koutchma, 2019). 20
Figure 2.7: UV light application area for food treatment (Koutchma, 2019). 24
Figure 2.8: Application of UV light technique for solid food surfaces (Koutchma, 2019). 25
Figure 3.1: Average pH values for storage days. Different letters indicate significant differences based on Tukey HSD (α=0.05) 44
Figure 3.2: Average pH values for the interaction between noodle packaging and storage days. Different letters indicate significant differences based on Tukey HSD (α=0.05). 45
Figure 3.3: Standard plate count for sample treated with 220 mJ/cm2 without MAP 46
Figure 3.4: Yeast and moulds count sample treated with 126 mJ/cm2 without MAP 46
Figure 4.1: The Characteristic Parameters for TEA (Li, 2008). 54
Figure 4.2: Springiness Measurement Schematic Pictures using TA.XT Plus (Stable Micro Systems Ltd, the United Kingdom) 55
Figure 4.3: pH Measurement Results for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C ... 56
Figure 4.4: Water Activity Measurement Results for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C 58
Figure 4.5: Colour Measurement Results (Lightness) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C 61

Figure 4.6: Colour Measurement Results (CIE-a*) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C 61
Figure 4.7: Colour Measurement Results (CIE-b*) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C 62
Figure 4.8: Tensile Force Measurement Results (CIE-b*) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C 66
Figure 4.9: Tensile Force Measurement Results (CIE-b*) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C 67

List of Tables

Table 2.1: Product Profile of Hokkien Noodle 4
Table 2.2: Water Activity of the Selected Foods and at Which Microorganisms Can Grow 9
Table 2.3: D10 UV Inactivation Doses (mJ/cm2) Measured At 254 nm for Various Microbes..... 15
Table 2.4: US FDA CFR 21 179.39 – UV for Treatment and Processing Foods 28
Table 3.1: Formulation (500 g per Batch) 34
Table 3.2: UV Doses for Multiple Log Reductions for Microorganisms @ 254 nm 35
Table 3.3: Factorial Design showing UV-C Light and Noodle Package levels used in the evaluation of Noodle Surface Decontamination @ 254nm..... 36
Table 3.4: pH Measurement Values for Control Samples and Samples Treated at four UV-C Dosages with or without MA Packaging for the Preliminary Experiment 38
Table 3.5: aw Measurement Values for Control Samples and Samples Treated at Various UV-C Dosage with or without MA Packaging for the Preliminary Experiment..... 41
Table 3.6: Standard Plate Count Over a 14-Day Storage Period 44
Table 3.7: Yeasts and Moulds Count over a 14-Day Storage Period 45
Table 4.1: Colour Profile Difference for Control Samples over a 42-day Storage at 4˚C..... 63
Table 4.2: Colour Profile Difference for Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C 63
Table 4.3: Colour Comparison Differences between Controls and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage Period .. 63
Table 4.4: Standard Plate Count Results for Phase Two..... 70
Table 4.5: Yeasts and Moulds Count Results for Phase Two 73
Table 4.6: Enterobacteriaceae Count Results for Phase Two..... 75

List of Abbreviations and Symbols

ACGIH	Conference of Governmental Industrial Hygienists
ANOVA	Analysis of variance
a_w	Water activity
CFU	Colony forming unit
CIE	Commission Internationale de l'Eclariage's
DOE	Design of Experiment
EB	*Enterobacteriaceae*
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization
FSANZ	Food Standards Australia New Zealand
GMP	Good Manufacturing Practices
HACCP	Hazard Analysis Critical Control Points
HMF	Hydroxymethylfurfural
ISO	International Organization for Standardization
LED	Light-emitting diodes
LPM	Low-pressure mercury
MAP	Modified atmosphere packaging
MLP	Medium-pressure mercury
MPI	Ministry for Primary Industries

MPN	Most Probable Number
N_2	Nitrogen
N/A	Not available
PCA	Plate count agar
PA	Polyamide
PE	Polyethylene
PL	Pulsed light
PUV	Pulsed UV
RTE	Ready-to-eat
SPC	Standard Aerobic Count
TEA	Texture extensibility analysis
TNTC	Too numerous to count
USFDA	United States Food and Drug Administration
UV	Ultraviolet
VRBG	Violet Red Bile Glucose
WHO	World Health Organization
Y&M	Yeasts and Moulds
YGCA	Yeast extract glucose chloramphenicol agar
d	Distance from a light source to an object
Dc	Total dosage of UV-C lights
S	Energy from the UV-light source
N	Number of microorganisms

N_0	Number of initial organisms
ΔC	Chroma difference
ΔE	Overall colour difference
˚C	Degree Celsius

Chapter 1 Introduction

Noodles are one of the most popular staple foods in Asian countries. Research indicates that approximately 20–50% of total wheat flour consumption is in the form of noodles (Diep et al., 2014). Noodles are not only a traditional food in Asia but have also gained widespread acceptance outside of the region. Hokkien noodles, a pre-cooked noodle product that contains added alkaline salt, are readily available in the New Zealand market. These noodles are made from wheat flour with a protein content of 11–12.5%, along with water, salt (sodium chloride), and alkaline salts (sodium and potassium carbonate), and are typically parboiled before being sold to consumers (Karim and Sultan, 2015).

The shelf life of traditional Hokkien noodles is only 1–1.5 days (Soraya et al., 2019) if not stored at chilled temperatures (4 ˚C), due to their high moisture content (from being parboiled), alkalinity, and the presence of rich nutritional compounds (Miskelly, 1998). Traditional preservation methods, such as adding chemical preservatives like benzoic acid and sorbitol, are unsuitable for Hokkien noodles, as these weak acids are ineffective in an alkaline environment (Stratford et al., 2007). Additionally, there is growing concern about the potential side effects of chemical preservatives in food and consumers have expressed an increasing demand for clean-label products.

In addition to the health concerns associated with chemical preservatives, sensory qualities such as taste, texture, and flavour can be compromised by using chemical additives or excessive heating (Sindelar & Milkowski, 2012). Ultraviolet (UV) light treatment is a novel technology used for food surface disinfection that can effectively inactivate microorganisms and enhance food safety.

According to the United States Food and Drug Administration (U.S. Food and Drug Administration [USFDA], 2021), the most common form of ultraviolet radiation is sunlight, which emits three primary types of UV rays: UVA, UVB, and UVC. Among these, UVA rays have the longest wavelengths, followed by UVB, while UVC rays have the shortest wavelengths. Ultraviolet-C (UV-C) radiation is a non-thermal and non-chemical intervention technology that

utilises physical light energy at a specific wavelength to inactivate microorganisms (Fan et al., 2017). UV-C light with wavelengths between 200 and 280 nm is defined as the "germicidal range," in which microorganisms can be effectively inactivated (Civello et al., 2006). Ultraviolet (UV)-C treatment is an eco-friendly technology, as it is free from chemicals and does not require sewage disposal. Additionally, UV-C radiation does not produce by-products, making it a cost-effective solution for manufacturers aiming to extend the shelf life of their food products.

According to Gonzalez et al., (2023), UV treatment alone lacks a sustained disinfection effect to prevent recontamination. This study will combine modified atmosphere packaging (MAP) with UV light treatment to further extend the shelf life of Hokkien noodles. MAP has been reported as an effective method when used in conjunction with UV technology, as it helps prevent the development of off-flavour and off-odour under high UV dosages (Blakistone, 1998). Additionally, MAP has been shown to minimize the growth of anaerobic bacteria by maintaining a minimal oxygen level of 2% (Hotchkiss, 1987).

Wheat flour-based noodle products play a crucial role in human daily diet and nutrition. In modern commercial noodle production, which usually occurs in manufacturing plants, the microbiological safety of the final products has become a significant public health concern. Microorganisms require specific conditions to grow and reproduce. It is anticipated that if manufacturers strictly adhere to good manufacturing practices and ensure that Hokkien noodles are packaged with a relatively low initial microbial count, the combined use of UV-C light and MA packaging can serve as an effective hurdle. This approach can significantly extend the shelf life of preservative-free Hokkien noodles without causing undesirable sensory changes to the product.

Aim

This study aims to investigate the effectiveness of surface decontamination through UV-C treatment and modified atmosphere packaging to extend the shelf life of pre-cooked Hokkien noodles.

Objectives

The objectives of this study are to:

i. Investigate the optimal range of UV-C dosage that produces effective decontamination results on the surface of the noodles.

ii. Identify the most effective UV-C light disinfection method when combined with Modified Atmosphere Packaging (MAP) for maximum results.

iii. Examine the synergistic effects of UV-C/MAP treatment on the surface of Hokkien noodles by evaluating the physicochemical characteristics of noodles and microbial inhibition at a chilled temperature of 4°C.

Chapter 2 Literature Review

2.1 Introduction

Alkaline Hokkien noodles are very popular in Southeast Asian countries and are gaining increasing acceptance in other parts of the world (Karim, & Sultan, 2015). Table 2.1 presents a quick overview of attributes such as product name, target market, and packaging in a clear, structured format.

Table 2.1: Product Profile of Hokkien Noodle

Product Description	Important Characteristics	Intended Purpose	Intended Consumer	Packaging	Intended Market
Hokkien Noodle	Pre-cooked oily noodles made with flour with high moisture content. Shelf stable at refrigerated storage temperatures.	A wide range of culinary purposes with further processing.	Human Consumption.	Modified atmosphere packaging	Domestic

The shelf life of Hokkien noodles at ambient temperature is about 1–1.5 days, which is relatively short due to their high moisture content and rich nutrient profile (Soraya et al., 2019). Hou (2010) reported that although alkaline noodles have a relatively high pH, they do not achieve the desired long shelf life due to their high moisture content and should be consumed within a day when stored at room temperature. As a result, traditional alkaline salts are currently not utilised to preserve commercial Hokkien noodle products. The formulation has been modified to

use lactic acid to acidify the product to a pH of approximately 4.6, replacing the alkaline salts traditionally used to maintain an alkaline pH of 9–11.

Food safety is a critical global concern, as many cases of foodborne illness stem from pathogens in contaminated food. Consequently, food safety regulations are becoming increasingly stringent. Systems such as Hazard Analysis Critical Control Points (HACCP) have been implemented by regulatory bodies and industries to effectively manage significant food safety risks, ensuring the safety and quality of food products.

Ultraviolet radiation treatment has been reported as an effective method for reducing microbial loads in food products, with efficacy depending on exposure time and radiation dose (Saraya, 2019). The germicidal effect of UV light is attributed to its ability to damage microbial DNA, which minimises significant alterations in food quality. It is considered a novel technology, and the application of UV-C radiation is regulated by authoritative bodies such as the U.S. Food and Drug Administration (USFDA, 2001a) and the European Food Safety Authority (EFSA, 2018).

Modified atmosphere packaging (MAP) technology can inhibit microbial growth at lower temperatures by modifying the oxygen levels within the packaging. Combining various preservation techniques has been reported as an effective approach to further extend the shelf life of food products (Singh and Shalini, 2016). This report studies the synergistic effects of integrating UV-C radiation and MAP in maintaining the overall quality of Hokkien noodles.

2.2 Noodles

Wheat-based noodles are a staple food in China and many other Asian countries. A remarkable archaeological discovery in 2005 revealed a 4,000-year-old well-preserved noodle made from millet, unearthed in northwestern China (Lu et al., 2005). Noodle was officially written in a Chinese book in the East Han Dynasty, which was 2000 years ago. Over time, Japan and other Asian countries adopted noodles, adapting them to their local cuisines, and noodles gradually became a dietary staple across the region. In recent decades, noodles have gained global popularity, especially with the invention of instant noodles. Today, manufacturers combine

modern processing and preservation techniques with traditional crafts to produce high-quality noodle products on an industrial scale (Gary, 2009).

Consumers may sometimes be confused between noodles and pasta, as both are popular globally. Noodles can be made from various flours, such as wheat, buckwheat, or rice, depending on the type, while pasta is normally made from durum wheat. Pasta is a broad category encompassing products like macaroni, spaghetti, ravioli, lasagna, vermicelli, and egg macaroni (Karim & Sultan, 2015).

Chinese noodles are mainly made with wheat flour and the colour of the noodles can be either bright creamy white or yellow, depending on whether alkaline salts are added to the recipe (Gary, 2009). Some select ingredients, such as duck eggs, are sometimes incorporated to enhance taste, texture, and flavour based on market preferences. During production, the dough is repeatedly pressed between rollers to form a sheet before being cut into strips. The pH of noodle products usually ranges from 9 to 11, and therefore, they have a limited shelf life (normally 2–3 days when stored in the fridge) (Hou & Kruk, 1998). The addition of alkaline salts not only affects the colour and pH but also contributes to the firm texture and alkaline flavour of the noodles (Karim, & Sultan, 2015). The ingredients for Hokkien noodles in this report include all-purpose flour, tapioca starch, salt, vegetable oil, Tartrazine, lactic acid and water. The noodles are coated with vegetable oil after being parboiled. These pre-cooked oily noodles can be categorised as boiled noodles, which are classified based on the processing. Boiled noodle refers to fresh noodle strands that are either parboiled or fully cooked. The typical products of boiled noodles include Chinese wet noodles, Hokkien noodles, udon noodles and soba noodles. Chinese wet noodles and Hokkien noodles are generally parboiled for 45 – 90 seconds to attain 80% - 90% gelatinisation of starch. Then the products will be blow-dried after parboiling and coated with 1-2% vegetable oil to prevent sticking together. This type of noodle product normally has an extended shelf life (2- 3 days) and high weight gain (60% - 70%) (Hou & Kruk, 1998). However, pre-cooked oily noodles with high weight gain are very susceptible to spoilage due to the high moisture content and abundant nutrients (Tuersuntuoheti et al. 2019). Some complicated physicochemical, biochemical changes, as well as microbial proliferation, will take place at different rates during the storage period (Huis in't Veld, 1996).

It is widely recognized that the spoilage of most foods is primarily caused by the proliferation and metabolism of microorganisms. In noodles, this deterioration negatively impacts sensory qualities, such as appearance and texture, as well as the nutritional content of the product. Without the application of appropriate preservation methods, such as irradiation or Modified Atmosphere Packaging (MAP), the shelf life of noodles is significantly shortened. Ren et al. (2010) reported that the sensory quality, such as colour and texture of fresh noodles reduced and meanwhile, the pH value and standard plate count (SPC) increased during storage time. Similarly, Ghaffar et al. (2009) reported that microbial growth and a decrease in pH value are the most noticeable indicators of fresh noodle degradation over time.

Browning significantly affects the sales of fresh noodles in markets. Non-enzymatic reactions are also reported to be the main factors that result in browning during storage (Ibarz et al., 1990). If the heating temperature is excessively high, a Maillard reaction may take place, leading to non-enzymatic browning and the darkening of the flour (Ma, et al., 2011). During the Maillard reaction, reducing sugars interact with α-amino groups, leading to the accumulation of hydroxymethylfurfural (HMF) and the subsequent formation of melanoidin pigments (Resnik & Chirife, 1979). In order to prevent non-enzymatic browning and prolong shelf life, appropriate control of factors like temperature, oxidation and light were availed to minimize browning and extend the product shelf life.

2.3 Microorganisms

2.3.1 Factors Affecting Microbial Reproduction

Microorganisms can proliferate and replicate at varying rates over time. Figure 2.1 below shows the growth curve of microbes.

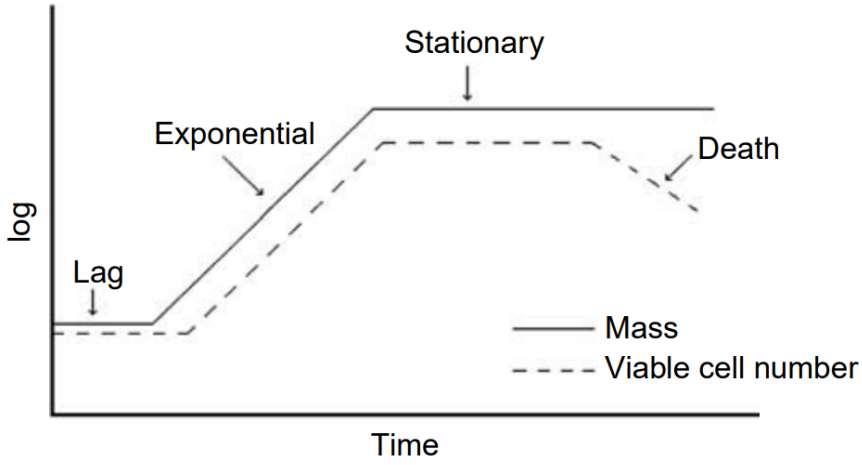


Figure 2.1: Bacterial growth curve (Jay et al., 2005).

The growth rate of microbes highly depends on the surroundings. Water and sufficient nutrients are the two primary elements for most microbes to survive. The surrounding temperature also significantly influences the rate of microbial reproduction. Microorganisms can grow across a wide range of temperatures from very low as −34 °C to very high exceeding 100 °C (Jay et al. 2005).

Microorganisms can be categorized into three groups according to their appropriate growth temperatures: microbes that grow well at or below 7 °C but their optimal growth temperature is between 20 and 30 °C are classified as psychrotrophs; the microbes that are categorized into the mesophilic group usually grow well between 20 and 45 °C and their optimal growth temperature is between 30 and 40 °C; microbes that grow well at and above 45 °C and their optimal growth temperature are between 55 and 65 °C are classified as thermophiles (Morita 1975; Jay 1987). Moulds can grow across the psychrotrophic temperature range. The optimal growth temperature for yeast is usually across the psychrotrophic and mesophilic temperature ranges, but it is not within the thermophilic growth temperature range (Jay et al. 2005). Although microorganisms typically exhibit growth potential across a broad range of temperatures, the optimal growth temperature for most organisms is usually around ambient temperature or body temperature (25–35°C) (Jay et al., 2005).

Other factors, such as pH, atmospheric gas concentrations, and water activity, also affect the ability of microorganisms to multiply. For example, lots of foods have a pH level ranging from 4 to 7, which is the most favourable pH range for the proliferation of many pathogenic and spoilage microorganisms. Meanwhile, the metabolic byproducts of microorganisms' reproduction can potentially modify the pH of their living environments. Water is an essential factor for the growth of microorganisms. However, not all the water in foods can be utilised as some of the water is bound with certain molecules present in the food. Water activity (a_w) is an indicator of the accessible water for microorganisms in food. It ranges from 0 to 1 (1 means pure water). Table 2.2 shows that most bacteria require a_w above 0.9 to reproduce, while yeasts and moulds can survive at water activities as low as 0.7; when the aw of foods is below 0.85, microorganism reproduction is suppressed (Jay et al., 2005).

Table 2.2: Water Activity of the Selected Foods and at Which Microorganisms Can Grow

Food	**Minimal a_w**
Fresh fruits, vegetables, meat, and fish	0.98
Cooked meat	0.98-0.95
Cured meat products, cheeses	0.91-0.87
Sausages, syrups	0.91-0.87
Most bacteria can grow	0.91
Most yeasts can grow	0.88
Flours, rice, beans, peas	0.87-0.80
Most moulds can grow	0.80
Jams	0.80-0.75
Halophilic bacteria can grow	0.75
Xerotolerant moulds can grow	0.71
Dried fruits	0.65-0.60
Spices, milk powder	0.60-0.20

(Source: Jay et al., 2005)

pH is scaled from 0 (extremely acidic) to 14 (extremely alkaline), and the middle between 0 – 14 (7) means neutral. The optimum pH value for most bacteria to grow is around neutral pH, yeasts and moulds are more acid-tolerant and the reproduction process of microbes will produce metabolic by-products, which is likely to change the pH value of foods. Like the temperature and pH, the requirement of oxygen for the growth of microbes is also varied. Aerobic bacteria require oxygen to grow while anaerobic bacteria can grow without oxygen, for instance, develop in vacuum-packed foods. Facultative anaerobes are those microbes that can survive either with or without oxygen and some microorganisms can tolerate and grow in the low oxygen environment (André et al., 2021).

2.3.2 Microbes Spoilage

Food spoilage is any change that leads to a food product that is undesirable or unacceptable to consume (Nychas & Panagou, 2011). Generally, the reproduction and metabolites of microorganisms will trigger the process of spoilage and when the spoilage microorganisms grow to a high amount, foods are not fit for consumption as a result. According to Goburdhun et al. (2019), ready-to-eat foods with total viable counts of 0–10^3 CFU/g, 10^4–10^5 CFU/g, and $\geqslant 10^6$ CFU/g may be classified as acceptable, marginally acceptable (tolerable), and unacceptable, respectively. Food is considered spoiled when the microbial load exceeds 10^7 CFU/g (or mL) for aerobic bacteria, 10^5 CFU/g (or mL) for yeasts and moulds, or when visible mould growth is observed (Sherkat & Hui, 2005).

The spoilage of foods can be induced by many types of microbes. Both fresh and processed foods are likely to be contaminated by microorganisms such as various species of bacteria, yeast, or moulds before eventually being consumed by the end-users. Contamination can take place during any step of food processing. The microorganisms produce metabolic byproducts during their reproduction processes, which may lead to the spoilage of foods. Such spoiled foods are usually not fit for consumption due to altered sensory attributes such as discolouration and the shelf life of foods will be reduced due to the food spoilage.

The original load of microbes that appear in foods will critically impact their shelf life. Foods with a high load of spoilage microorganisms normally have a shorter shelf life than those with lower levels of the same microorganisms. The enzyme produced by some of the spoilage microbes can break down fats or proteins into basic compounds, such as amine and ammonia; or alter the water-holding ability of foods, which may adversely affect the sensory attributes of foods (Gram, et al., 2002; Jay et al. 2005).

The deterioration of food products can be retarded through appropriate handling, packaging, and storage. Food spoilage can be suppressed by using premium materials with low microorganism levels. In addition, following close to the line of Good Manufacturing Practices (GMP) also significantly inhibits the growth of foodborne pathogens in processed foods.

2.4 Food Preservation Technologies

The quality of foods starts to deteriorate after postharvest or at the beginning of the processing attributed to the physical, chemical, enzymic or some microbiological reactions. Some of these deterioration reactions such as microorganisms' reproduction to some extent, can be prevented at the first stage by preservation techniques.

Traditional food preservation is usually through physical or chemical methods. Regarding physical means, both low-temperature preservations such as chill or frozen storage and heat treatment like pasteurisation or sterilisation can effectively suppress the growth of microorganisms. As mentioned above, the enzymatic reactions of microbes can lead to food spoilage, and the rate of enzymatic reactions is positively proportional to the temperature. A temperature increase of 10°C can typically lead to approximately a doubling of the enzymatic reaction rate in biological systems (Elias et al., 2014). The activation of most microbes is slow within the temperature range of 0 to 7 °C, and the activity will be stopped when the temperature drops below 0 °C (Jay et al., 2005).

Thermal treatment is a traditional preservation method that can inactivate most bacteria and pathogens as well as enzymes. However, high temperature may sometimes cause the undesired alteration of appearance, flavour or texture. Other means of physical methods include

reducing the water activity, applying modified atmosphere packaging or UV irradiation treatment. Chemical methods include reducing the pH of foods (acidification), adding chemical preservatives such as antioxidants, antimicrobials or anti-browning agents to food products to extend the shelf life. Nevertheless, even though the use of chemical preservatives is strictly controlled by the regulatory authorities, more and more consumers demand clean foods because of health concerns about certain health problems caused by some chemical preservatives (Cao & Miao, 2023).

Nowadays, some new methods are commercially used to extend the shelf life of foods without altering their sensory and nutritional quality. For example, high hydrostatic pressure is employed as a non-thermal treatment to suppress microbes in foods, which is known as pressure pasteurisation. High-voltage electric discharges are applied in food preservation but this method is more spore-tolerant. The application of irradiation is legally permitted for the disinfestation and pasteurisation of foods in nearly 40 countries (Grahame, 2000). The World Health Organisation (WHO) suggests that higher doses are safe for human beings and there shall be no limit to the irradiation dose of foods (Patterson, et al., 2000). Nevertheless, the application of new technologies is not broadly accepted either due to the high investment in equipment or some health concerns.

2.5 Ultraviolet

According to the US FDA, ultraviolet (UV) radiation represents only one type of radiation and is measured using a scientific scale called the electromagnetic (EM) spectrum. It is the portion of the EM spectrum between X-rays and visible light. The EM spectrum is divided into categories defined by a range of numbers. These ranges describe both the energy levels of photons and the corresponding wavelengths in each category. The most common form of UV radiation is sunlight, which produces three main types of UV rays: UV-A, UV-B and UV-C. UV-A rays have the longest wavelengths, followed by UV-B, and UV-C rays, which have the shortest wavelengths (U.S. Food and Drug Administration, 2020).

2.5.1 Ultraviolet (UV)-C

Due to the limitations of equipment and cost, chemical preservatives, such as potassium sorbate and sodium dehydroacetate, are widely employed as conventional preservation agents to extend the shelf life of fresh wet noodles (Hou et al., 2017). However, growing consumer demand for healthier foods has led both consumers and food manufacturers to seek alternative preservation methods (Novais et al., 2022). UV-C radiation is an effective and cost-efficient method for food decontamination. It can be used not only to ensure food safety but also to extend the shelf life of food products by reducing microbial loads and controlling spoilage microorganisms in food products. (Singh et al., 2021)

The range of UV processing wavelengths is between 100 nm – 400 nm and it can be further divided into three categories: UV-A (315 to 400 nm), UV-B (280 to 315 nm), and UV-C (200 to 280 nm).

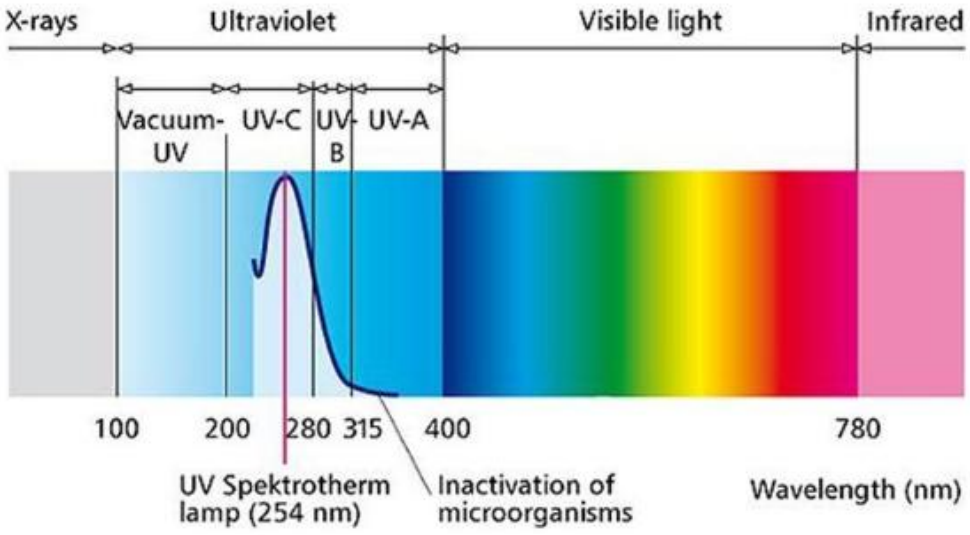


Figure 2.2: UV Spectrum (Universal Lab, 2024).

Ultraviolet C (UV-C) radiation is a non-thermal and non-chemical approach that uses the energy of physical light at a range of specific wavelengths to effectively destroy foodborne pathogens with less impact on the nutritional and sensorial properties of products (Condon et al.

2016). Ultraviolet C has the shortest wavelength and has been used in food decontamination for a long time. According to the US FDA, UV-C at the wavelength between 200 to 280 nm is defined as the “germicidal range” (Civello et al. 2006) and the microorganisms can be effectively restrained within this range due to its capacity to damage the DNA of microbes (Fan et al. 2017).

Figure 2.3: Significant factors influencing the UV-light treatment of food products (Singh et al., 2021)

The term "D_{10}" refers to the UV radiation dose (D) required to achieve a 10-fold reduction (equivalent to one order of magnitude) in the microbial population. Essentially, a D_{10} dose can deactivate 90% (one log10) of the microbes present in a food medium and is directly related to the energy absorbed by the fraction of viable cells.

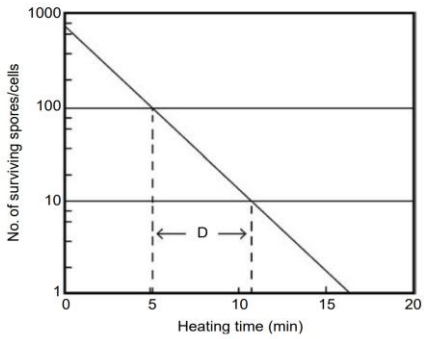


Figure 2.4: Death rate curve (Jay, et al., 2005).

The D_{10} value is derived from the linear portion of the microbial survival curve and represents the UV-C dose required to achieve a 1-log (90%) reduction in the microbial population under specified irradiation conditions. However, UV-C inactivation does not necessarily follow first-order kinetics over the entire treatment range. At higher UV-C doses, survival curves may deviate from linearity and exhibit tailing, resulting in a reduced rate of microbial inactivation. This parameter is commonly applied to assess the UV-C sensitivity of various microbial groups. Table 2.3 shows the range of average D_{10} doses for different microorganisms at 254 nm.

Table 2.3: D10 UV Inactivation Doses (mJ/cm2) Measured At 254 nm for Various Microbes

Microbial group	**D_{10} UV dose (mJ/cm^2)**
Enteral bacteria	2-8
Cocci and micrococci	1.5-20
Spore formers	4-30
Enteric viruses	5-30
Yeast	2.3-8
Fungi (spores)	30-300
Protozoa	60-120
Algae	300-600

Koutchma (2019).

Some microbial characteristics, including the microbial growth phase, environmental conditions (such as temperature, cell size, cell wall thickness, production of photoproducts, and genomic DNA composition), and microbial DNA repair capacity, are significant factors influencing the survival of microorganisms after UV-C irradiation (Singh et al., 2021).

A major product of DNA lesions caused by UV-C radiation is the cyclobutane-type pyrimidine dimer formation. Other types of DNA lesions include the pyrimidine pyrimidone dimer, diverse rare DNA photoproducts, and other indirect types, for example, DNA-protein cross-links

and singlet oxygen damage (Civello et al., 2006). The lethal effectiveness of UV-C lies in the effective absorption of UV radiation by microorganisms and the resistance of foodborne pathogens and bacteria to UV-C exposure. Because the UV-C targets DNA only, which means the adverse impact on cell envelopes will be minimised and therefore the physical properties of products like pH and water activity are rarely affected by using UV-C radiation (Fine & Gervais, 2004; Gayán, Serrano, Raso, Álvarez & Condón, 2012). However, the dosage of UV-C needs to be carefully chosen for food decontamination to ensure the desired quality attributes of noodle products. Studies found that irradiation can speed up the progress of lipid oxidation and oxidative rancidity, which leads to a slight change in colour and odour. The colour change is due to the oxidation of phenolic compounds to quinones, which generates melanoidins (Chen et al., 2007; Lacroix et al., 2004; Civello et al., 2006).

The wavelength employed to inactivate microorganisms is one of the most important factors. A relatively common broad-spectrum used for UV-C treatment in solid foods are within the range of 0.2 to 20 kJ/m^2 (0.02 to 2 J/cm^2) (Civello et al. 2006). The most directly lethal wavelengths will be those that are maximally absorbed by the bases of DNA. However, it is hard to define the most effective wavelength since the effectiveness varies from different species due to their DNA composition, and every single DNA displays its individual peak absorptivity of UV-C radiation (Shama, 2000). The efficacy of UV-C exposure on foodborne pathogenic bacteria and viruses depends on the exposure time and UV intensity of a product and it is also known as UV dose (Shama, 2000). Almost all living cells can reverse the damage caused by UV to their DNA. Generally, UV-C radiation of microbes will lead to damage to their DNA. However, this effect can be reversed by cell repair capacities. With the increase of UV-C intensity, the rate of DNA lesion formation will finally surpass the capability of repair systems, and the inactivation effect of microorganisms will be achieved (Shama, 2000).

As mentioned above, the degree of lethal effectiveness of UV-C against foodborne pathogens depends on many factors, such as surface characteristics of products, UV-C dose, intensity (wavelength), characteristics of microbes and location of microorganisms on the products, etc. Effective disinfection through ultraviolet irradiation depends on multiple factors. The UV intensity, exposure duration, and the distance between the light source and the target

object are key parameters that determine the dosage within a UV irradiation system (Semi, 2016). Therefore, the dosage delivered by a continuous UV light system can be quantified using the equation provided by Semi (2016):

$$Dc = \frac{S}{4\pi d^2} \times t \quad \text{..... (1)}$$

Where Dc is the total dosage of UV-C lights which is expressed in J/cm^2, S represents energy from the UV-light source, which is expressed in watts (W). d is the distance from a light source to an object which is expressed in cm, and t is the exposure time of an object which is expressed in seconds.

2.5.2 Source of Ultraviolet Lights

Traditional food preservation methods like heat treatment and chemical preservatives may adversely impact the physical properties such as colour, flavour, taste and texture and the demand for a clean label is growing recently. The interest in technologies that would not significantly change the physical and sensory quality and nutritional values results in the development of non-thermal food preservation technologies.

Ultraviolet light technology has been applied in food processing because of its wide range of antibacterial effects, cost-effectiveness and is a non-thermal treatment based on its physical nature. UV radiation and the adjacent visible spectral range are considered as non-ionising radiation, which is in contrast to ionising radiation, such as X-rays and Y-rays (Kovács and Keresztes, 2002; Koutchma, 2019).

There are many different types of UV lights and can be mainly divided into continuous and pulsed modes (UV and PUV); which are the two main sources that are used in commercial food disinfection. The commercially available continuous UV light sources for food processing include mercury emission lamps, excimer lamps, and UV light-emitting diodes (LEDs). USFDA currently only approves the utilisation of low-pressure mercury (LPM) lamps that operate at 253.7 nm based on USFDA. 21CFR179.39 PART 179 (U.S. FDA.2001a). The non-toxic rare gas, such as xenon or krypton is used as a pulsed-UV light source (Koutchma, 2019).

Mercury emission lamps usually contain a small quantity of methyl mercury (Hg) and an inert gas. Low-pressure mercury (LMP) lamps and medium-pressure mercury (MLP) lamps are two main types of mercury emission lamps. Technologies of LMP lamps are well developed, the UV light emission of LMP lamps can reach up to 10 mW/cm^2. The performance of LMP lamps would be affected by the temperature. The optimum operating temperature of LMP lamps is the ambient temperature (around 25 ℃), the maximum operating temperature of LPM lamps is up to 40°C and the output and efficacy of the LMP lamps would be lower if they are working in a cold or hot environment (Koutchma, 2019).

Figure 2.5: Inactivation of E. coli of LMP lamp - exposure wavelength of UV light vs. operating wavelength (Sharma and Demirci, 2003).

Figure 2.5 indicates that 254 nm is the most effective wavelength for LMP lamps; at this particular wavelength, most photons are absorbed by the DNA of microbes, which leads to the maximum sterilising effect. MPM lamps are usually operated at a high temperature (400 – 800 ℃) and therefore, the performance of MPM lamps would not be affected by the temperature. The emission of MPM lamps is polychromatic and the spectrum of MPM lamps spans from 250 nm to 600 nm. The emission of UV light within the visible range is deemed to have no germicidal effect.

When the wavelength of UV irradiation is below 200 nm, specifically at 185 nm, ozone can be produced and organic compounds can be oxidised (Little, R. 2007). The formation of ozone is undesirable during food processing since it neither has non-germicidal effects on microbes nor will it react with organic compounds in the food products, which leads to off-flavour or even toxic chemicals.

Excimer lamps can produce UV radiation within the wavelength range from 120 to 380 nm to form halogen excimers or rare-gas halide exciplexes and the efficiency depends on the different types of discharges (Oppenlander and Sosnin, 2005). Light-emitting diodes (LED) is a semiconductor diode that can generate light through electroluminescence (Koutchma, 2019). Ultraviolet (UV) LEDs can be designed to produce continuous light at the optimum germicidal (UV-C) wavelength in terms of specified microbes. Green et al. reported the potency of UV-C LEDs that emit between 255nm to 365 nm can kill common food pathogens such as *E.* coli, *Salmonella*, and *L.monocytogenes*. The range of wavelengths of UV-C LEDs emitting light is between 265 nm to 280 nm, which was considered to possess the maximum efficacy regarding the inactivation of microorganisms and overall power output. However, UV-C LEDs are costly compared to other sources (Green et al., 2018). The wavelength range of pulsed light (PL) is from 170 nm to 1000 nm. PL emits a few flashes of light per second with quick throughput and low energy consumption. Pulsed UV (PUV) possess UV-C germicidal capacity with higher intensity and shorter processing times compared to traditional mercury emission lamps (Koutchma, 2019). Therefore, PUV is utilised as a disinfection technique for food contact surfaces against *L. monocytogenes* as well as for opaque liquid food and beverages (Green et al., 2018). Figure 2.6 below shows the germicidal efficiency of mercury emission lamps and Pulsed UV lights.

Figure 2. 6: Comparison within UV-C wavelengths and the efficiency: mercury emission lamps vs. PUV lamps (Koutchma, 2019).

2.5.3 The Effect of UV-C Treatment on Food Quality

Sensory attributes, as well as physical and chemical properties, affect the overall quality of foods. The organoleptic quality of foods is considered a significant factor that affects the customers' selection of food products. Csapó et al. (2019) classified food products into four groups based on their sensitivity to light exposure, demonstrating that different types of food could have different levels and rates of quality deterioration when exposed to light. The noodles would be expected to fall within the fourth category, with off-flavour developing after 10 days of exposure to the UV light.

The effect of UV-C treatment on food quality is usually assessed in three aspects, one is sensory attributes which include colour and chewy texture; another aspect is the intrinsic characteristics of foods such as pH value, elasticity and protein content; the nutrients of foods

like the content of vitamins and minerals also will be evaluated to determine the impact of UV-C light on foods (Koutchma, 2019). Koutchma et al. (2016) reported that UV-C radiation does not significantly affect the sensory quality of foods.

The studies on the sensory quality of noodle products treated by UV-C light are limited. Koutchma et al. (2016) analysed 42 studies on a variety of fruit and vegetable juices and reported that the effects of UV treatment on the colour of most juices are insignificant. Tran and Farid (2004) also reported that UV-C light would not significantly affect the colour of orange juice. However, vitamins such as vitamin A, the vitamin B group, and vitamin C were reported to be destroyed to varying degrees under UV-C treatment (Ye et al., 2007). A study on milk products reported no significant changes in mineral and protein oxidation under UV-C processing. However, the p-value for lipid oxidation was less than 0.05, indicating a significant difference between raw and UV-treated milk (Cilliers et al., 2014).

2.5.4 UV-C Treatment of Microorganisms

Ultraviolet (UV)-C treatment was reported to successfully suppress a broad range of foodborne bacteria such as *E. coli, Listeria*, *Salmonella*, *Staphylococcus, Bacillus, Clostridium, Yersinia*, etc. (Souza & Koutchma, 2020); spoilage yeasts like *S. cerevisiae, Z. bailii* and moulds like *Neosartorya fischeri* (Singh et al., 2021). The UV-C light inactivates microorganisms by damaging the nucleic acid to prevent the repair or replacement of cells. Microbial inactivation rate follows a first-order reaction, assuming that the demise of microorganisms results from the reaction of one single UV photon in the DNA molecule, and that all cells have an equal likelihood of perishing. However, microorganisms differ in their sensitivity to UV light as a result of different cell wall structures, thicknesses, compositions, or variations in the structure of their nucleic acids.

Most of the microbes can be killed by UV-C light; however, the surviving cells will still metabolise and other functions will work as usual even if their nucleic acid has been damaged. Cells developed two mechanisms to repair the damage to nucleic acids caused by UV irradiation. The sensitivity of microbes to UV light is different and the thickness, structure and constitution of their cell wall or probably the constitution of their nucleic acid could be the reasons for the variation. The most effective UV wavelength for deactivating microbes is reported around 260

nm, and the microbicidal effectiveness for decontamination decreases from this peak. Hence, a sufficient UV irradiation dose needs to be determined for different objects to ensure that damage to nucleic acids exceeds the ability of cells to self-repair (Koutchma, 2019).

2.5.4.1 UV-C Treatment of Bacteria

Ray reported that bacteria have the highest rate of spoilage in processed foods, followed by yeast and mould (Ray, 2001). The most concerning microbes that cause microbial spoilage probably include infections and intoxications from bacteria, viruses, and parasites. These foodborne pathogens contribute to food spoilage and pose concerns for both food safety and quality. *Salmonella sp*. is a Gram (-), rod-shaped bacterium that is classified under the *Enterobacteriaceae* family. *Staphylococcus aureus* is a Gram (+) and small round-shaped cocci (Koutchma, 2019). They are two general bacteria that can cause diseases, and they were reported to be detected in pasta and uncooked noodle products (FDA,2018).

Food products will be exposed to bacteria and pathogens due to improper operation. The presence of these two bacteria in processed foods indicates the failure of hygiene. According to Koutchma, the sensitivity of bacteria to UV irradiation is directly proportional to the thymine contained in their DNA; while the Gram (+) bacteria and spore-forming bacteria are more resistant to UV irradiation compared to Gram (-) bacteria (Koutchma, 2019).

2.5.4.2 UV-C Treatment of Spore Formers

Spore-forming microorganisms such as *Clostridium* and *Bacillus* were classified as the specific spoilage microbes of certain food products. *Clostridia* are intolerant to oxygen and are usually found in vacuum-packed foods. *Bacillus* is able to produce spores after thermal treatment; the produced spores can tolerate harsh environments and will survive and grow in the food products. Koutchma carried out experiments of UV-C treatment (LMP light) to inactivate *Bacillus Subtilis* spores. The result showed the UV dosage for 1 log decimal reduction of *B. Subtilis* spores was between 23.86–24.47 mJ/cm^2. Chang et al. (1985) reported the 1 log reduction dosage for *B. Subtilis* spores was 36 mJ/cm^2 and the result from Sommer's study was 20–22 mJ/cm^2 (Sommer et al., 1999).

2.5.4.3 UV-C Treatment of Yeasts and Moulds

Yeasts and moulds can be found in a broad range of food products; their growth on foods is normally visible, accompanied by gas-forming, off odour or off flavour (Fleet, 1992), which usually affects both the sensory and nutritional quality (some yeasts are applied in the fermentation of certain foods). Taze et al. (2015) reported that the largest decimal reduction in the enumeration of yeasts and moulds of orange juice was gained as 1.76 $\log_{10}$ after 20 minutes of UV treatment at a dosage of 108.42 mJ/cm^2. Another research reported that just a 0.41 log reduction in the enumeration of yeasts and moulds was observed for orange juice at a UV dosage of 125 mJ/cm^2 (Torkamani and Niakousari, 2011). The studies mentioned above showed yeasts and moulds are more resistant to UV irradiation compared to bacteria.

2.5.5 Application of UV-C Light in the Food Industry

UV irradiation has been used in food decontamination for a long time. The first artificial UV source was patented in 1903, and it was used in water sterilisation. The first UV light was developed in the 1930s by Westinghouse for commercial use and this technology was applied in hospitals and different industries for sterilisation purposes since microbial contamination became a concern to the public (Andersen et, al., 2006). Nowadays, UV light technology has been used for processing water, disinfecting both surfaces and surfaces of solid foods, liquid foods and beverages to inactivate microbes and prolong the shelf life of food products (Koutchma, 2019). Figure 2.7 below shows the potential application area of UV light for the treatment of various foods.

Figure 2.7: UV light application area for food treatment (Koutchma, 2019).

The surface characteristics of products are reported as a significant factor that will affect the efficacy of UV-C decontamination in many studies (Fan et al., 2017; Condon-Abanto, S et al., 2016 & Shama, 2000). The UV-C approach is commonly used for liquid food decontamination because it readily penetrates transparent liquids. When the UV light technique is employed for treating solid foods, the foods' characteristics of their surfaces are the major concern since UV-C is not able to penetrate very far beyond the surface layers of the product (Shama, 2000). This is because UV-C light is readily absorbed in opaque solid materials (Fan et al., 2017). Civello et al. (2006) reported the penetration ability of UV-C is only 50 – 300 nm into the tissue and this limits the effectiveness of UV-C radiation. The irregularity, pores and cavities in the surface of noodle products lead to the shadow effect, which provides shields to microorganisms, reducing their exposure to UV-C light and as a result decreasing the lethal effect of radiation (Condon-Abanto et al., 2016).

Although the penetration ability to some extent limits the use of UV-C light for solid foods, recent research reported an increasing trend of UV lamp application on the decontamination of solid food surfaces. Continuous UV-C and PUV applications have been used for the devitalization

of bacteria, foodborne pathogens and spoilage on the surface of broad kinds of solid foods (Koutchma, 2019). The lethal effects of microbial contamination have been illustrated in numerous reports on the surfaces of processed food products, including flour, spices, whole or fresh-cut fruits, and raw animal products, as well as on post-harvest grain treatment (Koutchma, 2014b). Figure 2.8 below displays the application of the UV light technique for the treatment of solid food surfaces.

Figure 2.8: Application of UV light technique for solid food surfaces (Koutchma, 2019).

2.5.5.1 Application of UV-C Light in Meat and Poultry Processing

UV irradiation has been reported to be effective against *E. coli*, *Salmonella* and other non-spore-forming pathogenic microbes on pork skin, raw meats, and poultry surfaces (Koutchma, 2019). Chun et al. (2010) reported that *E. coli*, total viable counts (estimated concentration of bacteria, yeast and mould), and *Enterobacteriaceae* counts on the raw chicken fillet could be decreased by 0.98 log CFU/g, 1.76 log CFU/g and 1.29 log CFU/g respectively under the UV-C treatment at 200 mJ/cm^2. *L. monocytogenes* and *Salmonella* on chicken breasts were also

reported to decrease by 1.3 log CFU/g and 1.2 log CFU/g respectively at the UV dose of 500 mJ/cm^2. USDA established a new regulation regarding the outbreak of Listeria in ready-to-eat (RTE) meats in 2003 (FSIS, 2003). Sommers et al. (2009) reported that UV treatment can reduce Listeria on the surfaces of ready-to-eat products without adversely affecting their appearance. Even the penetration ability limits the broad application of UV light, researchers illustrated that UV treatment may have the potential to be widely used in meat and poultry processing to control the level of *L. monocytogenes* and other bacterial contamination since UV light can effectively reduce the bacteria and non-forming foodborne pathogens on raw meats and poultry surfaces according to the studies.

2.5.5.2 Application of UV Treatment on Grains

Mycotoxigenic fungal infections, such as *Aspergillus* and *Penicillium,* affect the yields of grains. At this late hour, most grains are dried by air on the fields due to the high cost of mechanical drying, which may lead to insufficient drying during rainy seasons. Fungi can grow under high moisture conditions during storage. For instance, *Aspergillus*, which belongs to xerophilic fungal species can grow even when the moisture content is just around 0.66 aw. The reproduction and spread rate of a species of fungi is directly proportional to the storage temperature and moisture content. This is probably the reason that *Aspergillus* and *Penicillium* are usually related to storage growth. Some research demonstrated that natural growth fungi found on grains can be partially reduced by UV-C light (Koutchma, 2019). Hidaka and Kubota (2006) reported that the application of UV-C light at a wavelength at 254 nm and the dose of 195 J/cm^2 can kill 90% of Aspergillus and Penicillium on wheat kernels. Therefore, UV light can be considered as an effective technique to diminish mycotoxins and fungi on grain surfaces and it will be a significant step in preventing microbial contamination of grains during processing and storage.

2.5.6 Compliance to Food Standards

The intended market of Hokkien noodles in this study is the New Zealand market. Therefore, the product must abide by government regulations to ensure food safety and ethnic

behaviour. New Zealand adopted the Australia New Zealand Food Standards Code, and all its amendments, as joint food standards in 2002. Therefore, the Food Standards Australia New Zealand (FSANZ) accounts for food standards in New Zealand. (MPI, 2023)

FSANZ was established under the Food Standards Australia New Zealand Act 1991 (FSANZ Act) and operates as an autonomous statutory agency within the Australian Government's Health portfolio. It operates through a collaborative partnership between the governments of Australia and New Zealand. FSANZ's primary mandate involves the formulation, evaluation, and implementation of food standards that apply to products distributed in both Australia and New Zealand. These food standards encompass emerging technologies like gene technology, stipulate guidelines for microbial levels, and define essential food processing criteria. (FSANZ, 2019)

2.5.7 Compliance to UV-C Technology Regulations

The US Food and Drug Administration (USFDA) and European Food Safety Authority (EFSA) are the main regulatory body in the world that regulates the use of UV-C technology. The United States Food and Drug Administration (US FDA) regulates the application of UV-C irradiation technology based on US FDA. 21CFR179.39 PART 179 (U.S. FDA.2001a). US FDA approves UV-light at 254 nm as a nonthermal intervention technology that allows the utilisation of food disinfection and food contact surfaces (Sommers, C.H. 2011). Table 2.4 below displays the US regulations regarding the application of UV for food treatment and processing.

UV irradiation may be linked to adverse health effects, depending on exposure time and specific wavelength. The US Conference of Governmental Industrial Hygienists (ACGIH) has set up Threshold Limit Values (TLVs) for UV occupational exposure. These TLVs pertain to ultraviolet radiation within the spectral range of 180 nm to 400 nm and represent conditions under which almost all workers can be exposed repeatedly without suffering adverse health effects. TLVs for UV exposure to the skin or eyes are determined based on factors such as irradiance and duration of exposure. Broadband sources are weighted to determine the effective irradiance compared with the spectral effectiveness curve at 270 nm. (Rochester, 2021).

Table 2.4: US FDA CFR 21 179.39 – UV for Treatment and Processing Foods

Irradiated food	Limitations	Use
Food and food products	Without ozone production: high fat-content food irradiated in vacuum or in an inert atmosphere; intensity of irradiation, 1 W (of 2,537 A. radiation) per 5 to 10 ft^2	Surface microorganism control
Potable water	Without ozone production; coefficient of absorption, 0.19 per cm or less; flow rate, 100 gal/h per watt of 2.537 A. radiation; water depth, 1 cm or less; lamp-operating temperature, 36-46°C	Sterilization of water used in food production
Juice products	Turbulent flow through tubes with a minimum Reynolds number of 2,200	Reduction of human pathogens and other microorganisms

Source: U.S. FDA.2001a

UV radiation is a novel technology compared to traditional food preservation technology. The European Union instituted and implemented novel food regulation in 2018, and EFSA regulates the use of UV-C radiation under this regulation. A recent case is that EFSA considered UV-treated milk a novel food, which is safe under the intended conditions of use as specified by the applicant (EFSA, 2016).

Foods in New Zealand and Australia are regulated by the Australia New Zealand Food Standards Code under the Legislation Act 2003. According to the FSANZ Standards Code, Part 1.5, Clause 1.5.1-2, a novel food in New Zealand is defined as "a non-traditional food that requires an assessment of the public health and safety considerations" (FSANZ, 2017). The sale of novel foods in New Zealand requires approval from the regulatory body. To manage inquiries about new foods, whether they are considered traditional or novel, the Advisory Committee on Novel Foods has been established by FSANZ.

According to the latest published "Record of views formed by the FSANZ Novel Foods Reference Group or the Advisory Committee on Novel Foods (FSANZ, 2021)," UV-treated foods do not fall into the category of novel foods, and FSANZ Standard 1.5.1 does not apply to the UV-treated noodle products in this study. Australia New Zealand Food Standards Code Part 1.5 Clause 1.5.3-2 defines "irradiation, in relation to food, means subjecting the food to ionising radiation, other than ionising radiation imparted to food by measuring or inspection instruments" (FSANZ, 2019). Even though UV irradiation is able to ionise sort of molecules under certain conditions, it is still deemed to be non-ionising radiation (Civello et al. 2006). FSANZ Standard 1.5.3 does not apply to UV technology. Therefore, there is no existing law applying to the use of UV technology for food processing in New Zealand at this stage.

2.6 Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) technology helps to retard the respiration rate and enzymatic degradation of complex substrates of foods, which enables manufacturers to prolong the shelf life of their food products (Kader 1986). MAP is any package that contains a gas composition deviant from atmospheric air (McMillin, 2008). It is either an active or passive dynamic process of modifying gaseous composition within a package (Caleb et al., 2013). Active MAP is a quick process of gas replacement, or the employment of gas scavengers to set up an expected gas mixture within a package (Kader and Watkins 2000). It is commonly used for the preservation of pre-cooked products. Since the natural microflora and foodborne pathogens have a significant impact on food safety, the application of MAP provides the possibility to inactivate foodborne pathogens to ensure the food safety of products.

Extrinsic factors such as temperature, relative humidity and level of oxygen inside the package play a significant role in achieving the desired modified atmosphere within the given package. For instance, the application of MAP aims to maintain the desired atmosphere within a certain temperature range. If the storage temperature is altered substantially, the atmosphere will also change within the package and may become improper for the products (Zagory 1995). Polymeric films are usually employed as a mechanical barrier to the movement of water vapour

in MAP. The application of polymeric films assists in keeping a high level of relative humidity within the package and decreases the weight loss of food products (Suparlan and Itoh 2003).

The selection of packing material is also an important parameter in obtaining the desired modified atmosphere for MAP. The extent of atmosphere modification that occurs within the package relies on the variables like film permeability to gases (eg, O_2) and water vapour, film thickness, package surface area and the headspace inside the package (Beaudry 1999; Mahajan et al. 2008). The Arrhenius equation that describes the temperature sensitivity of film permeability to gases is usually combined with other mathematical models to predict the package oxygen partial pressure as a function of product mass, the surface area of film, film thickness, and temperature (Cameron et al. 1994; Lakakul et al. 1999).

The biological safety concern about foodborne pathogen contamination for pre-cooked noodle products is relatively low in this study because the products are pre-cooked in boiled water for 1 minute, and they will also be subsequently cooked, and therefore, most of the pathogens are eliminated in the heat treatment process. However, Kim reported the D-value times of pathogens or spores were 8.5, 5.1 and 2.5 minutes at 100, 105, and 110°, respectively (Kim et al., 2005). Thus, heat-resistant spores are also a significant standard for food preservation by heat treatment.

The food safety and stability of noodle products utilising MAP are significantly influenced by storage conditions (Farber et al., 2003). Pathogenic microorganisms introduced during handling, processing, and distribution pose a considerable concern. While MAP can inhibit the growth of spoilage microorganisms, the primary factors ensuring the microbiological safety of MA-packaged noodle products include maintaining optimal storage conditions at low temperatures. Additionally, the safety of these products is determined by their intrinsic and extrinsic characteristics (Caleb et al., 2013).

The gases usually used for MAP are carbon dioxide and nitrogen. CO_2 itself has bacteriostatic and fungistatic properties and it is soluble in water and lipids (Doulia et al., 2000). Farber reported that at a high concentration of CO_2, the growth of microbes is retarded since CO_2 can reduce enzymatic reactions, influence the nutrient uptake for microbes and decrease the

intracellular pH of bacteria (Farber, 1991). The US FDA has raised the minimum recommended oxygen transmission rate (OTR) to 10,000 cc/m^2/24 h at 70°F because of concerns associated with *Clostridium botulinum*. However, the increase of CO_2 may induce certain physiological changes like the exudative loss of water. When CO_2 binds to moisture within the food products, it forms carbonic acid and eventually changes the pH. The alteration of pH is likely to result in undesirable flavours.

Nitrogen (N_2) is an inert, odourless, tasteless and colourless gas. Since the pre-cooked noodle products are coated with vegetable oil, N_2 can be used as a filler gas in MAP gas mixture to replace the O_2 in order to delay the process of oxidative rancidity and inhibit the growth of aerobic microorganisms as well. N_2 is also employed in MA- packaged with a high concentration of CO_2 to prevent package collapse due to its low solubility in water and lipids. Meng reported that the application of inert gases helps lower water activity in the products, thereby limiting the movement of microbes into deep tissues. Therefore, the microbiological quality is maintained by keeping the desired water activity level (Meng et al., 2012). According to Hotchkiss, retaining a 2% residual oxygen level within the packing can reduce the risk of anaerobic to a minimum (Hotchkiss, 1988).

The use of MAP may present an additional food safety consideration, as reduced oxygen availability can create conditions favourable for the growth of anaerobic pathogens such as *Clostridium botulinum*. Maintaining an appropriately low pH provides an important control measure against the growth of *C. botulinum* and other bacterial pathogens. In the present study, the noodles were acidified with lactic acid to achieve a pH of approximately 4.6. Maintaining the product pH below 4.6 would provide a more robust control measure against the growth of *C. botulinum* and thereby minimise the potential food safety risk associated with pathogenic bacteria under MAP conditions. This is particularly important when acidification is combined with reduced-oxygen packaging, as the interaction of these factors may influence the growth potential of foodborne pathogens.

2.7 Summary

Although UV-C radiation technology is not yet widely applied for the decontamination of noodle products, this literature review highlights its significant potential due to its exceptional germicidal efficacy while preserving the quality of the noodles. When combined with MAP technology, UV-C treatment effectively extends the shelf life of noodle products. The HACCP strategy was employed during the production of Hokkien noodles to ensure food safety in the Massay food processing laboratories.

Since UV-C light specifically targets DNA, its impact on the sensory properties and nutritional value of noodle products is minimal. However, the finished Hokkien noodle product is coated with 2% oil, raising concerns as studies suggest that radiation may accelerate lipid oxidation. Therefore, selecting an appropriate UV-C dose is critical to achieve sufficient germicidal effectiveness while minimising potential adverse effects on nutrients and sensory quality.

Chapter 3 Preliminary Experiment

3.1 Overview

This study employed systematic design methods to explore and identify an optimal combination of UV-C treatment and modified atmosphere packaging (MAP) that could extend the shelf life of pre-cooked Hokkien noodles during refrigerated storage at 4°C. The study was carried out in two phases. Phase one aimed to narrow the range of effective UV-C dosage for deactivating microbes (Standard Plate Count) and yeasts and moulds (Y&M). Modified atmosphere packaging (MAP) was used with UV-C light to further prolong the shelf life of fresh noodles. Nitrogen was employed as filling gas to maintain a 2% - 5% residual oxygen level within the packing, which could reduce the risk of anaerobic to a minimum (Hotchkiss, 1988). The pre-cooked noodles were treated at four different UV-C dosages: 50, 110, 126 and 220 mJ/cm^2. Standard Plate Count (SPC), yeast and moulds (Y&M), pH and water activity were studied for each UV-C treatment. The parameters of control samples were measured and recorded before the experiments started.

3.2 Materials and Methods

3.2.1 Formulation Development

Table 3.1 shows the formulation of the pre-cooked Hokkien noodles. About 500 grams (raw material input) of pre-cooked Hokkien noodles were made for each batch in trials. The all-purpose flour was weighed out first, followed by tapioca starch, table salt, and tartrazine. Next step, all the dried ingredients were combined and mixed in a large mixing bowl. The noodle-making machine was turned on and the noodle-making mode was selected. After that, the well-mixed dried ingredients were gently poured into the noodle-making machine. The weighed distilled water was gradually added to the mixture of dry ingredients and mixed at a preset shear speed (the default speed under the selected noodle mode). Separately, 7.5 grams (1.5%) of lye water was weighed and mixed with distilled water to reach a total of 500 grams. Meanwhile, water was brought to a boil, and the Hokkien noodles were cooked for 45 to 60 seconds.

Table 3.1: Formulation (500 g per Batch)

Ingredients	Amount (g)
All–purpose flour	315
Tapioca starch	50
Table salt	6
Tartrazine (colouring)	0.25 (0.05%)
Distilled water	135
Lactic acid	7.5
Vegetable oil (coating)	20

Note: The actual yield of the pre-cooked Hokkien noodles was about 600 grams per batch.

The pre-cooked Hokkien noodles were rinsed in distilled water until the temperature decreased to room temperature (about 25 °C to 30 °C). After that, the rinsed Hokkien noodles were immersed in acidified distilled water for about 3 minutes until they reached a pH value between 4 and 5. The acidified pre-cooked Hokkien noodles were blow-dried and packed in food-grade plastic bags.

3.2.2 Dosage Selection

Table 3.2 below indicates multiple log reduction of pathogenic bacteria, yeasts and moulds. Moulds of the genera *Aspergillus* and *Penicillium* are known to produce mycotoxins, and the most toxic mycotoxin is known as aflatoxins (Durakovic' S. & Durakovic' L., 2000). The flour used in this study was purchased from reputable supermarkets, which are highly unlikely to sell flour with visible mould. Supermarkets are expected to adhere to health and safety regulations, including quality control measures for the products they sell. However, mould usually thrives in damp conditions and pre-cooked noodles with high moisture content can be a suitable environment for mould growth. Therefore, the UV-C dosage was set at 50, 110, 126 and 220 mJ/cm^2 according to the summary of studies shown in Table 3.2.

Table 3.2: UV Doses for Multiple Log Reductions for Microorganisms @ 254 nm

Name of Microorganisms	**Lamp Type**	**Reduction Log**	**UV Dose (mJ/cm^2) for Microbes Reduction without photo-reactivation**	**Reference**
Bacillus subtilis	LP	3	47	Mamane-Gravetz and Linden 2004
Escherichia coli	LP	3	6.5	Zimmer et al. 2002
Salmonella spp.	LP	3	3.5	Yaun et al. 2003
Staphylococcus *aureus*	LP	3	6.5	Chang et al. 1985
Yeasts & Moulds	LP	1.76	108.42	Hakguder et al. 2015
Aspergillus niger	LP	2	220	Paola et al. 2023
Pencilium spp.	LP	2	126	Paola et al. 2023

A factorial design was applied to determine the UV-C dosage, that gave the maximum log reduction with the least exposure time. There were two types of noodle products: the pre-cooked noodle product with MAP and without MAP. Each type of noodle product was treated at four UV dosages: 50, 110, 126 and 220 mJ/cm^{2}and stored at 4°C for 14 days. After the UV-C light treatment, microbes were enumerated by Standard Plate Count and Yeasts & Moulds to evaluate noodle surface decontamination. Table 3.3 below shows the experimental design for Phase One. In addition to the full factorial design shown below, a control sample (no UV treatment and no MAP) was analysed to provide a baseline for evaluating the effect of UV treatment and MAP on the microbial reduction. Data was collected in duplicate.

Table 3.3: Factorial Design showing UV-C Light and Noodle Package levels used in the evaluation of Noodle Surface Decontamination @ 254nm

Run Order	Blocks	UV-C Doses (mJ/cm^2)	Noodle Package
1	1	220	Non-MAP
2	1	50	MAP
3	1	50	Non-MAP
4	1	110	Non-MAP
5	1	126	Non-MAP
6	1	126	MAP
7	1	220	MAP
8	1	110	MAP
9	2	220	Non-MAP
10	2	126	Non-MAP
11	2	50	Non-MAP
12	2	50	MAP
13	2	110	Non-MAP
14	2	220	MAP
15	2	110	MAP
16	2	126	MAP

3.2.3. Gas selection for modified atmosphere packaging

Although both carbon dioxide (CO_2) and nitrogen (N_2) are commonly used in MAP, CO_2 was not considered preferable in this study due to its potential interactions with the moisture and lipid phases of the oil-coated pre-cooked Hokkien noodles. Carbon dioxide readily dissolves in the aqueous phase of foods, where it forms carbonic acid and can consequently contribute to a reduction in product pH. Such pH changes may affect the sensory characteristics of the product

and may result in undesirable flavour or taste changes depending on the extent of acidification. Furthermore, CO_2 possesses inherent antimicrobial activity, which would introduce an additional preservation effect and potentially confound the assessment of MAP based primarily on oxygen displacement. Therefore, N_2, an inert gas with no direct antimicrobial or acidifying effect, was considered more appropriate for this study since it provided a reduced-oxygen atmosphere while minimising potential changes to the sensory and physicochemical properties of the noodles.

3.2.4. Water activity and pH measurements

Water activity was measured using a water activity meter (4TEV, Aqua LAB Ltd, New Zealand). The pH of the samples was measured using a pre-calibrated pH meter (PB-20; Pro-ISM, Sartorius Ltd, Germany). The pH and water activity were measured and recorded for the control and treatment samples before the 14-day storage test at 4 °C.

3.2.5. Microbiological tests

The microbiological quality of the Hokkien noodle samples was assessed using Standard Plate Count (SPC) and Yeast and Mould (Y&M) enumeration. These analyses were conducted to evaluate the antimicrobial efficacy of the various UV-C dosages and to identify the optimal treatment condition prior to the main storage study. SPC was employed to quantify the total viable aerobic bacterial population, whereas Y&M enumeration was performed to assess fungal contamination and the effectiveness of the treatments in controlling yeast and mould growth.

3.2.6. Statistical Analysis

A three-factor Analysis of Variance (ANOVA) involving UV dosage, noodle package and storage time was performed using XLSTAT version 23.0.25636 (Lumivero, New York, United States) as well as Minitab. The α-risk was set at 0.05. The post hoc comparisons of the sample means were also evaluated using Tukey's multiple-comparison test.

3.3 Results and Discussion of the Preliminary Experiment

A preliminary experiment was conducted to determine the effectiveness of UV-C dosage in combination with MAP. The pre-cooked Hokkien noodle samples were subjected to UV-C treatment at four different dosages. The pH value, water activity, and microbial tests (SPC and Y&M) were conducted to assess the quality of the noodle samples, to determine the optimal combination of UV-C dosage and MAP. In the preliminary experiment, data analysis was conducted using the mean values of duplicate measurements, along with their corresponding standard deviations, for pH and water activity. The results are presented in Tables 3.4 and 3.5. The results of the original data, the ANOVA test are presented in Appendix A (A1 to A17).

3.3.1 pH of samples

The pH measurement was carried out to evaluate the decontamination efficacy of the noodle samples treated with varying UV-C dosages, both with and without modified atmosphere packaging (MAP) during a 14-day storage period (Table 3.4).

Table 3.4: pH Measurement Values for Control Samples and Samples Treated at four UV-C Dosages with or without MA Packaging for the Preliminary Experiment

Samples	Day 0	Day 7	Day 14
Control	4.58 ± 0.07	4.61 ± 0.08	4.47 ± 0.05
50 mJ/cm^2 with MAP	4.58 ± 0.07	4.57 ± 0.07	4.53 ± 0.07
50 mJ/cm^2 Non-MAP	4.58 ± 0.07	4.57 ± 0.05	4.47 ± 0.02
110 mJ/cm^2 with MAP	4.58 ± 0.07	4.65 ± 0.03	4.55 ± 0.05
110 mJ/cm^2 Non-MAP	4.58 ± 0.07	4.67 ± 0.04	4.47 ± 0.04
126 mJ/cm^2 with MAP	4.58 ± 0.07	4.58 ± 0.09	4.52 ± 0.08
126 mJ/cm^2 Non-MAP	4.58 ± 0.07	4.62 ± 0.12	4.40 ± 0.03
220 mJ/cm^2 with MAP	4.58 ± 0.07	4.67 ± 0.06	4.60 ± 0.02
220 mJ/cm^2 Non-MAP	4.58 ± 0.07	4.70 ± 0.03	4.47 ± 0.04

According to 21 CFR Part 114, acid foods refer to foods that have a natural pH of 4.6 or below, and low-acid foods refer to general foods with a finished equilibrium pH of 4.6 or below and a water activity above 0.85 (FAO, 1999). All noodle samples were acidified with lactic acid. Each sample group was measured in duplicate. The initial pH values of the samples were recorded as 4.58. Therefore, at the beginning of the preliminary experiment the pre-cooked Hokkie noodle samples could be considered as a low-acid food based on the Food and Agriculture Organization's (FAO) definition. Table 3.4 shows that the pH values of most of the noodle samples increased on day 7, except for the samples treated at a UV-C dosage of 50 mJ/cm^2. At the end of the storage period (Day 14), the pH values of all noodle samples had decreased to 4.6 or below.

The analysis of variance test (ANOVA) and Tukey test were conducted at 95% confidence level. The final determination for a hypothesis test is on the basis of the p-value, which represents the probability of falsely rejecting the null hypothesis when it is actually true. If the p-value is less than or equal to a chosen significance level α (in this study $\alpha = 0.05$), the null hypothesis is rejected, and the alternative hypothesis is accepted, and vice-versa.

The results of the ANOVA test (Appendix A7) indicated that pH was not significantly affected by UV treatment or MAP packaging when considered individually, as no significant differences were observed among the pH values of the tested noodle samples. The corresponding p-values were 0.151 for UV treatment and 0.14 for MAP packaging, both of which are greater than 0.05 at the 95% confidence level. In contrast, storage duration had a significant effect ($p < 0.01$) on pH (Figure 3.1). Furthermore, the interaction between MAP packaging and storage duration was also statistically significant (Figure 3.2), indicating that this combined effect influenced the pH of the noodle samples. Specifically, the sample with no packaging and stored for 14 days had a significantly lower pH than the rest of the samples.

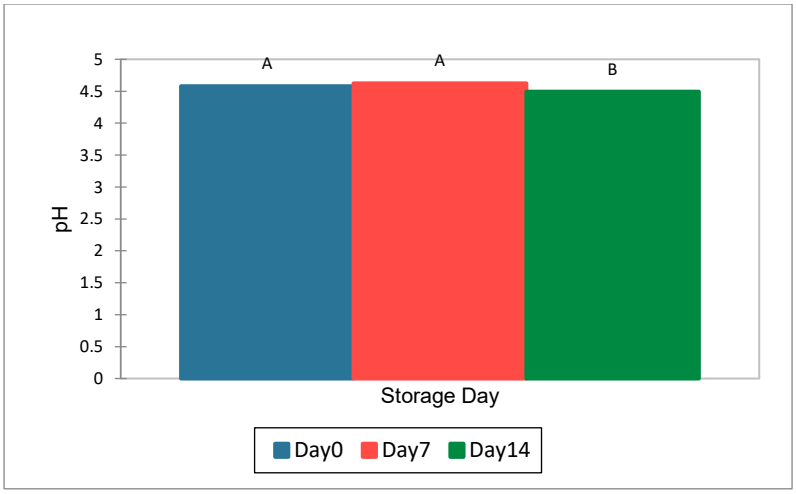


Figure 3.1: Average pH values for storage days. Different letters indicate significant differences based on Tukey HSD (α=0.05).

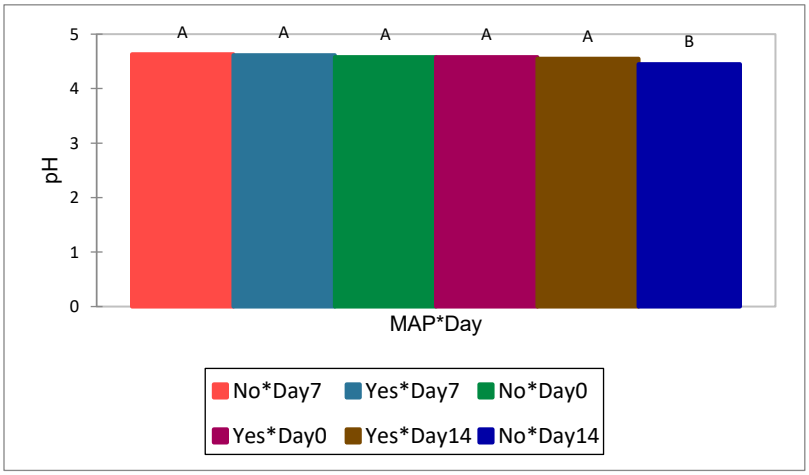


Figure 3.2: Average pH values for the interaction between noodle packaging and storage days. Different letters indicate significant differences based on Tukey HSD (α=0.05).

The pH values at the end of the storage period ranged from 4.4 to 4.6, with no obvious difference between samples treated with different UV-C dosages. However, slight variations in pH values were observed in the noodle samples treated with different UV-C dosages combined with MAP, particularly in the sample treated with 110 mJ/cm² and 220 mJ/cm² of UV-C under MAP conditions. The results indicate that during this short-term storage (14 days), the pH values of the noodle samples complied with the FAO's definition of low-acid foods. This suggests that

microorganism growth may be inhibited, which may potentially extend the shelf life before decomposition occurs.

3.3.2 Water Activity of samples

As water activity is one of the significant factors that affect the growth of microorganisms, it was also tested to obtain the best combination of UV-C dosage with MAP during the storage period. The results of water activity are shown in Table 3.5 below.

Table 3.5: aw Measurement Values for Control Samples and Samples Treated at Various UV-C Dosage with or without MA Packaging for the Preliminary Experiment

a_w Measurement	Day 0	Day 7	Day 14
Control	0.9994 ± 0.0003	0.9980 ± 0.0000	0.9971 ± 0.0000
50 mJ/cm^2 with MAP	0.9994 ± 0.0005	0.9984 ± 0.0001	0.9970 ± 0.0001
50 mJ/cm^2 Non-MAP	0.9988 ± 0.0001	0.9972 ± 0.0001	0.9957 ± 0.0000
110 mJ/cm^2 with MAP	0.9986 ± 0.0001	0.9976 ± 0.0004	0.9962 ± 0.0002
110 mJ/cm^2 Non-MAP	0.9983 ± 0.0001	0.9955 ± 0.0003	0.9936 ± 0.0001
126 mJ/cm^2 with MAP	0.9967 ± 0.0003	0.9960 ± 0.0007	0.9951 ± 0.0004
126 mJ/cm^2 Non-MAP	0.9966 ± 0.0000	0.9941 ± 0.0001	0.9929 ± 0.0000
220 mJ/cm^2 with MAP	0.9948 ± 0.0000	0.9939 ± 0.0000	0.9930 ± 0.0000
220 mJ/cm^2 Non-MAP	0.9943 ± 0.0001	0.9928 ± 0.0004	0.9915 ± 0.0004

The results indicate that at the end of the storage period (14 days), the water activity of control samples and noodle samples treated at all levels of UV-C dosages with or without MAP were above 0.99. The noodle samples with no UV-C treatment (control) or a lower UV-C dose treatment have a relatively higher water activity at the beginning. From the internal plot of water

activity versus samples treated with various UV-C dosages at time 0 at the 95% confidence level (Appendix A8), no overlapping intervals were observed. This indicates that water activity decreases with increasing dosage at time 0, and that the difference is significant. During a 14-day storage, the water activity was reduced from almost 1 to 0.99 for control samples or samples with a lower UV-C dose treatment under MP packaging conditions. Table 3.5 indicates that the water activity of noodle samples treated with higher UV-C doses or not packaged under MAP conditions decreased significantly, reaching a minimum value of 0.99. An ANOVA test was conducted at the 95% confidence level to provide a more comprehensive evaluation of these results. The ANOVA outcomes for all noodle samples are presented in Appendix A9. The p-values for all variables (UV, MAP, Day) were less than 0.05, indicating statistically significant differences in water activity due to UV treatment, MAP packaging, and storage duration. Among the explanatory variables, UV treatment was the most influential factor, as indicated by Table 3.5 and the the large F-value for UV in the Type III sum of squares table presented in Appendix A9. As a result, the ANOVA test was performed on the control samples combined with samples treated with different UV-C dosages to better illustrate the differences in water activity across the various groups of samples.

The ANOVA test results, as shown in Appendix A10 to Appendix A13, indicate that the p-values between control samples and the samples treated with UV-C dosages of 50 mJ/cm² and 110 mJ/cm² are greater than 0.05. This indicates no statistically significant differences in water activity among the above-mentioned samples. The data presented in Table 3.5 indicate that the initial water activity of the control samples was approximately 0.9994 (average water activity value of controls). This value gradually decreased, reaching 0.9971 at the end of a 14-day storage period. Table 3.5 also shows that the water activity of the samples treated with UV-C dosages of 50 mJ/cm² and 110 mJ/cm² with MAP was reduced to a moderate level of 0.99. The results suggest that the control samples, as well as the samples treated with UV-C dosages of 50 mJ/cm² and 110 mJ/cm², maintained a relatively high moisture content under modified atmosphere packaging conditions. Moisture content is a crucial factor influencing the texture of the noodles, as moisture in partially cooked foods can impact the breakage of the final products. (Irie et al., 2004).

However, the p-values presented in Appendix A14 to Appendix A17 are less than 0.05, the results illustrate a statistically significant difference in the water activity of samples treated with a UV-C dosage of 126 mJ/cm², as well as those treated with a dosage of 220 mJ/cm². Table 3.5 further indicates that the water activity of the samples treated with UV-C dosages of 126 mJ/cm² and 220 mJ/cm² decreased to a low level of 0.99 by the end of the storage period. As a result, the noodle samples treated with UV-C dosages of 50 mJ/cm² and 110 mJ/cm² were selected to retain a relatively higher moisture content in order to prevent breakage of the product.

3.3.3 Standard Plate Count Enumeration for the Preliminary Experiment

The standard plate count for the noodle samples was conducted in duplicate for the preliminary experiment; the test was performed at 7-day intervals over a 14-day storage period. The data on the effectiveness of different UV-C light dosages in suppressing the growth of microorganisms are presented in Table 3.6.

The results show that on Day 0, the initial microbial count for the control samples was 1.3 $\log_{10}$ CFU/g for the dilution 10^{-1}, and the microbes were reported as not detected after UV-C treatment at each selected dosage. The SPC for the control samples increased slowly and reached 1.7 $\log_{10}$ CFU/g at the end of the storage period (Day 14). By day 14, the SPC results for noodle samples treated with selected UV-C dosages remained not detected, except for the duplicate sample treated with 220 mJ/cm^2 without MAP for the dilution 10^{-1}.

Table 3.6: Standard Plate Count Over a 14-Day Storage Period

Standard Plate Count											
Day	**Dilution**	**C**	**50M**	**50NM**	**110M**	**110NM**	**126M**	**126NM**	**220M**	**220NM**	**220NMD**
		Microbial Count (cfu/plate)									
0	10^{-1}	2	<10	<10	<10	<10	<10	<10	<10	<10	<10
	10^{-2}	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	10^{-3}	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
7	10^{-1}	2	<10	<10	<10	<10	<10	<10	<10	<10	<10
	10^{-2}	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	10^{-3}	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
14	10^{-1}	5	<10	2	<10	<10	<10	1	<10	<10	TNTC
	10^{-2}	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
	10^{-3}	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Note: C=Control; 50M=50 mJ/cm^2 MAP; 50NM=50 mJ/cm^2 Non-MAP; 110M=110 mJ/cm^2 MAP; 110NM=110 mJ/cm^2 Non-MAP; 126M=126 mJ/cm^2 MAP; 126NM=126 mJ/cm^2 Non-MAP; 220M=220 mJ/cm^2 MAP; 220NM=220 mJ/cm^2 Non-MAP. Standard plate count was conducted in duplicate and the average results of the duplicates for all sample groups were used for data analysis.

3.3.4 Yeasts and Moulds Enumeration for the Preliminary Experiment

The yeasts and moulds tests for the noodle samples were also carried out in duplicate at the beginning of the preliminary experiment, with additional counts performed at 7-day intervals over the 14-day storage period.

Table 3.7: Yeasts and Moulds Count over a 14-Day Storage Period

Yeasts and Moulds										
Day	**Dilution**	**C**	**50M**	**50NM**	**110M**	**110NM**	**126M**	**126NM**	**220M**	**220NM**
		Microbial Count (cfu/g)								
0	10^0	<10	<10	<10	<10	<10	<10	<10	<10	<10
	10^{-1}	<10	<10	<10	<10	<10	<10	<10	<10	<10
7	10^0	<10	<10	<10	<10	<10	<10	<10	<10	<10
	10^{-1}	<10	<10	<10	<10	<10	<10	TNTC	<10	<10
14	10^0	<10	<10	1	<10	<10	<10	<10	<10	<10
	10^{-1}	<10	<10	<10	<10	<10	<10	<10	<10	<10

Note: C=Control; 50M=50 mJ/cm^2 MAP; 50NM=50 mJ/cm^2 Non-MAP; 110M=110 mJ/cm^2 MAP; 110NM=110 mJ/cm^2 Non-MAP; 126M=126 mJ/cm^2 MAP; 126NM=126 mJ/cm^2 Non-MAP; 220M=220 mJ/cm^2 MAP; 220NM=220 mJ/cm^2 Non-MAP. Yeasts and moulds count was conducted in duplicate and the average results of the duplicates for all sample groups were used for data analysis.

Since the Hokkien noodle samples were partially cooked in boiled water for 1 minute, followed by acidification with lactic acid to achieve a pH of approximately 4.6, the initial yeast and mould counts presented in Table 3.7 were found to be negative across all sample groups. The yeasts and moulds count was still negative across all sample groups on day 7 except for the duplicate noodle sample treated with UV-C dosage of 126 mJ/cm^2 without MAP for the dilution 10^{-1}. The Y&M count for the sample in which fungi were detected was too numerous to count (TNTC). At the end of the storage period (Day 14), the Y&M count remained undetectable for all samples, except for the noodle sample treated with a UV-C dosage of 50 mJ/cm² without MAP at a dilution 10^0, where the Y&M count was 0.1 log CFU/g. The detection of Y&M may be due to the germicidal effect of the 50 mJ/cm² UV-C treatment. The inhibitory capacity of a 50 mJ/cm² UV-C dosage may not have been sufficient to suppress the growth of fungi without the combined effect of MAP.



Figure 3.3: Standard plate count for sample treated with 220 mJ/cm^{2}without MAP

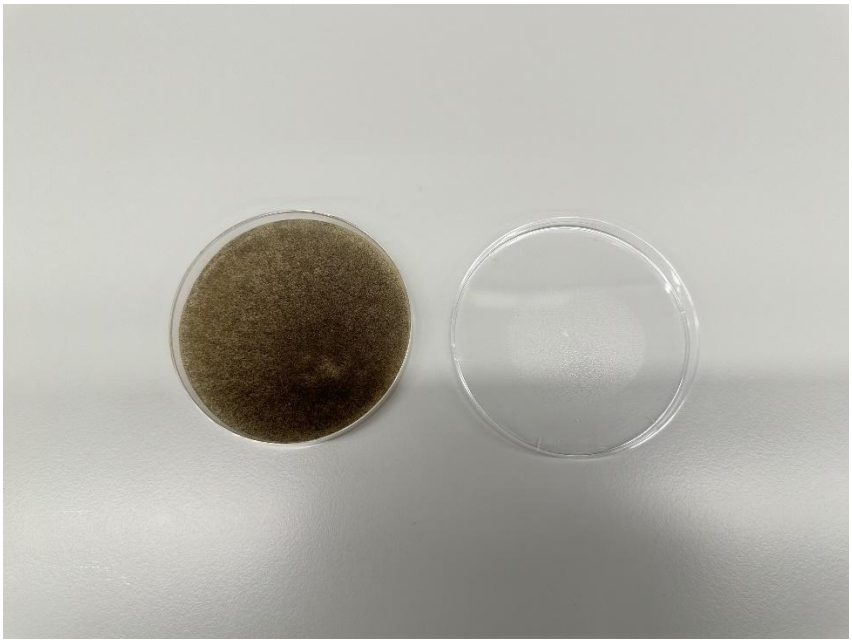


Figure 3.4: Yeast and moulds count sample treated with 126 mJ/cm^{2}without MAP

Since both bacteria and fungi were detected in the samples without modified atmosphere packaging, this indicates that nitrogen has the capacity to slow oxidative rancidity and suppress

the growth of aerobic microorganisms. Given that the SPC and Y&M count results for other samples treated with lower UV-C dosages were not detected, the unexpected phenomena observed in Figure 3.5 and Figure 3.6 were likely due to contamination of the cultures.

3.3.5 Conclusion of the Preliminary Experiment

The pH value, water activity, and microbial measurements were carried out to determine the optimal UV-C dosage in combination with an efficient packaging method to extend the shelf life of pre-cooked Hokkien noodles. The samples were stored at 4 °C for a period of 14 days.

The p-values obtained from the pH measurements in the preliminary experiment indicated that there were no statistically significant differences in pH among the tested samples subjected to UV treatment or MA packaging; however, pH was statistically significant affected by storage duration. The pH values of all the noodle samples remained 4.6 or below at the end of the storage period (Day 14). In this regard, acidified Hokkien noodles can be classified as low-acid food according to FAO, and their relatively lower acidity may contribute to inhibiting microbial growth and extending shelf life.

The p-value of water activity of all the variances (UV, MAP and Day) for noodle samples was observed less than 0.0001, which indicates statistically significant differences in water activity among all tested samples. Therefore, an ANOVA test was conducted between the control sample and the samples treated with different UV-C dosage groups. The p-values between the control sample and the noodle samples treated with UV-C dosages of 50 mJ/cm² and 110 mJ/cm² (regardless of whether under MAP conditions or not) were 0.915, 0.467, 0.510, and 0.193, respectively. These results were greater than 0.05, which indicates no distinct differences in water activity among the aforementioned samples. However, the p-values between the control sample and the noodle samples treated with UV-C dosages of 126 mJ/cm² and 220 mJ/cm² were 0.042, 0.046, 0.007 and 0.007, respectively. The p-values were observed to be less than 0.05, indicating statistically significant differences in water activity at a 95% confidence level for the aforementioned samples. Based on the observed p-values for water activity, the samples treated with UV-C dosages of 50 mJ/cm² and 110 mJ/cm² were selected to maintain the texture and prevent breakage of the Hokkien noodles.

The initial standard plate counts for the control samples were observed to be 0.1 log CFU/g and 0.2 log CFU/g for the 10^{-1} dilution, respectively, while no counts were detected for the noodle samples treated with UV-C light at each selected dosage. The SPC for the control samples increased to 0.9 log CFU/g and 1.5 log CFU/g by the end of the storage period, whereas SPC for the other tested samples were negative, except for the duplicate sample treated with a UV-C dosage of 220 mJ/cm² without MAP for the 10^{-1} dilution.

The yeast and mould count was reported as 0.1 log CFU/g for the sample treated with a UV-C dosage of 50 mJ/cm² without modified atmosphere packaging (MAP) for the 10^{o} dilution. Moreover, an unexpected phenomenon was observed for Y&M count, with the count recorded as too numerous to count (TNTC) for the sample treated with a UV-C dosage of 126 mJ/cm² without MAP for the 10^{-1} dilution.The unexpected microbial enumeration results were likely caused by culture contamination, as enumeration results indicated that microorganisms in the other samples treated with lower UV-C dosages were not detected.

Based on the observations of both the standard plate count and yeasts and moulds count, the UV-C treatment across all selected dosages demonstrated a notable bactericidal effect on the noodle samples, as the initial microbial count was reported as not detected. Furthermore, the results also indicated that all the detected microorganisms were observed in samples without modified atmosphere packaging (MAP). As a result, it is concluded that UV-C treatment combined with MAP may help the product to obtain a longer shelf life.

Since yeasts and moulds were detected in the sample treated with a UV-C dosage of 50 mJ/cm², this indicates that this level of UV-C dosage may not be sufficient to suppress the growth of microorganisms. As the Hokkien noodle was parboiled, the high moisture content of the product may provide a suitable environment for microbial growth, and additional methods are necessary to be used together to extend the product's shelf life.

Based on the observations from pH and water activity measurements, the UV-C dosage of 110 mJ/cm² combined with modified atmosphere packaging was selected for use in the phase two experiment, as this combination is expected to provide sufficient germicidal efficacy while maintaining the texture (preventing breakage) of the Hokkien noodle product.

However, as the differences in microbial counts between the control and treated samples in this study were relatively small, future studies should further investigate the effectiveness of UV-C treatment and MAP using a more targeted experimental design. A challenge study, in which the noodles are inoculated with a known concentration of selected microorganisms after parboiling, could provide a more sensitive and controlled assessment of the efficacy of UV-C inactivation and the subsequent effects of MAP during storage. Inoculation with bacteria and yeasts and moulds at defined initial levels would enable treatment effects to be evaluated from a consistent microbial starting population and would increase the likelihood of obtaining counts within the quantifiable range of the enumeration method (approximately 10–300 CFU per plate). This approach would also allow the magnitude of microbial reductions achieved by different UV-C doses and packaging conditions to be more accurately quantified.

Alternatively, future experiments could also evaluate the application of UV-C and MAP to chilled noodles with a near-neutral pH. This study used acidified noodles with a pH of approximately 4.6, which may have inherently restricted the growth of many microorganisms in both control and treated samples, thereby reducing the observable differences between treatments during storage. Using noodles with a near-neutral pH may provide more favourable conditions for microbial proliferation in the untreated control, thereby increasing the potential for determining the effects of UV-C treatment and MAP on microbial growth. Together, these approaches could provide a more robust assessment of the individual and combined effects of UV-C and MAP on microbial inactivation and subsequent microbial growth, while also allowing the optimal UV-C dose to be evaluated in relation to both microbial reduction and preservation of noodle quality.

Chapter 4. Characterization of Hokkien Noodle Packaging Using Modified Atmosphere Packaging and UV-C Treatment at a Dosage of 110 mJ/cm²

4.1 Introduction

The results obtained from the preliminary experiment indicated that the optimum preservation method of pre-cooked Hokkien Noodle in this study was a UV-C treatment at a dosage of 110 mJ/cm² combined with modified atmosphere packaging. This combination may be able to maintain a balance between microbial safety as well as overall organoleptic acceptance of the product. During this first pahse, the pre-cooked Hokkien noodles were prepared, treated with UV-C light at a dosage of 110 mJ/cm², packaged using modified atmosphere packaging, and stored under chilled conditions at 4°C. In the second phase of the experiment, pH value and water activity measurements were still conducted. Additionally, other key parameters, including colour profile and texture (springiness), were assessed to evaluate the quality of the product. For microbial evaluation, the *Enterobacteriaceae* (EB) test was introduced at this stage to assess environmental hygiene to ensure product safety. The noodle samples were then evaluated over a storage period of 42 days. The analysis of Hokkien noodles was performed in duplicate, with two bags of control samples and two bags of UV-C treated samples (at a dosage of 110 mJ/cm²) analysed at a 7-day interval.

The objectives of the Phase Two experiment were to:

- determine the bacterial growth suppression of the combination of UV-C treatment at a dosage of 110 mJ/cm² with modified atmosphere packaging.
- determine the antifungal potency of the combination of UV-C treatment at a dosage of 110 mJ/cm² with modified atmosphere packaging.
- assess the overall quality and acceptability of the product through the evaluation of important characteristics.
-

4.2 Materials and Methods for Phase Two Experiment

This section outlines the materials and methods utilised in the phase two experiment. Materials and methods previously detailed in the preliminary experiment will not be repeated here. In addition to pH and water activity measurements, other instrumental measures, such as colour and texture (springiness), were included in the phase two study to obtain a more comprehensive understanding of changes in product quality over the storage period. The fresh noodles were treated with the optimum UV-C dosage and MAP in phase two, and their shelf life was studied under 4°C storage temperature for a 42-day storage period. An investigation of the physiochemical attributes and food quality changes of the noodle product was conducted for both UV-C treated and control samples. The *Enterobacteriaceae* (EB) test was incorporated into the phase two experiment to guarantee environmental hygiene throughout the entire manufacturing and storage process. Therefore, standard plate count (SPC), Yeast & Moulds, *Enterobacteriaceae*, pH, colour, texture (springiness) and water activity were measured in the phase two study.

4.2.1 Preparation of UV-C Treated Hokkien Noodle Sample for Phase Two

Two batches (the actual yield of Hokkien noodles was about 1200 grams) of pre-cooked Hokkien noodle samples were prepared in the Massey University, Auckland, food processing lab for final analysis. The noodles were divided into fifty-six samples for physiochemical attributes (eg, colouring, pH, stringiness) and microbial testing (56x20g).

Half of the samples were subjected to UV-C treatment at an intensity of 110 mJ/cm² and then packed in food-grade vacuum bags using modified atmosphere packaging with nitrogen gas. The remaining half of the samples were designated as controls and were packaged in food-grade vacuum bags without undergoing UV-C treatment or modified atmosphere packaging (MAP). All the samples were stored in the fridge to ensure the storage temperature was within the range of 4±2°C before the experimental tests started.

4.2.2 Enterobacteriaceae

The *Enterobacteriaceae* (EB) test was conducted to evaluate the hygiene of the environment, ensuring the safety of the products and the absence of sanitation issues. This microbial technique is applied when the expected number of colonies is more than 100 per millilitre or gram of the test sample. As described in ISO 21528-1 (ISO, 2017), the most probable number (MPN) method is usually employed when the expected number is less than 100 per millilitre or gram of the test sample (ISO 21528-1). The noodle samples were serially diluted by factors of 10 (diluted to 10^{-1}) in duplicates and plated onto Violet Red Bile Glucose (VRBG) agar and then incubated at 37 °C for 24 hours to detect the presence of typical colonies of *Enterobacteriaceae*. The number of colonies was calculated as follows:

$$\textit{Enterobacteriaceae}\ \text{Count (CFU/mL)} = \frac{\text{number of colonies}}{\text{dilution factor}} \times \frac{1}{\text{volume plated}}$$

4.2.3 Colour Measurement

The colour development of the Hokkien noodle samples was determined using the CIE - L*a*b*colour system. CIE - L*a*b* values were measured with a colourimeter (Minolta CR200) following the manufacturer's guidelines. The noodle samples were cut into small pieces and evenly placed into a plastic petri dish. The samples were gently compressed to minimise the scattering of illumination. The colourimeter was calibrated against the standard calibrating pad and the calibration data were compared with the standard data (L*, a*, b* colour values) obtained from the instrument under D65 illuminant with 2° standard observer, calibrated against the white standard plate supplied with the instrument); Following calibration, the Petri dish containing the noodle sample was measured in triplicate, and the average of the measurement results was recorded as the final result for the sample.

In the phase two experiment, both the chroma difference (ΔC) and the overall colour difference (ΔE) were calculated to illustrate the colour profile of the product over a 42-day storage period (Markovic et al., 2013).

C* stands for Chroma, and the a* and b* values correspond to green and yellow, respectively, as measured by the colourimeter (Minolta CR200). The difference in colour chroma between the two samples was calculated using Equation (3) as follows:

$$\Delta C = \sqrt{\Delta a^{*2} + \Delta b^{*2}} \quad \text{.....(3)}$$

where

Δa^* = $(a1^*)$ − $(a2^*)$ .....(4)

Δb^* = $(b1^*)$ − $(b2^*)$..... (5)

In addition, the overall colour difference was determined by ΔE using the following equation. According to Markovic et al. (2013)., a ΔE value greater than 3 indicates a significant colour difference, which is easily noticeable between samples. When ΔE values are between 1.5 and 3, the difference is not obvious and may be only perceptible to a trained observer. A ΔE value below 1.5 indicates that the difference is hardly perceptible to the human eye (Bona, et al., 2015).

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad \text{.....(6)}$$

where

ΔL^* = $(L1^*)$ − $(L2^*)$.....(7)

4.2.4 Texture (Springiness) Measurement

According to Ross (2006), the quality of the noodles is predominantly characterised by their texture and appearance. The texture of Chinese Hokkien noodles should be chewy and exhibit good elasticity. Therefore, tapioca starch was introduced during the product development stage to enhance the elasticity of the Hokkien noodles. According to Wang et al., 2003, noodle

extensibility analysis (TEA) is primarily utilised for pre-cooked noodles. Therefore, TEA was selected to evaluate the springiness of the product. The springiness measurement was performed by using a TA.XT Plus texture analyser (Stable Micro Systems Ltd, the United Kingdom) equipped with a pair of plastic L-shaped tensile probes (A/SPR). One probe was placed on the platform, while the other was connected beneath the moving components. A single noodle string was twined to both L-shaped probe, with no pulling force applied. The initial distance between the two apparatuses was predetermined and recorded. As the upper *apparatus* ascended at a specified speed (2.00 mm/sec) to its final position, it is anticipated that the string will break before the apparatus returns to its initial position. The tensile force and extended distance of the probe movement were recorded. Figures 4.1 and 4.2 below present the characteristic parameters for TEA and schematic illustrations of the springiness measurement, respectively.

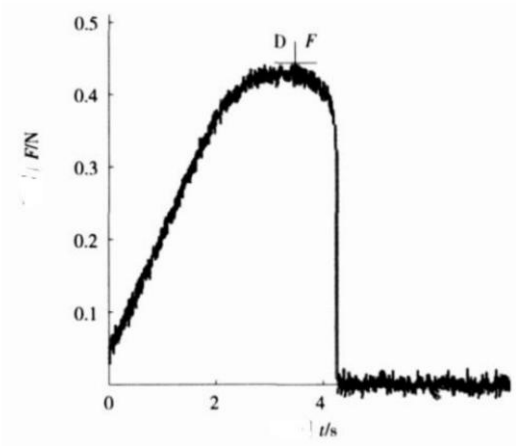


Figure 4.1: The Characteristic Parameters for TEA (Li, 2008).

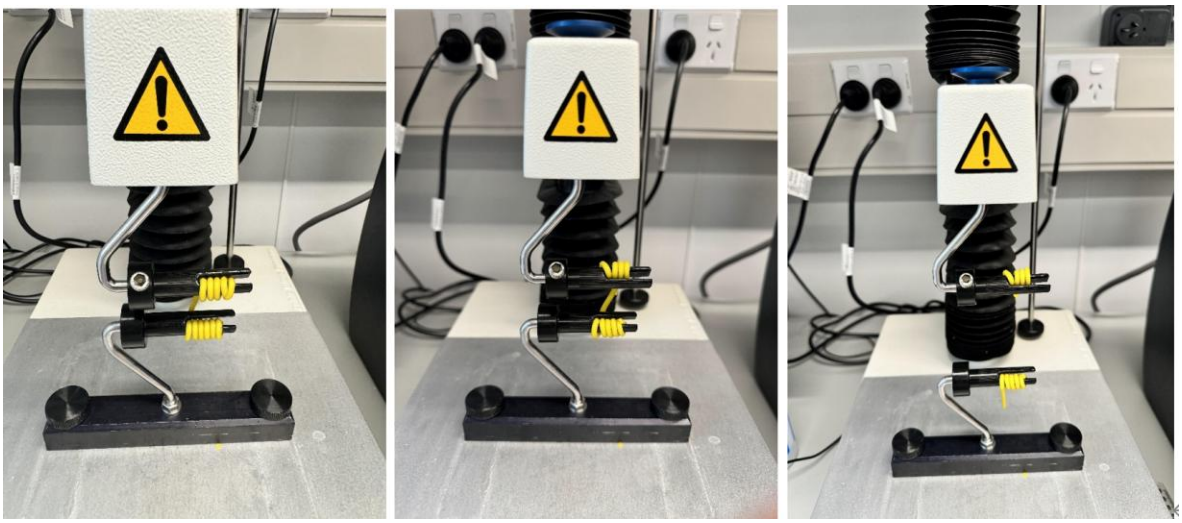


Figure 4.2: Springiness Measurement Schematic Pictures using TA.XT Plus (Stable Micro Systems Ltd, the United Kingdom)

Figure 4.1 illustrates that, in the texture (springiness) measurement process, the tensile force reaches its maximum value just before the string breaks. The peak force (F) and the time required to reach this peak (D) were recorded (Chen, J., 2020). Therefore, tensile force and extended distance were utilised to assess changes in springiness in the pre-cooked Hokkien noodle samples over a 42-day storage period.

4.2.5 Microbiological testing

Violet red bile glucose (VRBG) agar was purchased from Thermo Fisher Scientific (Auckland, New Zealand). Plastic petri dishes for colour measurement were obtained from the food processing laboratory, Massey University, Auckland, New Zealand.

For the *Enterobacteriaceae* (EB) test, 39.5 g of the Violet Red Bile Glucose (VRBG) medium was dissolved in 1 litre of distilled water and allowed to soak. The mixture was brought to boil in the microwave to fully dissolve the powder. After that, continue boiling for about 2 minutes to dissolve completely with frequent agitation. Then, the solution was cooled down to about 45°C. VRBGA was sterilised by autoclaving as per the manufacturer's instructions.

4.3 Results and Discussion for Phase Two Experiment

Phase two of the experiment was conducted to evaluate the germicidal effectiveness of the combination of UV-C treatment at a dosage of 110 mJ/cm² with modified atmosphere packaging, in addition to evaluating the overall quality and acceptability of the noodle samples. The results of the ANOVA test are outlined in the appendices.

4.3.1 pH of samples

The pH values were measured for control samples, and the samples were treated with a UV-C dosage of 110 mJ/cm² under modified atmosphere packaging in the phase two experiment. All the samples were chilled and stored at 4 °C for a 42-day storage period. In the initial phase of the experiment, the Hokkien noodle samples that were acidified by lactic acid showed an initial pH value of 4.63 for both the control samples and the UV-C treated samples packed with MAP.

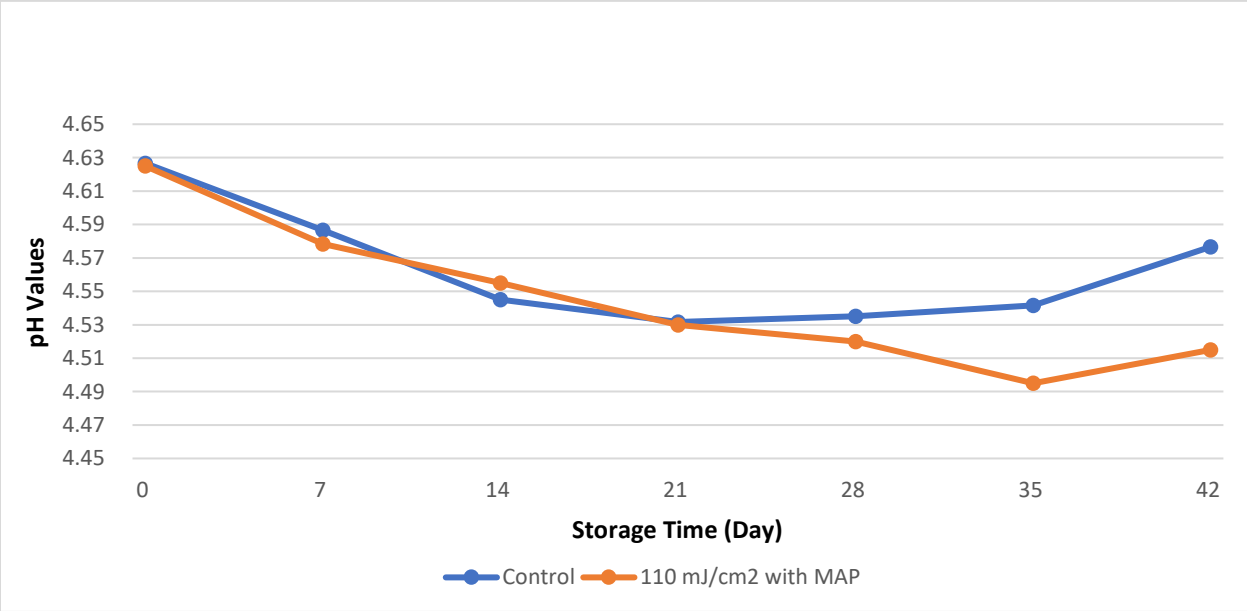


Figure 4.3: pH Measurement Results for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

Note: C=Control; 110M=110 mJ/cm² MAP

Figure 4.3 shows that the pH values of both the control and UV-C treated samples decreased over the storage period and converged on Day 21. The pH value of the control samples increased from Day 21, reaching 4.58 by the end of the storage period (Day 42). In contrast, the pH value of the UV-C treated samples continued to decrease until Day 35, followed by a slight increase to 4.52 by the end of the storage period (Day 42).

Disregarding moisture content, both sample groups can be considered acidified foods by the end of the storage period as the pH values were below 4.6. The decrease in pH value in Hokkien noodle samples during storage period was because of the microbial fermentation and enzymatic activity which produced organic acids such as acetic acid. These bacteria metabolise sugars and other carbohydrates present in the noodles, generating acids, and as a result, the pH of the product was reduced. Additionally, since the samples were acidified by lactic acid to inhibit spoilage, this effect may further contribute to the gradual pH reduction over time. In this study, nitrogen (N_2) was utilised as the filler gas in modified atmosphere packaging (MAP) mixtures to replace oxygen (O_2). This approach helps to slow down the oxidative rancidity and suppress the growth of aerobic bacteria and moulds. However, it also promotes the growth of lactic acid bacteria, which are anaerobic and more tolerant of low-oxygen conditions, allowing them to continue producing acid throughout the storage period. Therefore, the pH value of the control samples increased from Day 21, while the pH of the UV-C treated samples continued to decrease until Day 35. The pH of samples increased at the end of the storage period, likely due to the depletion of available sugars and carbohydrates in the noodle products, thereby slowing the activity of organic acids. Other factors, such as the growth of fungi (yeasts and moulds), began to consume the nutrients in the noodle product, resulting in the production of alkaline by-products that subsequently increased the pH of the product.

The ANOVA test was conducted at a 95% confidence level, and the p-value for the effect of storage duration was reported as 0.001 as shown in Appendix B14. Since the p-value is less than 0.05, it indicates that storage duration has a statistically significant effect on the pH of the noodle product. Although the pH values of the noodle samples were below 4.6 at the end of the storage period, the observed trend in Figure 4.3 indicates a likely increase in pH, which may not

be sufficient to inhibit the growth of bacteria and fungi. Therefore, additional methods are necessary to extend the shelf life of Hokkien noodles.

4.3.2 Water Activity Measurement Results

The water activity (a_w) was measured in duplicate for both control samples and samples treated with a UV-C dosage of 110 mJ/cm² under modified atmosphere packaging, at 7-day intervals over a 42-day storage period.

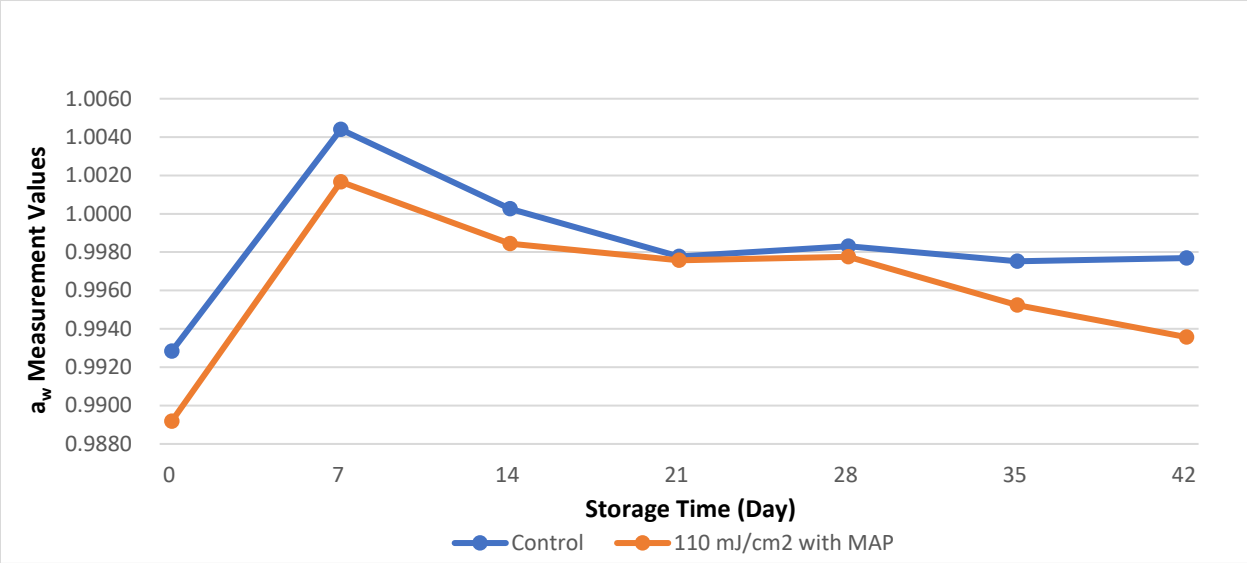


Figure 4.4: Water Activity Measurement Results for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

Note: C=Control; 110M=110 mJ/cm² MAP

The initial water activity of controls and UV-C treated samples was 0.9928 and 0.9892, respectively. By Day 7, the water activity increased to 1.0044 for the control samples and 1.0017 for the UV-C treated samples. As shown in Figure 4.4, after Day 7, the a_w began to decrease for both groups of samples until Day 21. Then, a slight increase in water activity (aw) was observed by Day 28 for both samples. After Day 28, the a_w of control samples slightly decreased again and then increased to 0.9977 at the end of the storage period (Day 42). The a_w of UV-C treated samples dropped, reaching 0.9936 at the end of the storage period. Apart from the sharp increase

observed at the beginning of storage (Day 0 to Day 7), the a_w of the control samples remained relatively stable. The difference in aw between Day 21 and Day 28 was minimal, whereas the a_w of the UV-C treated samples showed a continuous decline with increasing storage time from Day 7 onwards.

The initial water activity of parboiled Hokkien noodles was approximately 1. Moisture content is a critical factor as it affects the texture, microbial stability, and overall freshness of the noodle products. The high a_w helps to prevent the breakage of noodle stripe. However, fungi can survive when the a_w low as 0.7 and when the a_w of foods is less than 0.85. Therefore, it may lead to spoilage and a shorter shelf life. The samples treated with a UV-C Dosage of 110 mJ/cm² showed a slightly lower water activity. This is likely due to the UV-C light primarily acting on the surface of the noodles and removing the surface moisture of the product. MAP was utilised to further enhance the stability and shelf life of the noodles. Meng et al. (2012) noted that the application of nitrogen within MAP may reduce water activity, thereby limiting microbial migration into deeper tissues.

An initial increase in water activity during storage may be attributed to the storage conditions. After cooking the Hokkien noodles in boiling water for about one minute, they were cooled to room temperature, then packed in vacuum-sealed bags, and stored in refrigeration following all treatments. Therefore, the initial increase in water activity at the beginning of the storage period was likely due to condensation. The noodle samples were initially exposed to room temperature to complete all the treatments. After that, they were moved to the refrigerator for storage at a chilled temperature. As the storage environment changed from a warmer to a cooler condition, a slight condensation may have occurred inside the packaging and increased the water activity. Additionally, the noodle samples were packed in a sealed MAP environment, allowing moisture within the product to redistribute and increase surface moisture, which led to a higher measurable water activity by Day 7.

A decreasing trend in water activity was observed over the storage period for both groups of samples. The growth of microorganisms and oxidative processes may consume oxygen and produce water as a byproduct within the sealed bag, which may result in the relative stability of

water activity in the control samples over storage. However, in the MAP with nitrogen, the displacement of oxygen within the packaging reduced microbial activity and oxidative reactions, which would otherwise generate additional water and increase a_w. This may lead to a more obvious decrease in the overall water activity of the UV-C treated samples at the end of the storage.

An ANOVA test was conducted to compare the water activity of the control and UV-C–treated samples. As shown in Appendix B15, the p-value for the effect of storage duration was 0.001, which is below the 0.05 significance threshold, indicating that storage duration has a statistically significant impact on water activity between the two groups.

4.3.3 Colour Measurement Results

The colour development of Hokkien noodle samples was analysed using the CIE L* a* b* system, which is a widely used method for describing colours based on human visual perception. The UV-C treated samples were compared to the control samples to evaluate the colour differences and assess the efficacy of the UV-C light treatment in combination with modified atmosphere packaging throughout the storage period.

The control and UV-C treated Hokkien noodle samples were stored at 4 ˚C to monitor colour changes over a 42-day storage period. The colour, or chroma of the noodle samples was obtained through the addition of tartrazine. At the beginning of storage, the initial lightness of both sample groups was approximately 92. As shown in Figure 4.5, lightness in both groups increased slightly by Day 7, followed by a substantial decline to around 70 by Day 21. For the control samples, lightness continued to decrease until Day 28, then it increased, reaching 69.74 by the end of the storage period (Day 42). The lightness of the UV-C treated samples that were packed under modified atmosphere conditions was observed to steadily increase and reached 75.3 by Day 42. The decrease in L* values indicates that the colour of the noodle samples became darker, and the colour change over time is likely due to a non-enzymatic browning reaction. The CIE a* values for both sample groups initially increased, followed by a significant decrease by Day 7.

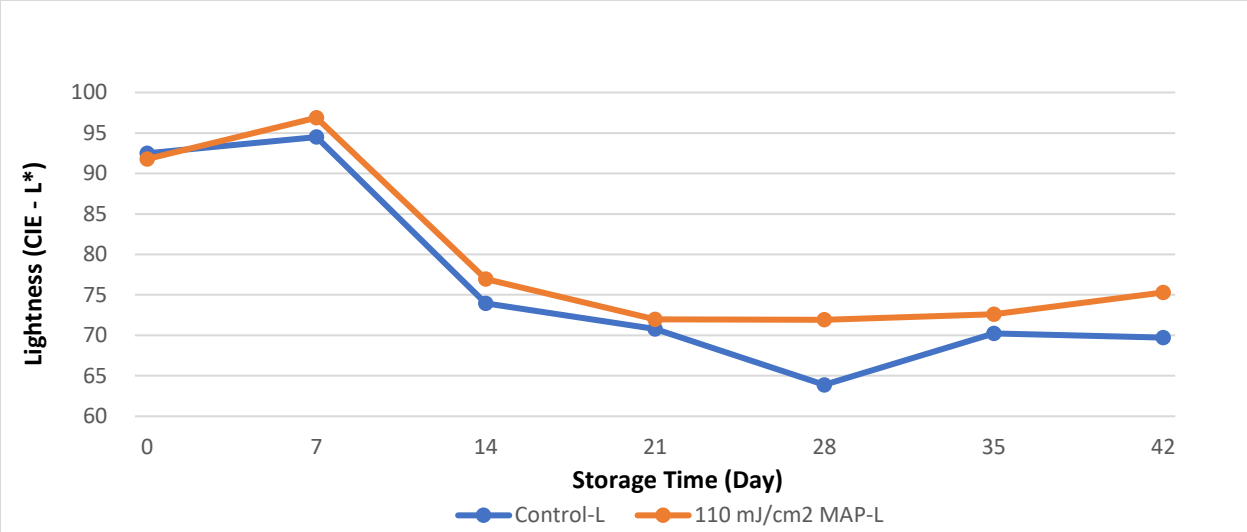


Figure 4.5: Colour Measurement Results (Lightness) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

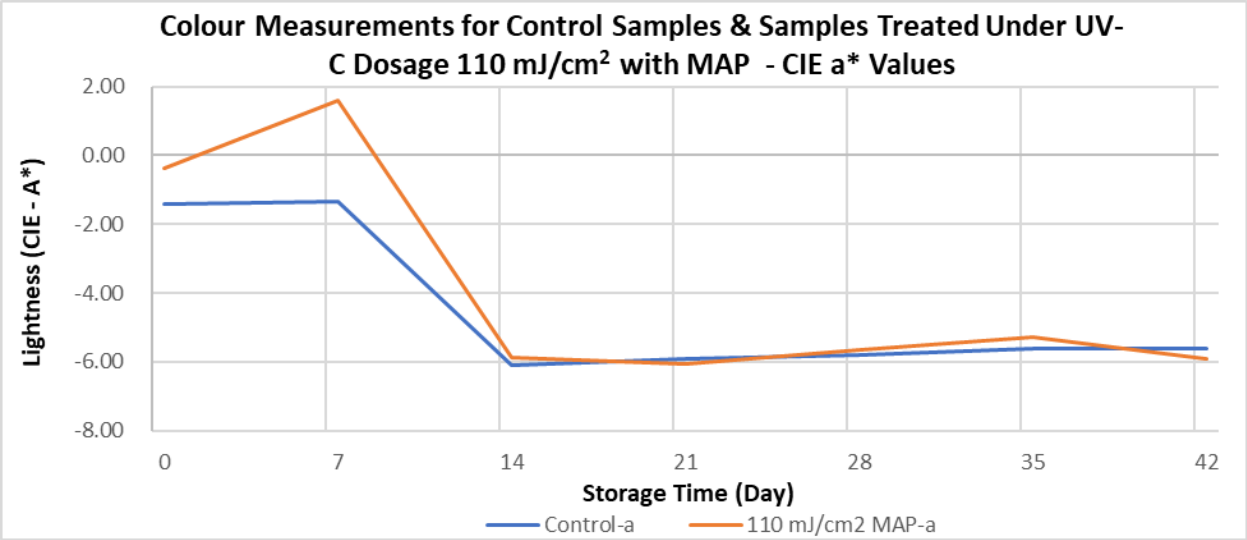


Figure 4.6: Colour Measurement Results (CIE-a*) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

As shown in Figure 4.6, the trends for both groups stabilised after Day 14. The increase in CIE a* values indicate a shift in colour from green to red, and vice versa. Thus, the samples initially appeared redder, then gradually shifted back toward green by the end of the storage period.

The CIE b* values for both sample groups initially showed a slight decrease, followed by a sharp increase to approximately the middle of 50 by Day 14, as observed in Figure 4.7.

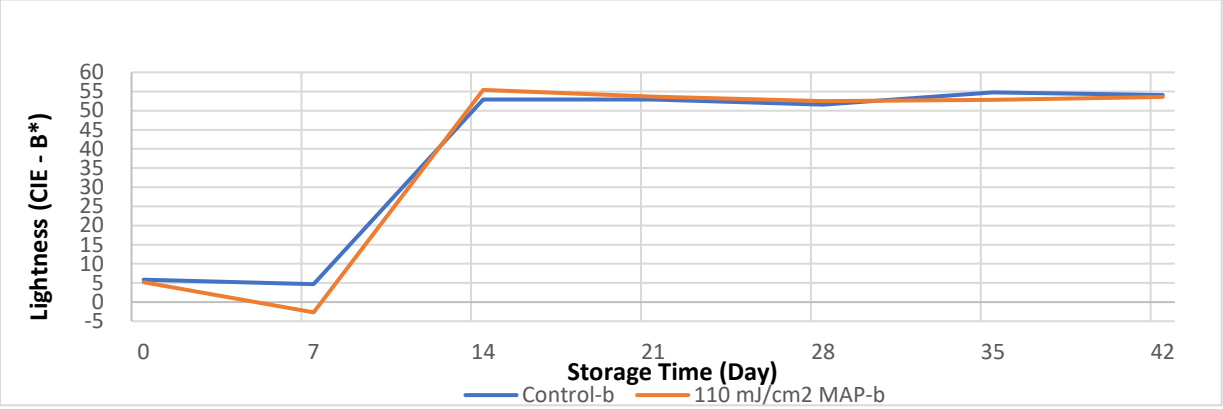


Figure 4.7: Colour Measurement Results (CIE-b*) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

Thereafter, the b* values remained stable. A decrease in b* values reflect a colour shift from yellow to blue, and vice versa. The overall increase in b* values over the storage period suggests the formation of new brown pigments through non-enzymatic browning, consistent with findings in the literature (Zhu, 2010). The observed trend for both groups aligns with the previous research. The initial decrease in b* values may be attributed to the inclusion of 0.05% tartrazine in the formulation, which significantly enhanced the bright yellow hue of the noodle samples and could potentially influence the measurement results of the b* values.

Table 4.1: Colour Profile Difference for Control Samples over a 42-day Storage at 4˚C

Control	Day 0	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42
ΔE	N/A	2.34	52.63	3.20	7.00	7.11	1.07
ΔC	N/A	1.20	48.46	0.19	1.31	3.17	0.93
ΔL^*	N/A	-2.01	20.53	3.19	6.88	-6.36	0.52
Δa^*	N/A	-0.10	4.75	-0.19	-0.09	-0.19	-0.62
Δb^*	N/A	1.20	-48.23	0.00	1.30	-3.16	0.70

Note: N/A= Not available.

Table 4.2: Colour Profile Difference for Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

110 mJ/cm² MAP	Day 0	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42
ΔE	N/A	9.57	61.86	5.30	1.25	0.88	2.86
ΔC	N/A	8.11	58.57	1.79	1.25	0.56	0.96
ΔL^*	N/A	-1.98	7.46	0.21	-0.40	-0.39	0.62
Δa^*	N/A	7.86	-58.09	1.77	1.19	-0.40	-0.73
Δb^*	N/A	-5.09	19.93	4.99	0.04	-0.68	-2.70

Note: N/A= Not available.

Table 4.3: Colour Comparison Differences between Controls and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage Period

Parameters	Day 0	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42
ΔE	0	7.23	9.24	2.11	-5.75	-6.23	1.80
ΔC	0	6.90	10.11	1.60	-0.06	-2.61	0.03

Chroma describes the intensity of a colour, and the chroma difference (ΔC) represents the variation in colour intensity between two colours. As shown in Table 4.1, the initial ΔC for both the control and UV-C treated samples (obtained by comparing to the fresh samples made on Day 0), were calculated as 1.20 and 8.11, respectively. After that, the ΔC increased sharply during the storage period, reaching peak values of 48.46 and 58.57, respectively. Subsequently, the chroma difference declined and remained low with minor fluctuations until the end of the storage period.

The overall colour difference (ΔE) was used to quantify the difference between two colours. Table 4.2 shows a similar pattern of ΔE compared with ΔC. The ΔE values of both sample groups increased at the beginning, reached peak values and were followed by a sharp decrease with a few fluctuations until the end of the storage period. The ΔE values of the control samples calculated from Day 14 to Day 35 (52.63, 3.2, 7, 7.11) indicated noticeable colour differences that could easily be perceived by an untrained observer, as the calculated ΔE values were greater than 3. For UV-C treated samples packed under MAP conditions, the ΔE values calculated for Day 7 and Day 14 (8.11, 58.57) also showed apparent colour differences. A particularly large colour difference was observed in both sample groups on Day 14.

Tables 4.2 and 4.3 indicate that the control samples exhibited a more pronounced colour difference throughout the storage period compared with the UV-C treated samples. This suggests that the control samples underwent more significant colour changes, implying a faster decline in sensory quality compared to the UV-C treated samples, as appearance is closely linked to freshness and consumer appeal (Lawless & Heymann, 2010). The UV-C treatment suppressed microbial activity, while the modified atmosphere packaging displaced oxygen within the packaging to minimise oxidation of the product. Together, the combined treatments helped maintain the appearance of the noodles and thereby extend their shelf life. However, the ΔE values for both groups of samples were calculated to be less than 3 by Day 42, indicating that the consumer would not be expected to perceive the colour difference at the end of the storage period compared with the fresh Hokkien noodle.

The initial increase in chroma difference (ΔC) and overall colour difference (ΔE) observed in Hokkien noodle samples during storage was likely due to non-enzymatic browning reactions within the product. Given that the noodles contain both carbohydrates and proteins, browning reactions can occur between amino acids and reducing sugars at the start of storage. These reactions produce brown pigments, which enhance colour intensity and give the Hokkien noodle a more vivid (yellowish) appearance. Consequently, the newly formed pigments lead to a sharp increase in chroma and intensify the colour of the product during the initial phase.

Additionally, microbial growth may contribute to the discolouration, particularly in the early stages of storage. Microbial activity generated by-products that affect the colour of the samples, resulting in an increase in ΔC and ΔE. Furthermore, tartrazine was included in the formulation as a colouring to impart a bright yellow colour to the Hokkien noodles. It may only be temporarily stable in the early storage phase. The colour may break down rapidly upon exposure to factors such as light or oxygen, leading to significant colour changes due to pigment degradation or oxidation. This breakdown of colour compounds leads to a rise of ΔC and ΔE values as the colour of the samples changed quickly compared to the fresh sample.

Tables 4.2 and 4.3 also reveal a declining trend in ΔC and ΔE over the later stages of the storage period. This trend may be attributed to stabilised microbial activity, where metabolic processes slow down, resulting in minimal colour changes as storage progresses. Similarly, the degradation of colour pigments likely occurs predominantly in the initial stages, eventually reaching a chemical equilibrium as storage continues, resulting in a decrease in both ΔC and ΔE values.

Table 4.3 presents the colour parameter differences between UV-C treated samples stored under MAP conditions and control samples over the same storage period. The two groups exhibited a substantial difference in ΔC (>10) as well as a high ΔE value (>9). According to Table 4.3, UV-C treated samples showed a visible colour difference compared to control samples on Days 7, 14, 28, and 35, indicating a noticeable colour change in the Hokkien noodle product.

4.3.4 Texture (Springiness) Measurement Results

Springiness is a key quality attribute of traditional Chinese noodles, contributing significantly to the overall texture and mouthfeel. The springiness profile was assessed by measuring the tensile force (g) and extended distance (mm) using a texture analyser (TA.XT.Plus, Stable Micro Systems Ltd., United Kingdom).

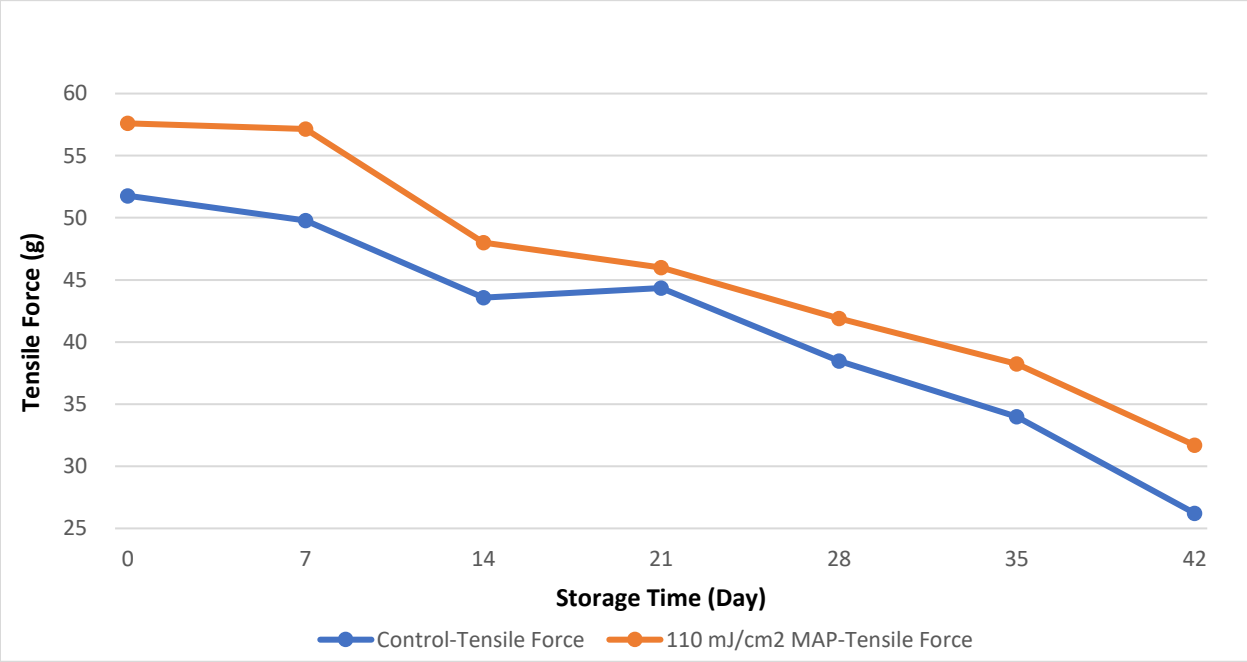


Figure 4.8: Tensile Force Measurement Results for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

Figure 4.8 demonstrates that UV-C treated samples stored under MA packaging conditions exhibited a relatively higher initial tensile force at the beginning of the storage period. Figure 4.8 further illustrates a gradually decreasing trend in tensile force for both sample groups. As observed, the tensile force for the control samples declined from 51.78 g to 26.23 g, while the UV-C treated samples showed a reduction from 57.6 g to 31.7 g over the storage period. An ANOVA test was conducted to compare the two sample groups, yielding a p-value of less than 0.0001 for the effect of storage duration (Appendix B16). Based on the Type III sum of squares

presented in Appendix B16, “Days” was the most influential explanatory variable, indicating that storage duration has a statistically significant impact on the tensile force between the two sample groups.

As shown in Figure 4.9, the extended distance exhibited a similar pattern to the tensile force. Figure 4.9 shows that the extended distance for both sample groups was similar during the initial storage period (up to Day 7).

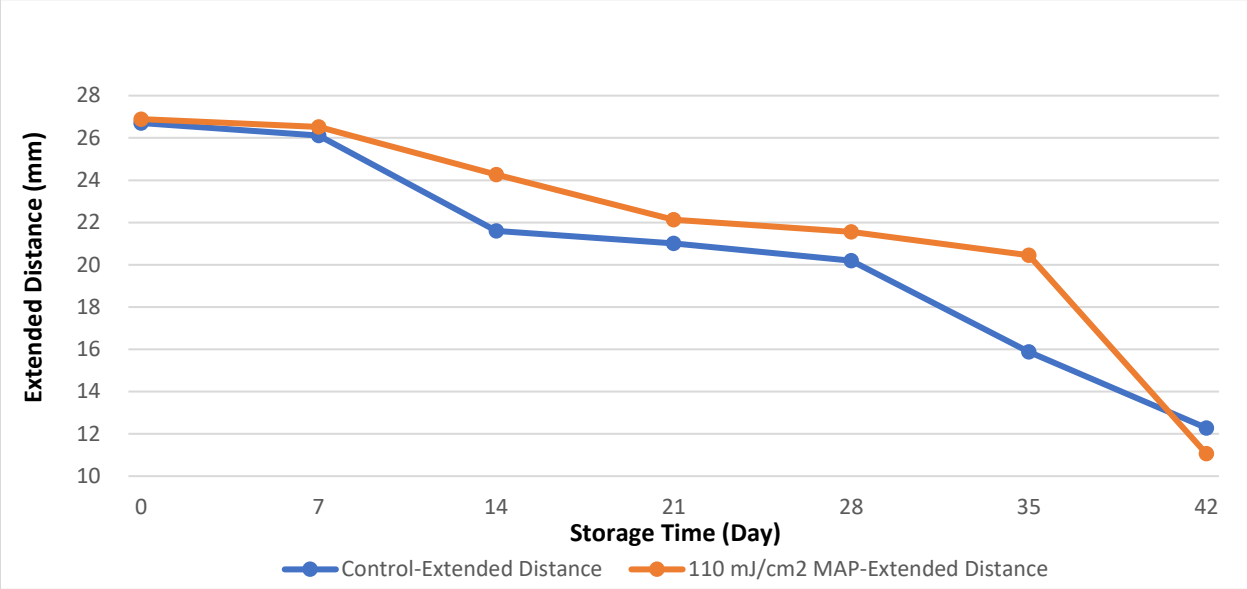


Figure 4.9: Tensile Force Measurement Results (CIE-b*) for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

A declining trend was observed over the storage period for both groups; however, the decline in UV-C treated samples was more gradual. Control samples experienced a sharp decrease after Day 28, ultimately reaching 12.28 mm by the end of storage. The sharp decrease for UV-C treated samples occurred on Day 35, reaching 11.06 mm by Day 42. As shown in Appendix B17, the ANOVA test yielded a p-value of less than 0.0001 for the effect of storage duration, which is below the 0.05 significance level. Similar to the tensile force analysis, “Days” was the dominant explanatory variable, demonstrating a statistically significant influence of storage duration on extension distance between the two sample groups.

The ANOVA results indicated that both the tensile force and extension distance of the noodle samples decreased progressively over the storage period at the 95% confidence level. In light of the data provided in Figures 4.8 and 4.9, these findings demonstrate that UV-C treatment and MA packaging were insufficient to maintain noodle springiness throughout storage, as evidenced by p-values of less than 0.05 for both tensile force and extension distance.

The reduction in the springiness of Hokkien noodles may be attributed to several factors, including the retrogradation of noodles, moisture content, storage, and the growth of microorganisms. As additional starch was included in this formulation, the gelatinised starch molecules tended to re-associate, leading to retrogradation as the product cooled, giving a more crystalline structure. This change reduces the elasticity and tensile force of noodles. Jeong and Lee (2023) reported that refrigerated storage accelerates starch retrogradation in pre-cooked noodles, causing water molecules to become trapped within the crystalline structure, thereby contributing to textural changes. Moisture loss during storage was also noted in the noodle samples during the storage. As Hokkien noodles aged, the reduced water content likely affected extensibility, making the noodles more brittle and prone to breakage, thus lowering the tensile strength of the product. Furthermore, as the microorganism's population increased over time, its microbial activity during storage can influence noodle structure. Some microorganisms can produce enzymes such as amylases and proteases may degrade structural components of the noodles, compromise the gluten network and break down starches and proteins. This degradation reduces the tensile strength and elasticity of the noodles, making them more prone to breaking under tension. Moreover, the spoilage bacteria and fungi that grow over the storage can produce organic acids and other metabolic by-products. These by-products can alter the pH of the noodles and weaken the gluten structure, further reducing tensile force and extending distance due to loss of elasticity. Last but not least, the traditional Hokkien noodles are coated with vegetable oil. The microbial activity may lead to lipid degradation and impact the texture and tensile properties of the noodles.

Li et al. (2011) reported that the deterioration in the noodle product texture was primarily due to microbial activity. Since UV-C treatment and modified atmosphere packaging are not effective in significantly slowing the decline in springiness, other alternative methods should be considered to further delay the decrease in tensile force in Hokkien noodles.

4.3.5 Standard Plate Count Enumeration for Phase Two Experiment

The standard plate count (SPC) is commonly used in food safety and quality control to evaluate the overall microbiological quality and shelf life stability of food products. SPC estimates the number of viable aerobic and facultatively anaerobic microorganisms present in a food sample under the specified incubation conditions. It is widely used as an indicator of the hygienic quality of food because high microbial counts may reflect inadequate processing, handling, sanitation, or storage conditions. In addition, increasing SPC values during storage may indicate microbial increase and the onset of food spoilage, which is useful for assessing the effectiveness of preservation treatments. Since the Hokkien noodle samples in this study were prepared and packaged in the food processing laboratory at Massey University, the SPC test was selected to monitor changes in the overall microbial population and to evaluate the microbiological stability of the noodles during refrigerated storage. The SPC was conducted in duplicate on both control samples and samples treated with a UV-C dose of 110 mJ/cm² under MAP conditions at 7-day intervals over a 42-day storage period at 4 °C.

Table 4.4: Standard Plate Count Results for Phase Two

Standard Plate Count			
Day	**Dilution**	**Control**	**110 mJ/cm² under MAP**
		Microbial Count (cfu/plate)	
0	10^{-1}	2	<10
	10^{-2}	<10	<10
	10^{-3}	<10	<10
7	10^{-1}	3	<10
	10^{-2}	<10	<10
	10^{-3}	<10	<10
14	10^{-1}	5	<10
	10^{-2}	<10	<10
	10^{-3}	<10	<10
21	10^{-1}	11	<10
	10^{-2}	<10	<10
	10^{-3}	<10	<10
28	10^{-1}	34	<10
	10^{-2}	<10	<10
	10^{-3}	<10	<10
35	10^{-1}	118	8
	10^{-2}	13	<10
	10^{-3}	<10	<10
42	10^{-1}	198	15
	10^{-2}	24	<10
	10^{-3}	1	<10

Note: Standard plate count was conducted in duplicate and the average result of the duplicates was used for data analysis.

On Day 0, the SPC count for control samples was recorded at 1.3 $\log_{10}$ CFU/g for the 10^{-1} dilution, while the initial SPC count for all dilutions in UV-C-treated samples was recorded as undetectable, as shown in Table 4.4. Over time, the SPC count for control samples increased slightly, reaching 1.5 $\log_{10}$ CFU/g by Day 7 and 1.7 $\log_{10}$ CFU/g by Day 14 for the 10^{-1} dilution. In contrast, the SPC for UV-C-treated samples under MAP conditions remained not detected for all dilutions during the same period. The growth pattern of bacteria is similar to the observation from the preliminary experiment for both sample groups until Day 14 (the end of the preliminary experiment), which matches the preliminary study. The microorganisms in control samples were observed to enter the exponential phase after Day 28, and proliferated rapidly, reaching 2.5 $\log_{10}$ CFU/g for the 10^{-1} dilution and 3.1 $\log_{10}$ CFU/g for the 10^{-2} dilution by Day 35. In comparison, the SPC count for UV-C-treated samples under MAP conditions remained lower, reporting 1.9 $\log_{10}$ CFU/g for the 10^{-1} dilution on Day 35. At the end of the storage period, the SPC count for the control samples reached approximately 3.3 $\log_{10}$ CFU/g for the 10^{-1} dilution and 3.4 $\log_{10}$ CFU/g for the 10^{-2} dilution. The SPC for UV-C treated samples under MAP conditions reached 2.2 $\log_{10}$ CFU/g for the 10^{-1} dilution by Day 42.

The combination of heat treatment (cooked in boiled water for about 1 minute) and UV-C treatment effectively reduced the initial SPC bacterial load on the surface of Hokkien noodles. Consequently, the initial SPC count for UV-C-treated samples under MAP conditions was undetectable. MAP lowered oxygen levels within the packaging, creating an environment less conducive to aerobic bacterial growth. The SPC represents a broader group of bacteria, including various aerobic and facultatively anaerobic bacteria. Since many SPC bacteria are aerobic, reducing oxygen levels can significantly inhibit their growth. As a result, bacterial growth in UV-C-treated samples was observed to be very slow, with an SPC count of 1.15 log CFU/g recorded at the end of the storage period. However, UV-C light has limited penetration in solid foods, so microorganisms within the food matrix may not be fully inactivated and propagated during the late phase of the storage.

New Zealand's regulatory limits (national limits) for SPC in food products are set and enforced by the Ministry for Primary Industries (MPI) and the limits vary by product type. According to MPI's interpretation of SPC count, foods that undergo heat treatments, such as pasteurisation or cooking, should have a low SPC count (less than 3 log CFU/g to 4 log CFU/g) after processing (FSANZ, 2025). By the end of the storage period, bacterial growth in both sample groups was observed in the exponential phase. However, the SPC levels remained well below the national limits, indicating that both groups of Hokkien noodles remained suitable for consumption at the end of the storage period.

4.3.6 Yeasts and Moulds Enumeration for Phase Two Experiment

The yeast and mould (Y&M) count is commonly used in food safety and quality control to evaluate the presence of spoilage fungi in food products. The presence of yeasts and moulds may indicate inadequate hygiene practices, post-processing contamination, or conditions that favour fungal growth during storage. Yeasts are commonly associated with fermentation and spoilage of foods with relatively high moisture content, whereas moulds can cause visible deterioration, off-flavours, off-odours, and texture defects, thereby reducing product quality and shelf life. Monitoring Y&M counts during storage is therefore useful for evaluating the fungal stability of food products and the effectiveness of preservation treatments. Since the Hokkien noodle samples were stored under refrigerated conditions for an extended period, the Y&M test was selected to monitor fungal growth throughout storage. The yeast and mould counts for both the control and UV-C-treated samples under MAP conditions were below the detection limit at the beginning of storage and remained undetectable until Day 14.

Table 4.5: Yeasts and Moulds Count Results for Phase Two

Yeasts and Moulds			
Day	**Dilution**	**Control**	**110 mJ/cm² under MAP**
		Microbial Count (cfu/g)	
0	10^0	<10	<10
	10^{-1}	<10	<10
7	10^0	<10	<10
	10^{-1}	<10	<10
14	10^0	<10	<10
	10^{-1}	<10	<10
21	10^0	4	<10
	10^{-1}	<10	<10
28	10^0	5	<10
	10^{-1}	<10	<10
35	10^0	8	<10
	10^{-1}	<10	<10
42	10^0	10	<10
	10^{-1}	<10	<10

An increase in yeasts and moulds was observed over time in the control samples. For the 10^0 dilution, the yeasts and moulds count was recorded as 0.4 log CFU/g on Day 21, 1.12 log CFU/g on Day 28, 1.15 log CFU/g on Day 35, and reached 1.23 log CFU/g by the end of the storage period. For the 10^{-1} dilution, yeasts and moulds count in the control samples were observed at 0.1 log CFU/g. The fungal growth was noted to be in the exponential phase for control samples by the end of the storage period. In contrast, the yeasts and moulds count for samples treated with a UV-C dosage of 110 mJ/cm² under MAP conditions remained undetectable over the 42-

day storage period in both the 10^0 and 10^{-1} dilutions. The growth of yeasts and moulds was observed in the exponential phase by the end of the storage period.

The heat treatment provided a germicidal effect on the Hokkien noodle, resulting in an initial yeast and mould load of 0 for both sample groups. Yeasts and moulds were detected in control samples by the mid-storage period (Day 21), as they generally have a slower growth rate compared to bacteria. In UV-C treated samples combined with MA packaging, the yeasts and moulds count remained undetectable by the end of the storage period. While UV-C treatment is somewhat effective against yeasts and moulds by damaging cellular DNA (Singh et al., 2021), its penetration is limited in solid foods (Fan et al., 2017). In particular, moulds can form spores that exhibit higher resistance to UV-C. A review of the literature in this study also indicates that yeasts and moulds are generally more resistant to UV irradiation compared to bacteria. Although UV-C can reduce surface-level yeasts and moulds count, it may not completely inhibit growth if viable spores persist or if UV-C light does not reach deeper tissues. The results shown in Table 4.5 demonstrate that UV-C treatment is effective in reducing yeasts and moulds growth when combined with MAP, as this slows down the growth of microorganisms.

Although the FSANZ documents do not provide specific guidelines for yeasts and moulds limits, a generally acceptable level for ready-to-eat foods is considered to be less than 2 log CFU/g (Gilbert et al., 2000). Accordingly, the yeasts and moulds count for both groups of Hokkien noodles are within acceptable limits and considered fit for consumption at the end of the storage period.

4.3.7 *Enterobacteriaceae* Enumeration for Phase Two Experiment

The *Enterobacteriaceae* (EB) test is commonly used in food safety and quality control to evaluate the hygiene, quality, and potential contamination of food products. The presence of EB may indicate inadequate hygiene practices during food processing, handling, or storage because this group of bacteria is normally associated with fecal contamination. The detection of EB can suggest potential contamination points in the production process. Additionally, high levels of EB also indicate poor quality or spoilage of foods, as bacteria can proliferate rapidly in inadequately processed or stored foods. Since the Hokkien noodle samples were produced and packaged in

the food processing laboratory at Massey University rather than sourced from a commercial facility, the EB test was chosen for phase two of the experiment to ensure food safety.

Table 4.6: *Enterobacteriaceae* Count Results for Phase Two

Enterobacteriaceae			
Day	**Dilution**	**Control**	**110 mJ/cm² under MAP**
		Microbial Count (cfu/plate)	
0	10^0	7	<10
	10^{-1}	<10	<10
7	10^0	4	<10
	10^{-1}	<10	<10
14	10^0	5	<10
	10^{-1}	<10	<10
21	10^0	9	3
	10^{-1}	<10	<10
28	10^0	11	6
	10^{-1}	<10	<10
35	10^0	16	6
	10^{-1}	<10	<10
42	10^0	13	4
	10^{-1}	<10	<10

On Day 0, the initial EB count was recorded at 0.85 $\log_{10}$ CFU/g for the control samples and was recorded as 0 for the UV-C treated samples under MAP conditions for the 10^0 dilution. The EB count showed a slight increase during storage, reaching a peak of 1.04 $\log_{10}$ CFU/g for the control samples and 0.78 $\log_{10}$ CFU/g for the UV-C treated samples for the 10^0 dilution in the later phase of the storage period (Day 28). The EB count On Day 35 was 1.20 $\log_{10}$ CFU/g in the control samples and 0.78 $\log_{10}$ CFU/g in the UV-C-treated samples at the 10^0 dilution. At the end of the

storage period (Day 42), the EB count decreased and finally reaching 1.11 $\log_{10}$ CFU/g for the control samples and 0.6 $\log_{10}$ CFU/g for the UV-C treated samples for the 10^0 dilution. The EB count has remained undetectable for the 10^{-1} dilution for both groups of samples. The growth pattern of EB differed from that of SPC and yeasts and moulds, as the EB numbers remained in the lag phase throughout the shelf life trial since the numbers were observed at low levels ranging from 7 to 16 CFU/g as shown in Table 4.6.

As shown in Table 4.6, the heat and UV-C treatments effectively reduced EB populations on food surfaces, inhibiting their growth and reproduction. From the literature review, EB are more sensitive to UV-C than yeasts and moulds, so the UV-C treatment can significantly reduce levels of EB, especially on the product's surface. However, similar to SPC, the limitation of UV-C penetration for solid foods means it may not be able to reach EB cells within the Hokkein noodle. Thereof, EB growth was observed over time, with viable cells detected by the mid-storage phase. In addition, as many EB are facultative anaerobes, they can survive in low-oxygen environments. MAP alone may not be sufficient to prevent EB growth completely, as some species in this family can grow in anaerobic or low-oxygen conditions. While not fully effective in eliminating EB, MAP can still reduce the growth rate of EB, especially if combined with other hurdles such as heat and UV-C treatments as well as refrigeration. This effect is evidenced by the lower EB counts observed in UV-C treated samples under MAP conditions compared to control samples, with a further decrease observed by the end of the storage period.

FSANZ does not specify a uniform regulatory limit for EB across all food products, as acceptable levels can vary based on the food type and processing conditions. Generally, limits for *Enterobacteriaceae* are set as quality indicators rather than safety standards, particularly in ready-to-eat and processed foods, where a low EB count is desired to indicate good hygiene and processing controls. For many ready-to-eat foods, the limit is below 2 log CFU/g. Therefore, EB count for both groups of Hokkien noodles remained well within the permissible limit and were deemed suitable for consumption by the end of the storage period.

4.3.8 Conclusion for Microbial Enumeration for Phase Two Experiment

The microbial counts for SPC, Y&M, and EB indicated that the noodles treated with UV-C at 110 mJ/cm² and stored under modified-atmosphere packaging (MAP) at 4 °C generally exhibited lower microbial counts than the control samples at the end of the storage period. However, the differences between the control and treated samples were relatively small; therefore, these findings should be interpreted cautiously and do not provide conclusive evidence that the combined UV-C and MAP treatment substantially inhibited microbial growth. The growth patterns differed among the microbial groups during storage, with EB counts declining towards the end of the storage period, whereas SPC and Y&M counts continued to increase. These differences may reflect the distinct physiological characteristics, environmental tolerances, and nutritional requirements of the microorganisms represented by each enumeration method.

As shown in Tables 4.4 to 4.6, the differences in growth patterns among SPC, EB, and Y&M may be associated with their respective growth rates and environmental tolerances. The SPC represents a broad population of viable microorganisms with diverse nutritional and physiological characteristics, and therefore the measured population may comprise microorganisms with different growth rates and adaptation periods. Some members of this population may remain capable of growth under the refrigerated and modified-atmosphere conditions applied in this study. Similarly, EB organisms generally require relatively favourable nutritional and moisture conditions and may be more sensitive to environmental stresses imposed by acidification, refrigeration, and reduced oxygen availability. The observed decline in EB counts may indicate that the EB number remained in lag phase over the shelf life trial as the numbers were at low levels.

In contrast, yeasts and moulds possess several characteristics that may enable them to persist under conditions that restrict the growth of many bacteria. Many fungi can tolerate acidic environments and relatively low water activity and may therefore remain viable under refrigerated and modified-atmosphere storage conditions. Consequently, the slower but continued increase in Y&M counts observed during storage may reflect their greater tolerance

to the environmental conditions of the product. However, the relatively low fungal counts observed throughout the study suggest that fungal proliferation remained limited and that the observed increase should not be interpreted as evidence of substantial spoilage.

The different microbial trends may also be influenced by competition for nutrients and available ecological niches within the noodle matrix. Microorganisms with different metabolic requirements may compete for available nutrients, while environmental stresses associated with acidification, refrigeration, reduced oxygen availability, and UV-C exposure may selectively affect different microbial groups. Nevertheless, because SPC, EB, and Y&M enumeration methods measure broad microbial groups rather than individual species, the specific mechanisms responsible for the observed differences cannot be established from the present data.

Overall, the observed microbial patterns indicate that SPC and Y&M populations remained detectable and showed some degree of increase during storage, whereas EB counts declined towards the end of the storage period. However, these differences should be interpreted in the context of the relatively low overall microbial counts and the limited differences between control and treated samples. The results therefore provide an indication of microbial changes during storage but are insufficient to establish definitive differences in microbial growth kinetics or to confirm that UV-C and MAP substantially extended the microbiological shelf life of the noodles.

4.4 Overall Conclusion

This study investigated the application of UV-C treatment and MAP as a multi-hurdle preservation strategy for improving the microbiological and physicochemical stability of pre-cooked Hokkien noodles during refrigerated storage at 4 °C. The study evaluated the effects of different UV-C doses on product quality and microbial reduction and subsequently examined the combined effects of the optimal UV-C treatment and MAP over a 42-day storage period.

The findings demonstrated that UV-C treatment was effective for surface decontamination within a defined dosage range. Among the doses evaluated (50, 110, 126, and 220 mJ/cm^2), 110 mJ/cm^2 was identified as the optimal treatment because it provided the best

balance between microbial reduction and preservation of noodle integrity. Higher UV-C doses did not produce proportionally greater microbial reductions and were associated with an increased risk of noodle breakage and textural deterioration. This finding is the principal outcome of the study and provides practical guidance for applying UV-C treatment to pre-cooked noodle products.

The physicochemical analyses showed that storage duration had a greater influence on product quality than either UV-C treatment or MAP. Although statistically significant changes in pH and water activity were observed over time, the magnitude of these changes was small, and no substantial differences were detected between the control and treated samples. Similarly, colour and springiness changed gradually during storage, but these changes were largely attributable to refrigerated storage rather than the preservation treatments. The slight decrease in pH (approximately 0.1 units) could not be conclusively attributed to microbial fermentation because lactic acid bacteria were not specifically enumerated and overall microbial growth remained limited throughout the study.

The microbiological results indicated that the combined UV-C and MAP treatment generally produced lower SPC, EB, and Y&M counts than the control samples at the end of storage. However, the differences between treatments were relatively small, and microbial proliferation remained limited under all storage conditions. Consequently, while the combined treatment showed potential for improving microbiological stability, the present results do not provide sufficient evidence to conclude that UV-C and MAP substantially enhanced microbial inhibition or extended shelf life under the experimental conditions investigated. Furthermore, the SPC method was conducted under aerobic incubation conditions and therefore did not enumerate strictly anaerobic microorganisms, such as *Clostridium botulinum*, thereby preventing assessment of the effectiveness of MAP against oxygen-sensitive pathogens.

Overall, this study demonstrates that the combination of UV-C treatment, MAP, acidification, and chilled storage represents a promising clean-label, multi-hurdle preservation approach for pre-cooked Hokkien noodles. However, the principal contribution of the research lies in identifying an appropriate UV-C dosage that achieves effective surface decontamination

without compromising product quality, rather than providing definitive evidence of shelf life extension through the combined preservation strategy. The relatively small microbiological differences observed between treatments suggest that these findings should be regarded as preliminary.

Future research should incorporate controlled microbial challenge studies using defined bacterial and fungal inoculation, together with anaerobic microbiological enumeration and monitoring of lactic acid bacteria and organic acid production. Such approaches would provide a more robust evaluation of the individual and combined effects of UV-C treatment and MAP on microbial inactivation, food safety, and the potential extension of shelf life in fresh noodle products.

References

Alnaimat, S., & Abushattal, S. (2012). Laboratory manual in general microbiology for undergraduate students: Short version.

André, A. C., Debande, L., & Marteyn, B. S. (2021). The selective advantage of facultative anaerobes relies on their unique ability to cope with changing oxygen levels during infection. *Cellular Microbiology*, *23*(8), 1–8. https://doi.org/10.1111/cmi.13338

Baird-Parker, T. C., Gould, G. W., & Lund, B. M. (2000). *The microbiological safety and quality of food / edited by Barbara M. Lund, Tony C. Baird-Parker, Grahame W. Gould*. Aspen Publishers.

Beaudry, R. M. (1999). Effect of O2 and CO2 partial pressure on selected phenomena affecting fruit and vegetable quality. Postharvest Biology and Technology, 15(3), 293–303. https://doi.org/10.1016/S0925-5214(98)00092-1

Blakistone, B. A. (1998). Principles and applications of modified atmosphere packaging of foods / edited by B.A. Blakistone (2nd ed). Blackie Academic & Professional.

Boal, D. (2001). Lecture 3 - Stellar luminosities [Microsoft Word document]. Simon Fraser University. Retrieved from https://www.sfu.ca/~boal/390lecs/390lec3.pdf

Caleb, O. J., Mahajan, P. V., Al-Said, F. A.-J., & Opara, U. L. (2013). Modified Atmosphere Packaging Technology of Fresh and Fresh-cut Produce and the Microbial Consequences—A

Review. Food and Bioprocess Technology: An International Journal, 6(2), 303–329. https://doi.org/10.1007/s11947-012-0932-4

Cameron, A. C., Beaudry, R. M., Banks, N. H., & Yelanich, M. V. (1994). Modified-atmosphere packaging of blueberry fruit: Modeling respiration and package oxygen partial pressures as a function of temperature. Journal of the American Society for Horticultural Science, 119(3), 534–539. https://doi.org/10.21273/jashs.119.3.534

Cao, Y., & Miao, L. (2023). Consumer perception of clean food labels. *British Food Journal, 125*(2), 433-448. https://doi.org/10.1108/BFJ-03-2021-0246

Chang, J. C. H., Ossoff, S. F., Lobe, D. C., Dorfman, M. H., Dumais, C. M., Qualls, R. G. A., & Johnson, J. D. (1985). UV inactivation of pathogenic and indicator microorganisms. Applied and Environmental Microbiology, 49, 1361–1365.

Chen, Y. J., Zhou, G. H., Zhu, X. D., Xu, X. L., Gao, F., & Tang, X. Y. (2007). Effect of low dose gamma irradiation on beef quality and fatty acid composition of beef intramuscular lipid. Meat Science, 75(3), 423–431. https://doi.org/10.1016/j.meatsci.2006.08.014

Chen, J. (2020). Application of essential oils to prolong the shelf life of the pre-cooked Asian noodle - Hokkien noodle : a case study of the systematic design approach : a thesis presented in partial fulfilment of the requirements for the degree of Master of Food Technology / Jiajun Chen, School of Food and Advanced Technology, College of Science, Massey University, Albany, New Zealand.

Chun, H. H., Kim, J. Y., Lee, B. D., Yu, D. J., & Song, K. B. (2010). Effect of UV-C irradiation on the inactivation of inoculated pathogens and quality of chicken breasts during storage. Food Control, 21(3), 276–280. https://doi.org/10.1016/j.foodcont.2009.06.006

Christiansson, A. (2011). PATHOGENS IN MILK | Bacillus cereus. In (pp. 24-30).

Cilliers, F. P., Gouws, P. A., Koutchma, T., Engelbrecht, Y., Adriaanse, C., & Swart, P. (2014). A microbiological, biochemical and sensory characterisation of bovine milk treated by heat and ultraviolet (UV) light for manufacturing Cheddar cheese. Innovative Food Science and Emerging Technologies, 23, 94–106. https://doi.org/10.1016/j.ifset.2014.03.005

Civello, P. M., Vicente, A. R., & Martinez, G. A. (2006). UV-C technology to control postharvest diseases of fruits and vegetables. Postharvest Biology and Technology, 39(3), 247–254.

Condón-Abanto, S., Condón, S., Raso, J., Lyng, J. G., & Álvarez, I. (2016). Inactivation of *Salmonella* typhimurium and Lactobacillus plantarum by UV-C light in flour powder. Innovative Food Science and Emerging Technologies, 35, 1–8. https://doi.org/10.1016/j.ifset.2016.03.008

Csapó, J., Prokisch, J., Albert, C., & Sipos, P. (2019). Effect of UV light on food quality and safety. *Acta Universitatis Sapientiae, Alimentaria, 12*, 21–41. https://doi.org/10.2478/ausal-2019-0002

Della Bona, A., Pecho, O. E., Ghinea, R., Cardona, J. C., & Pérez, M. M. (2015). Colour parameters and shade correspondence of CAD–CAM ceramic systems. Journal of Dentistry, 43(6), 726–734. https://doi.org/10.1016/j.jdent.2015.02.015

Diep, S., Scanlon, M., Daugelaite, D., Hatcher, D., Strybulevych, A., & Page, J. (2014). Use of ultrasound to discern differences in Asian noodles prepared across wheat classes and between varieties. Canadian Journal of Plant Science, 94(3), 525–534. https://doi.org/10.4141/CJPS2013-043

Dodds, K. L., & Farber, J. M. (1995). Principles of modified-atmosphere and sous vide product packaging (pp. 175–204) / edited by Jeffrey M. Farber, PhD., Karen L. Dodds, Ph.D. Technomic Publishing Company, Inc.

Doulia, D., Katsinis, G., & Mougin, B. (2000). International Journal of Food Properties, 3(3), 447–457.

Elias, M., Wieczorek, G., Rosenne, S., & Tawfik, D. S. (2014). The universality of enzymatic rate–temperature dependency. *Trends in Biochemical Sciences, 39*(1), 1–7. https://doi.org/10.1016/j.tibs.2013.11.001

Fan, X., Huang, R., & Chen, H. (2017). Application of ultraviolet C technology for surface decontamination of fresh produce. Trends in Food Science & Technology, 70, 9–19. https://doi.org/10.1016/j.tifs.2017.10.004

Farber, J. M. (1991). Microbiological aspects of modified-atmosphere packaging technology - A review. Journal of Food Protection, 54(1), 58–70. https://doi.org/10.4315/0362-028X-54.1.58

Farber, J. N., Harris, L. J., Parish, M. E., Beuchat, L. R., Suslow, T. V., Gorney, J. R., Garrett, E. H., & Busta, F. F. (2003). Microbiological safety of controlled and modified atmosphere packaging

of fresh and fresh-cut produce. Comprehensive Reviews in Food Science and Food Safety, 2(1 SUPPL.), 142–160. https://doi.org/10.1111/j.1541-4337.2003.tb00032.x

Fine, F., & Gervais, P. (2004). Efficiency of pulsed UV light for microbial decontamination of food powders. Journal of Food Protection, 67(4), 787–792. https://doi.org/10.4315/0362-028X-67.4.787

Fleet, G. (1992). Spoilage yeasts. Crit Rev Biotechnol, 12(1-2), 1-44. doi:10.3109/07388559209069186

Food and Agriculture Organization (FAO). (1999). Acidified foods (Title 21, Part 114 in Code of Federal Regulations, 21 CFR 114). Government Printing Office.

Food and Drug Administration (FDA). (2014). Water activity (aw) in foods. Retrieved from https://www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/inspection-technical-guides/water-activity-aw-foods

Food and Drug Administration (FDA). (2018). Safe practices for food processes. Retrieved from http://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm094147.htm

Food and Drug Administration (FDA). (2022). BAM chapter 18: Yeasts, molds, and mycotoxins. Retrieved from https://www.fda.gov/food/laboratory-methods-food/bam-chapter-18-yeasts-molds-and-mycotoxins

Food Standards Australia New Zealand (FSANZ). (2017). FSANZ 1.5.1 – Novel foods. Retrieved from https://www.legislation.gov.au/Series/F2015L00403

Food Standards Australia New Zealand (FSANZ). (2020). FSANZ 1.5.3 – Irradiation of food. Retrieved from https://www.legislation.gov.au/Series/F2015L00406

Food Standards Australia New Zealand (FSANZ). (2021). Advisory Committee Novel Foods - Novel food - Record of views formed in response to inquiries. Retrieved from https://www.foodstandards.govt.nz/industry/novel/novelrecs/pages/default.aspx

Food Standards Australia New Zealand. (2025). Compendium of microbiological criteria for food. https://www.foodstandards.govt.nz/publications/Compendium-of-Microbiological-Criteria-for-Food

Food Safety and Inspection Service (FSIS). (2003). FSIS rule designed to reduce *Listeria monocytogenes* in ready-to-eat meat and poultry products (April 2003). Retrieved from www.fsis.usda.gov/OA/background/lmfinal.htm

Garbutt, J. H. (1997). Essentials of food microbiology / John Garbutt. Arnold.

Gayán, E., Serrano, M. J., Raso, J., Álvarez, I., & Condón, S. (2012). Inactivation of *Salmonella* enterica by UV-C light Alone and in combination with mild temperatures. Applied and Environmental Microbiology, 78(23), 8353–8361. https://doi.org/10.1128/AEM.02010-12

Goburdhun, D., Beeharry, M. D., Reega, K., Ruggoo, A., & Neetoo, H. (2019). Assessment of the microbiological quality of popular food items on sale in secondary school canteens of Mauritius. *Italian Journal of Food Safety, 8*(1), 7326. https://doi.org/10.4081/ijfs.2019.7326

González, Y., Gómez, G., Vidal, G., & Moeller-Chávez, G. E. (2023). UV Disinfection Systems for Wastewater Treatment: Emphasis on Reactivation of Microorganisms. Sustainability (Switzerland), 15(14). https://doi.org/10.3390/su151411262

Gilbert, R. J., de Louvois, J., Donovan, T., Little, C., Nye, K., Ribeiro, C. D., Richards, J., Roberts, D., & Bolton, F. J. (2000). Guidelines for the microbiological quality of some ready-to-eat foods sampled at the point of sale. PHLS Advisory Committee for Food and Dairy Products. Communicable Disease and Public Health / PHLS, 3(3), 163–167.

Gould, G. W. (2000). Preservation: past, present and future. British Medical Bulletin, 56(1), 84–96.

Gram, L., Ravn, L., Rasch, M., Bruhn, J. B., Christensen, A. B., & Givskov, M. (2002). Food spoilage—interactions between food spoilage bacteria. *International Journal of Food Microbiology*, *78*(1), 79–97. https://doi.org/10.1016/S0168-1605(02)00233-7

Granum, P. E. (2005). Bacillus cereus. In P. Fratamico, A. Bhunia, & J. Smith (Eds.), Foodborne pathogens: Microbiology and molecular biology (pp. 409–420). Caister Academic Press.

Green, A., Popović, V., Pierscianowski, J., Biancaniello, M., Warriner, K., & Koutchma, T. (2018). Inactivation of Escherichia coli, Listeria and *Salmonella* by single and multiple wavelength

ultraviolet-light emitting diodes. Innovative Food Science and Emerging Technologies, 47, 353–361. https://doi.org/10.1016/j.ifset.2018.03.019

Hakguder Taze, B., Unluturk, S., Buzrul, S., & Alpas, H. (2015). The impact of UV-C irradiation on spoilage microorganisms and colour of orange juice. Journal of Food Science and Technology, 52(2), 1000–1007. https://doi.org/10.1007/s13197-013-1095-7

Halt, M. (1984a). Contamination of wheat flour with fungi and aflatoxin B1. Znanstvena i Praktična Poljoprivredna Tehnologija, 14, 490–511.

Hou, G. G. (2010). Asian noodles: science, technology, and processing / edited by Gary G. Hou. John Wiley & Sons.

Hou, J., Li, Y.-Q., Wang, Z.-S., Sun, G.-J., & Mo, H.-Z. (2017). Applicative effect of glycinin basic polypeptide in fresh wet noodles and antifungal characteristics. LWT - Food Science and Technology, 83, 267–274. https://doi.org/10.1016/j.lwt.2017.05.028

Houyuan Lu, Xiaoyan Yang, Maolin Ye, Kam-Biu Liu, Zhengkai Xia, Xiaoyan Ren, Linhai Cai, Naiqin Wu, & Tung-Sheng Liu. (2005). Culinary archaeology: Millet noodles in Late Neolithic China. Nature, 437(7061), 967–968. https://doi.org/10.1038/437967a

Halt, M., Kovačević, D., Pavlović, H. & Jukić, J. (2004). Contamination of pasta and the raw materials for its production with moulds of the genera Aspergillus. Czech Journal of Food Sciences, 22(2), 67–72. https://doi.org/10.17221/3408-CJFS

Hotchkiss, J. H. (1987). Microbiological hazards of controlled/modified atmosphere food packaging. In Proceedings of the 3rd International Conference on Controlled/Modified Atmosphere/Vacuum Packaging CAP '87 (pp. 16-18). Schotland Business Research, Inc.

Hotchkiss, J. H. (1988). Experimental approaches to determining the safety of food packaged in modified atmospheres. Food Technology, 42(9), 55–64.

Huis In't Veld, J. H. J. H. I. (1996). Microbial and biochemical spoilage of foods: An overview. International Journal of Food Microbiology, 33(1), 1–18. https://doi.org/10.1016/0168-1605(96)01139-7

Ibarz, A., Gonzalez Azon, C., Esplugas, S., & Miguelsanz, R. (1990). Non-enzymatic browning kinetics of clarified peach juice at different temperatures. *Confructa Studien, 34*, 152-159.

Irie, K., Motoi, H., Horigane, A. K., Naito, S., & Yoshida, M. (2004). Moisture Distribution and Texture of Various Types of Cooked Spaghetti. Cereal Chemistry, 81(3), 350–355. https://doi.org/10.1094/CCHEM.2004.81.3.350

Jay, J. M. (1987). The tentative recognition of psychrotrophic Gram-negative bacteria in 48 h by their surface growth at 10°C. International Journal of Food Microbiology, 4(1), 25–32. https://doi.org/10.1016/0168-1605(87)90056-0

Jay, J. M., Golden, D. A., & Loessner, M. J. (2005). *Modern food microbiology / James M. Jay, Martin J. Loessner, David A. Golden (7th ed)*. Springer.

Jeong, S., & Lee, S. (2024). Retrogradation-induced physicochemical changes in pre-cooked rice noodles stored at different temperatures: a viewpoint from water dynamics and structure. Journal of the Science of Food and Agriculture, 104(4), 2406–2416. https://doi.org/10.1002/jsfa.13125

Karim, R., & Sultan, M. T. (2015). Yellow alkaline noodles [electronic resource]: processing technology and quality improvement / Roselina Karim, Muhammad Tauseef Sultan. Springer.

Kader, A. A. (1986). Biochemical and physiological basis for effects of controlled and modified atmospheres on fruit and vegetables. Food Technology, 40, 99–104.

Kader, A. A., & Watkins, C. B. (2000). Modified atmosphere packaging - Toward 2000 and beyond. HortTechnology, 10(3), 483–486. https://doi.org/10.21273/horttech.10.3.483

Karim, R., & Sultan, M. T. (2015). Yellow alkaline noodles [electronic resource]: processing technology and quality improvement / Roselina Karim, Muhammad Tauseef Sultan. Springer.

Kim, H. H., Jeong, E. J., Jeong, D. Y., Kim, Y. S., & Shin, D. H. (2005). Identification, characteristics, and growth inhibition of the strain isolated from spoiled wet noodle. Food science and biotechnology, 14(4), 461-465.

Koutchma, T. (2014). Food plant safety UV applications for food and non-food surfaces. Elsevier, Academic Press.

Koutchma, T., Popovic, V., Ros-Polski, V., & Popielarz, A. (2016). Effects of Ultraviolet Light and High-Pressure Processing on Quality and Health-Related Constituents of Fresh Juice Products. COMPREHENSIVE REVIEWS IN FOOD SCIENCE AND FOOD SAFETY, 15(5), 844–867. https://doi.org/10.1111/1541-4337.12214

Koutchma, T. N. (2019). Ultraviolet light in food technology: principles and applications / Tatiana Koutchma. CRC Press, Taylor & Francis Group. https://doi.org/10.1201/9780429244414

Lacroix, M., Ouattara, B., Saucier, L., Giroux, M., & Smoragiewicz, W. (2004). Effect of gamma irradiation in presence of ascorbic acid on microbial composition and TBARS concentration of ground beef coated with an edible active coating. Radiation Physics and Chemistry, 71(1), 73–77. https://doi.org/10.1016/j.radphyschem.2004.04.057

Lamikanra, O., Bett-Garber, K. L., Kueneman, D., & Ukuku, D. (2005). Effect of processing under ultraviolet light on the shelf life of fresh-cut cantaloupe melon. Journal of Food Science, 70(9), C534–C539. https://doi.org/10.1111/j.1365-2621.2005.tb08301.x

Lakakul, R., Beaudry, R. M., & Hernandez, R. J. (1999). Modeling respiration of apple slices in modified-atmosphere packages. Journal of Food Science, 64(1), 105–110. https://doi.org/10.1111/j.1365-2621.1999.tb09870.x

Lawless, H. T., & Heymann, H. (2010). Sensory evaluation of food : principles and practices / Harry T. Lawless, Hildegarde Heymann (2nd ed) (2nd ed). Springer.

Li, M., Zhu, K., Guo, X., Peng, W., & Zhou, H. (2011). Effect of water activity (aw) and irradiation on the shelf life of fresh noodles. Innovative Food Science & Emerging Technologies, 12(4), 526–530. https://doi.org/10.1016/j.ifset.2011.06.005

Ling, Q., & Hou, G. G. (2010). Packaging of noodle products. In Asian Noodles: Science, Technology, and Processing (pp. 145–162). John Wiley & Sons, Inc. https://doi-org.ezproxy.massey.ac.nz/10.1002/9780470634370.ch7

Little, R. (2007). An analysis of microwave generated UV devices, their track record and their potential. In UV and Ozone World Congress: IOA/IUVA Congress, Los Angeles, California, USA, 27–29 August 2007.

Mahajan, P. V., Oliveira, F. A. R., Montanez, J. C., & Iqbal, T. (2008). Packaging design for fresh produce: An engineering approach. New Food, 1, 35–36.

Mamane-Gravetz, H., & Linden, K. G. (2004). UV disinfection of indigenous aerobic spores: implications for UV reactor validation in unfiltered waters. Water Research, 38(12), 2898–2906. https://doi.org/10.1016/j.watres.2004.03.035

Markovic, I., Ilic, J., Markovic, D., Simonovic, V., & Kosanic, N. (2013). Colour measurement of food products using CIE L*a*b* and RGB colour space. *Journal of Hygienic Engineering and Design*, *4*, 50–53.

McMillin, K. W. (2008). Where is MAP going? A review and future potential of modified atmosphere packaging for meat. *Meat Science*, *80*(1), 43–65. https://doi.org/10.1016/j.meatsci.2008.05.028

Meng, X., Zhang, M., & Adhikari, B. (2012). Extending shelf life of fresh-cut green peppers using pressurised argon treatment. Postharvest Biology and Technology, 71, 13–20. https://doi.org/10.1016/j.postharvbio.2012.04.006

Miskelly, D. M. (1998). Modern noodle based foods—Raw material needs. In Pacific people and their food (pp. 123–142). American Association of Cereal Chemists, Inc.

Ministry for Primary Industries (MPI). (2020). Hazard analysis and critical control point. https://www.mpi.govt.nz/food-business/food-safety-codes-standards/hazard-analysis-critical-control-point/

Ministry for Primary Industries. (2022). Compendium of microbiological criteria for food. Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/36759-Compendium-of-Microbiological-Criteria-for-Food

Morita, R. Y. (1975). Psychophilic bacteria. Bacteriological Reviews, 39, 144–167.

Novais, C., Molina, A. K., Abreu, R. M. V., Santo-Buelga, C., Ferreira, I. C. F. R., Pereira, C., & Barros, L. (2022). Natural Food Colorants and Preservatives: A Review, a Demand, and a Challenge. Journal of Agricultural & Food Chemistry, 70(9), 2789–2805. https://doi.org/10.1021/acs.jafc.1c07533

Nychas, G.-J. E., & Panagou, E. (2011). Microbiological spoilage of foods and beverages. In D. Kilcast & P. Subramaniam (Eds.), *Food and beverage stability and shelf life* (pp. 3–28). Woodhead Publishing. https://doi.org/10.1533/9780857092540.1.3

Oppenlander, T., & Sosnin, E. (2005). Mercury free vacuum (VUV) and UV excimers: Lamps of the future? IUVA News, 7(4), 16–20.

Paola Duque-Sarango, Nicole Delgado-Armijos, Leonardo Romero-Martínez, & Verónica Pinos-Vélez. (2023). Assessing the potential of ultraviolet irradiation for inactivating waterborne fungal spores: kinetics and photoreactivation studies. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1212807

Popović, V., Fairbanks, N., Pierscianowski, J., Biancaniello, M., Zhou, T., & Koutchma, T. (2018). Feasibility of 3D UV-C treatment to reduce fungal growth and mycotoxin loads on maize and wheat kernels. Mycotoxin Res, 34(3), 211-221. doi:10.1007/s12550-018-0316-3

Ren, S. C., Wang, T., & Li, C. C. (2010). Quality change and preservation of wet noodles at room temperature. Journal of Henan University of Technology (Natural Science Edition), 31(6), 6–10. (In Chinese with English abstract).

Resnik, S., & Chirife, J. (1979). Effect of Moisture Content and Temperature on some Aspects of Nonenzymatic Browning in Dehydrated Apple. Journal of Food Science, 44(2), 601–605. https://doi.org/10.1111/j.1365-2621.1979.tb03845.x

Ross, A. (2006). Instrumental measurement of physical properties of cooked Asian wheat flour noodles. CEREAL CHEMISTRY, 83(1), 42–51. https://doi.org/10.1094/CC-83-0042

Sanders, E. R. (2012). Aseptic laboratory techniques: Plating methods. Journal of Visualized Experiments: JoVE, 63, e3064. https://doi.org/10.3791/3064

Semi, M. F. B., Massey University, degree granting institution, & Massey University. School of Engineering and Advanced Technology. (2016). UV-light treatment of fruit in a rotating drum: Engineering project submitted as part requirement for B. Eng (Hons), paper number 228798 / Mohd Fadhil Bin Semi.

Shama, G. (2000). Ultraviolet light. In C. A. Batt, P. Patel, & R. K. Robinson (Eds.), Encyclopedia of Food Microbiology (Vol. 3). San Diego: Academic Press.

Sharma, R., & Demirci, A. (2003). Inactivation of Escherichia coli O157 : H7 on inoculated alfalfa seeds with pulsed ultraviolet light and response surface modeling. JOURNAL OF FOOD SCIENCE, 68(4), 1448–1453.

Sherkat, F., & Hui, Y. H. (Eds.). (2005). Handbook of food science, technology, and engineering (1st ed., 4-volume set). CRC Press. https://doi.org/10.1201/b15995

Singh, H., Khatri, M., Bhardwaj, N., Bhardwaj, S. K., & Kim, K.-H. (2021). UVC radiation for food safety: An emerging technology for the microbial disinfection of food products. Chemical Engineering Journal, 417. https://doi.org/10.1016/j.cej.2020.128084

Sindelar, J. J., & Milkowski, A. L. (2012). Human safety controversies surrounding nitrate and nitrite in the diet. *Nitric Oxide*, *26*(4), 259–266. https://doi.org/10.1016/j.niox.2012.03.011

Sisti, M., Schiavano, G. F., De Santi, M., & Brandi, G. (2017). Ultraviolet germicidal irradiation in tap water contaminated by Aspergillus spp. Journal of Preventive Medicine and Hygiene, 58(4), E315–E319. https://doi.org/10.15167/2421-4248/jpmh2017.58.4.777

Sommer, R., Cabaj, A., Sandu, T., & Lhotsky, M. (1999). Measurement of UV radiation using suspensions of microorganisms. Journal of Photochemistry & Photobiology, B: Biology, 53(1), 1–6. https://doi.org/10.1016/S1011-1344(99)00113-X

Sommers, C. H., Geveke, D. J., Pulsfus, S., & Lemmenes, B. (2009). Inactivation of Listeria innocua on frankfurters by ultraviolet light and flash pasteurisation. Journal of Food Science, 74(3), M138–M141. https://doi.org/10.1111/j.1750-3841.2009.01107.x

Sommers, C. H. (2011). Ultraviolet light—An FDA approved technology [Abstract]. International Association of Food Protection Annual Meeting, July 31–August 3, 2011, Milwaukee, Wisconsin, p. 1.

Soraya, A., Chay, S. Y., Shukri, R., Mohamad Ghazali, F., Muhammad, K., Noranizan, M. A., & Karim, R. (2019). Reduction of microbial load in yellow alkaline noodle using optimised microwave and pulsed-UV treatment to improve storage stability. Journal of Food Science and Technology, 56(4), 1801–1810. https://doi.org/10.1007/s13197-019-03624-w

Souza, V., & Koutchma, T. (2020). Ultraviolet Light Microbial Inactivation in Liquid Foods. In.

Stratford, M., Plumridge, A., & Archer, D. B. (2007). Decarboxylation of sorbic acid by spoilage yeasts is associated with the PAD1 gene. Applied and Environmental Microbiology, 73(20), 6534–6542. https://doi.org/10.1128/AEM.01246-07

Suparlan, & Itoh, K. (2003). Combined Effects of Hot Water Treatment (HWT) and Modified Atmosphere Packaging (MAP) on Quality of Tomatoes. Packaging Technology and Science, 16(4), 171–178. https://doi.org/10.1002/pts.626

Suwaibah, G., Abdulamir, A., Bakar, F., Karim, R., & Saari, N. (2009). Microbial Growth, Sensory Characteristic and pH as Potential Spoilage Indicators of Chinese Yellow Wet Noodles from Commercial Processing Plants. *American Journal of Applied Sciences, 6*. doi:10.3844/ajassp.2009.1059.1066

Taze, B. H., Unluturk, S., Buzrul, S., & Alpas, H. (2015). [The impact of UV-C irradiation on spoilage microorganisms and colour of orange juice]. Journal of Food Science and Technology, 52(2), 1000–1007. https://doi.org/10.1007/s13197-013-1095-7

Tandon, K., Worobo, R., Churey, J., & Padilla-Zakour, O. (2003). Storage quality of pasteurized and UV treated apple cider. JOURNAL OF FOOD PROCESSING AND PRESERVATION, 27(1), 21–35. https://doi.org/10.1111/j.1745-4549.2003.tb00006.x

Torkamani, A. E., & Niakousari, M. (2011). Impact of UV-C light on orange juice quality and shelf life. International Food Research Journal, 18(4), 1265–1268.

Tuersuntuoheti, T., Wang, Z., Wang, Z., Duan, M., Zheng, Y., Wu, Y., Liang, S., Li, X., & Zhang, M. (2019). Microbes, bioactive compounds, quality characteristics, and structural changes during the storage of Qingke barley fresh noodles. Journal of Food Processing and Preservation, 43(12). https://doi.org/10.1111/jfpp.14275

Universal Lab. (2024). Basic principles of UV diffuse reflectance spectroscopy. https://universallab.org/blog/blog/basic_principles_of_uv_diffuse_reflectance_spectroscopy/

U.S. Food and Drug Administration. (2001a). CFR 21 179.39 – Code of Federal Regulations. 21 CFR Part 179. Irradiation in the production, processing and handling of food. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=179

U.S. Food and Drug Administration. (2018). *Fish and fishery products hazards and controls guidance* (Chapter 13: Clostridium botulinum toxin formation). Centre for Food Safety and Applied Nutrition, FDA.

https://www.fda.gov/media/119399/download

U.S. Food and Drug Administration. (2020). *Ultraviolet (UV) radiation*. https://www.fda.gov/radiation-emitting-products/tanning/ultraviolet-uv-radiation

Verma, R. K., Kumari, P., Maurya, R. K., Kumar, V., Verma, R. B., & Singh, R. K. (2018). Medicinal properties of turmeric (Curcuma longa L.): A review. International Journal of Chemical Studies, 6(4), 1354–1357. https://www.researchgate.net/publication/354967877_Medicinal_properties_of_turmeric_Curcuma_longa_L_A_review

Yaun, B. R., Sumner, S. S., Eifert, J. D., & Marcy, J. E. (2003). Response of *Salmonella* and Escherichia coli O157:H7 to UV energy. *J Food Prot, 66*(6), 1071-1073. doi:10.4315/0362-028x-66.6.1071

Yousif, E. I., Gadallah, M. G. E., & Sorour, A. M. (2012). Physico-chemical and rheological properties of modified corn starches and its effect on noodle quality. Annals of Agricultural Sciences, 57(1), 19–27. https://doi.org/10.1016/j.aoas.2012.03.008

Zimmer, J. L., & Slawson, R. M. (2002). Potential repair of Escherichia coli DNA following exposure to UV radiation from both medium- and low-pressure UV sources used in drinking water treatment. *Appl Environ Microbiol, 68*(7), 3293-3299. doi:10.1128/aem.68.7.3293-3299.2002

Zhu, D., Qing, Z., Ji, B., & Zude, M. (2010). Analysing the browning of apple juice by fluorescence spectroscopy (Vol. 858, pp. 419–424). International Society for Horticultural Science. https://doi.org/10.17660/ActaHortic.2010.858.64

Appendixes

Appendix A: Data for Hokkien Noodles for the Preliminary Experiment

Table A1: Raw data for pH Measurement at Various UV-C Dosages with or without MA Packaging

pH Measurement	Day 0	Day 7	Day 14
C	4.5	4.6	4.4
CD	4.6	4.7	4.5
50M	4.5	4.5	4.5
50MD	4.6	4.6	4.6
50NM	4.5	4.5	4.5
50NMD	4.6	4.6	4.5
110M	4.5	4.6	4.5
110MD	4.6	4.7	4.6
110NM	4.5	4.6	4.4
110NMD	4.6	4.7	4.5
126M	4.5	4.5	4.5
126MD	4.6	4.6	4.6
126NM	4.5	4.5	4.4
126NMD	4.6	4.7	4.4
220M	4.5	4.6	4.6

220MD	4.6	4.7	4.6
220NM	4.5	4.7	4.4
220NMD	4.6	4.7	4.5

Note: C=Control; CD=Control in Duplicate; 50M=50 mJ/cm^2 MAP; 50MD=50 mJ/ cm^2 MAP Duplicate; 50NM=50 mJ/ cm^2 Non-MAP; 50NMD=50 mJ/ cm^2 Non-MAP in Duplicate; 110M=110 mJ/ cm^2 MAP; 110MD=110 mJ/ cm^2 MAP Duplicate; 110NM=110 mJ/ cm^2 Non-MAP; 110NMD=110 mJ/ cm^2 Non-MAP in Duplicate; 126M=126 mJ/ cm^2 MAP; 126MD=126 mJ/ cm^2 MAP Duplicate; 126NM=126 mJ/ cm^2 Non-MAP; 126NMD=126 mJ/ cm^2 Non-MAP in Duplicate; ; 220M=220 mJ/cm2 MAP; 220MD=220 mJ/ cm^2 MAP Duplicate; 220NM=220 mJ/ cm^2 Non-MAP; 220NMD=220 mJ/ cm^2 Non-MAP in Duplicate

Table A2: Raw data for a_w Measurements at Various UV-C Dosages with or without MA Packaging

a_w Measurement	Day 0	Day 7	Day 14
C	0.9996	0.9980	0.9971
CD	0.9992	0.9980	0.9971
50M	0.9998	0.9984	0.9971
50MD	0.9991	0.9985	0.9969
50NM	0.9989	0.9973	0.9958
50NMD	0.9988	0.9971	0.9957
110M	0.9986	0.9979	0.9963
110MD	0.9985	0.9974	0.9961
110NM	0.9984	0.9957	0.9937
110NMD	0.9982	0.9953	0.9936

126M	0.9969	0.9965	0.9954
126MD	0.9964	0.9956	0.9948
126NM	0.9966	0.9941	0.9930
126NMD	0.9966	0.9940	0.9929
220M	0.9948	0.9938	0.9931
220MD	0.9948	0.9939	0.9930
220NM	0.9944	0.9925	0.9912
220NMD	0.9942	0.9931	0.9917

Note: C=Control; CD=Control in Duplicate; 50M=50 mJ/cm^2 MAP; 50MD=50 mJ/ cm^2 MAP Duplicate; 50NM=50 mJ/ cm^2 Non-MAP; 50NMD=50 mJ/ cm^2 Non-MAP in Duplicate; 110M=110 mJ/ cm^2 MAP; 110MD=110 mJ/ cm^2 MAP Duplicate; 110NM=110 mJ/ cm^2 Non-MAP; 110NMD=110 mJ/ cm^2 Non-MAP in Duplicate; 126M=126 mJ/ cm^2 MAP; 126MD=126 mJ/ cm^2 MAP Duplicate; 126NM=126 mJ/ cm^2 Non-MAP; 126NMD=126 mJ/ cm^2 Non-MAP in Duplicate; ; 220M=220 mJ/cm2 MAP; 220MD=220 mJ/ cm^2 MAP Duplicate; 220NM=220 mJ/ cm^2 Non-MAP; 220NMD=220 mJ/ cm^2 Non-MAP in Duplicate

Table A3: Raw data for Initial SPC Measurement

SPC			
Sample	Day	Dilution	Initial Count (cfu/g)
Control	0	10^{-1}	1
		10^{-2}	0
		10^{-3}	0

Control in Duplicate		10^{-1}	2
		10^{-2}	0
		10^{-3}	0

Table A4: Raw data for SPC Measurement at Various UV-C Dosages with or without MA Packaging

SPC																			
Day	Dilution	C	CD	50M	50MD	50NM	50NMD	110M	110MD	110NM	110NMD	126M	126MD	126NM	126NMD	220M	220MD	220NM	220NMD
		Microbial Count (cfu/g)																	
7	10^{-1}	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10^{-2}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10^{-3}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	10^{-1}	5	4	0	0	3	0	0	0	0	0	0	0	19	1	0	0	0	TNTC
	10^{-2}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10^{-3}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: C=Control; CD=Control in Duplicate; 50M=50 mJ/cm^2 MAP; 50MD=50 mJ/ cm^2 MAP Duplicate; 50NM=50 mJ/ cm^2 Non-MAP; 50NMD=50 mJ/ cm^2 Non-MAP in Duplicate; 110M=110 mJ/ cm^2 MAP; 110MD=110 mJ/ cm^2 MAP Duplicate; 110NM=110 mJ/ cm^2 Non-MAP; 110NMD=110 mJ/ cm^2 Non-MAP in Duplicate; 126M=126 mJ/ cm^2 MAP; 126MD=126 mJ/ cm^2 MAP Duplicate; 126NM=126 mJ/ cm^2 Non-MAP; 126NMD=126 mJ/ cm^2 Non-MAP in Duplicate; ; 220M=220 mJ/cm2 MAP; 220MD=220 mJ/ cm^2 MAP Duplicate; 220NM=220 mJ/ cm^2 Non-MAP; 220NMD=220 mJ/ cm^2 Non-MAP in Duplicate

Table A5: Raw data for Initial Y&M Measurement

Y&M			
Sample	Day	Dilution	Initial Count (cfu/g)
Control	0	10^0	0
		10^{-1}	0
Control in Duplicate		10^0	0
		10^{-1}	0

Table A6: Raw data for Y&M Measurement at Various UV-C Dosages with or without MA Packaging

Y&M																			
Day	Dilution	C	CD	50M	50MD	50NM	50NMD	110M	110MD	110NM	110NMD	126M	126MD	126NM	126NMD	220M	220MD	220NM	220NMD
		Microbial Count (cfu/g)																	
7	10^0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10^{-1}	0	0	0	0	0	0	0	0	0	0	0	0	TNTC	0	0	0	0	0
14	10^0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	10^{-1}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

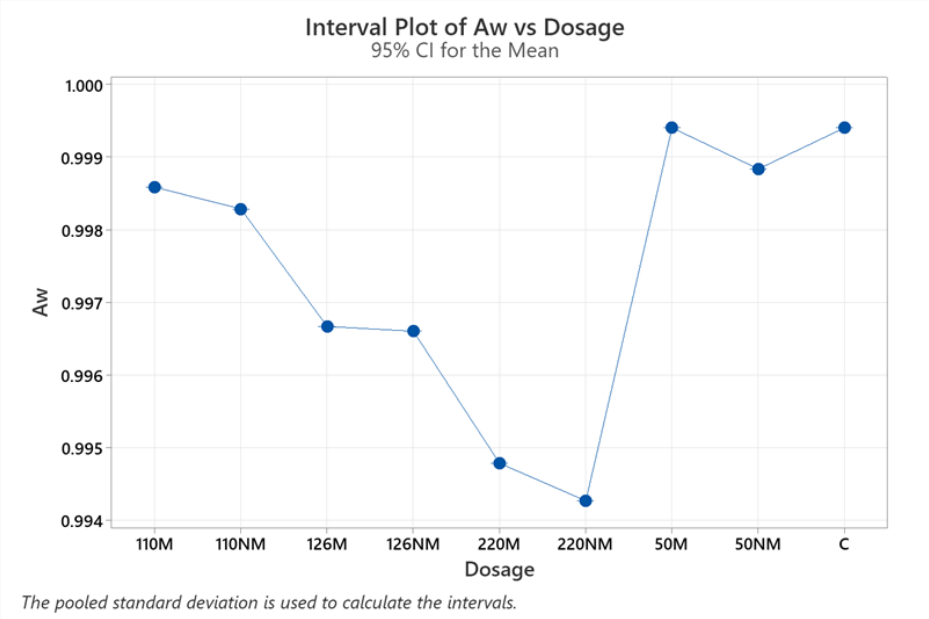
A7: ANOVA Test Results for pH Measurements of All the Noodle Samples

Type III Sum of Squares analysis (pH):

Source	DF	Sum of squares	Mean squares	F	Pr > F	p-values significati on codes
UV	4.000	0.025	0.006	1.807	0.151	°
MAP	1.000	0.008	0.008	2.290	0.140	°
Day	2.000	0.117	0.059	16.756	**<0.0001**	***
UV*MAP	3.000	0.000	0.000	0.028	0.994	°
UV*Day	8.000	0.023	0.003	0.823	0.588	°
MAP*Day	2.000	0.033	0.016	4.691	**0.016**	*

*Signification codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*

A8: Internal plot of a_w vs. samples treated with various UV-C dosages at time 0



A9: ANOVA test results for a_w measurements of all noodle samples

Type III Sum of Squares analysis (Aw):

Source	DF	Sum of squares	Mean squares	F	Pr > F	p-values significat ion codes
UV	4.000	0.000	0.000	486.284	**<0.0001**	***
MAP	1.000	0.000	0.000	220.056	**<0.0001**	***
Day	2.000	0.000	0.000	287.988	**<0.0001**	***
UV*MAP	3.000	0.000	0.000	2.951	**0.047**	*
UV*Day	8.000	0.000	0.000	4.174	**0.002**	*
MAP*Day	2.000	0.000	0.000	29.940	**<0.0001**	***

*Signification codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*

A10: ANOVA test results for a_w measurements between control samples and samples treated with a UV-C dosage of 50 mJ/cm² under MAP conditions

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.000000	0.000000	0.01	0.915
Error	4	0.000006	0.000001		
Total	5	0.000006			

A11: ANOVA test results for a_w measurements between control samples and samples treated with a UV-C dosage of 50 mJ/cm² without MAP

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.000001	0.000001	0.65	0.467
Error	4	0.000007	0.000002		
Total	5	0.000009			

A12: ANOVA test results for a_w measurements between control samples and samples treated with a UV-C dosage of 110 mJ/cm² under MAP conditions

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.000001	0.000001	0.52	0.510
Error	4	0.000006	0.000001		
Total	5	0.000006			

A13: ANOVA test results for a_w measurements between control samples and samples treated with a UV-C dosage of 110 mJ/cm² without MAP

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.000008	0.000008	2.44	0.193
Error	4	0.000014	0.000003		
Total	5	0.000022			

A14: ANOVA test results for a_w measurements between control samples and samples treated with a UV-C dosage of 126 mJ/cm² under MAP conditions

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.000008	0.000008	8.65	0.042
Error	4	0.000004	0.000001		
Total	5	0.000012			

A15: ANOVA test results for a_w measurements between control samples and samples treated with a UV-C dosage of 126 mJ/cm² without MAP

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.000020	0.000020	8.17	0.046
Error	4	0.000010	0.000002		
Total	5	0.000029			

A16: ANOVA test results for a_w measurements between control samples and samples treated with a UV-C dosage of 220 mJ/cm² under MAP conditions

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.000027	0.000027	26.29	0.007
Error	4	0.000004	0.000001		
Total	5	0.000032			

A17: ANOVA test results for a_w measurements between control samples and samples treated with a UV-C dosage of 220 mJ/cm² without MAP

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.000042	0.000042	26.00	0.007
Error	4	0.000007	0.000002		
Total	5	0.000049			

Appendix B: Raw Data for Hokkien Noodles for Phase Two

Table B1: Raw data for pH Measurement for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage

pH Measurement	Day 0	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42
Control	4.7	4.6	4.6	4.6	4.6	4.6	4.6
Control in Duplicate	4.6	4.6	4.5	4.5	4.5	4.5	4.6
110 mJ/cm^2 MAP	4.7	4.6	4.6	4.6	4.6	4.5	4.5
110 mJ/cm^2 MAP in Duplicate	4.6	4.5	4.5	4.5	4.5	4.5	4.5

Table B2: Raw data for a_w Measurement for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage

a_w Measurement	Day 0	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42
Control	0.9908	1.0025	0.9986	0.9971	0.9965	0.9960	0.9954
Control in Duplicate	0.9949	1.0063	1.0020	0.9984	1.0001	0.9990	0.9999
110 mJ/cm^2 MAP	0.9887	1.0004	0.9957	0.9957	0.9952	0.9934	0.9907
110 mJ/cm^2 MAP in Duplicate	0.9896	1.0030	1.0012	0.9994	1.0003	0.9970	0.9964

Table B3: Raw data for Initial SPC Measurement for Phase Two

SPC			
Sample	Day	Dilution	Initial Count (cfu/g)
Control	0	10^{-1}	2
		10^{-2}	0
		10^{-3}	0
Control in Duplicate		10^{-1}	1
		10^{-2}	0
		10^{-3}	0

Table B4: Raw data for SPC Measurement for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage for Phase Two

SPC					
Day	Dilution	Control	Control in Duplicate	110 mJ/cm^2 MAP	110 mJ/cm^2 MAP in Duplicate
		Microbial Count (cfu/g)			
7	10^{-1}	3	2	0	0
	10^{-2}	0	0	0	0
	10^{-3}	0	0	0	0
14	10^{-1}	5	4	0	0
	10^{-2}	0	0	0	0
	10^{-3}	0	0	0	0

21	10^{-1}	12	9	0	0
	10^{-2}	0	0	0	0
	10^{-3}	0	0	0	0
28	10^{-1}	23	45	0	0
	10^{-2}	0	0	0	0
	10^{-3}	0	0	0	0
35	10^{-1}	98	137	7	8
	10^{-2}	11	15	0	0
	10^{-3}	1	1	0	0
42	10^{-1}	175	211	12	17
	10^{-2}	23	24	2	1
	10^{-3}	1	1	0	0

Table B5: Raw data for Initial Y&M Measurement for Phase Two

Y&M			
Sample	Day	Dilution	Initial Count (cfu/g)
Control	0	10^{0}	0
		10^{-1}	0
Control in Duplicate		10^{0}	0
		10^{-1}	0

Table B6: Raw data for Y&M Measurement for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage for Phase Two

Day	Dilution	Control	Control in Duplicate	110 mJ/cm^2 MAP	110 mJ/cm^2 MAP in Duplicate
		Microbial Count (cfu/g)			
7	10^0	0	0	0	0
	10^{-1}	0	0	0	0
14	10^0	0	0	0	0
	10^{-1}	0	0	0	0
21	10^0	6	1	0	0
	10^{-1}	0	0	0	0
28	10^0	5	4	0	0
	10^{-1}	0	0	0	0
35	10^0	8	7	0	0
	10^{-1}	0	0	0	0
42	10^0	13	7	0	0
	10^{-1}	0	0	0	0

Table B7: Raw data for Initial EB Measurement for Phase Two

EB			
Sample	Day	Dilution	Initial Count (cfu/g)
Control	0	10^0	6

Control in Duplicate		10^{-1}	0
		10^{0}	2
		10^{-1}	0

Table B8: Raw data for EB Measurement for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage for Phase Two

Day	Dilution	Control	Control in Duplicate	110 mJ/cm^2 MAP	110 mJ/cm^2 MAP in Duplicate
		Microbial Count (cfu/g)			
7	10^{0}	8	4	0	0
	10^{-1}	0	0	0	0
14	10^{0}	7	3	0	0
	10^{-1}	0	0	0	0
21	10^{0}	8	10	3	2
	10^{-1}	0	0	0	0
28	10^{0}	5	17	8	4
	10^{-1}	0	0	0	0
35	10^{0}	9	22	9	2
	10^{-1}	0	0	0	0
42	10^{0}	10	15	5	3
	10^{-1}	0	0	0	0

Table B9: Raw Data for CIE L* (lightness) Values for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage

Storage Time (Day)	Control-L	Control in Duplicate-L	110 mJ/cm^2 MAP-L	110 mJ/cm^2 MAP in Duplicate-L
0	92.9	92.1	92.2	91.4
7	95.1	93.9	97.8	96.0
14	73.7	74.3	77.1	76.8
21	69.9	71.7	71.2	72.7
28	63.3	64.5	71.0	72.8
35	69.5	71.0	72.2	73.0
42	69.1	70.4	72.7	77.9

Table B10: Raw Data for CIE a* Values for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage

Storage Time (Day)	Control-a	Control in Duplicate-a	110 mJ/cm^2 MAP-a	110 mJ/cm^2 MAP in Duplicate-a
0	-1.3	-1.6	-0.9	0.1
7	-1.1	-1.6	0.7	2.5
14	-6.5	-5.7	-6.3	-5.4
21	-5.5	-6.3	-5.5	-6.7

28	-5.5	-6.2	-5.3	-6.1
35	-5.1	-6.1	-4.8	-5.7
42	-4.8	-5.2	-5.5	-6.3

Table B11: Raw Data for CIE b* Values for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage

Storage Time (Day)	Control-b	Control in Duplicate-b	110 mJ/cm^2 MAP-b	110 mJ/cm^2 MAP in Duplicate-b
0	5.5	6.2	6.7	3.7
7	4.3	5.0	-1.3	-4.1
14	52.6	53.2	56.6	54.3
21	52.0	53.8	51.8	55.5
28	49.7	53.5	53.9	51.0
35	53.3	56.2	51.8	53.9
42	54.2	53.9	53.0	54.2

Table B12: Raw Data for Tensile Force for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage

Storage Time (Day)	Tensile Force (g)			
	Control	Control in Duplicate	110 mJ/cm^2 MAP	110 mJ/cm^2 MAP in Duplicate
0	52.0	51.6	58.7	56.7
7	50.1	49.5	58.4	55.9
14	44.3	42.9	48.7	47.3
21	44.7	44.1	46.1	45.9
28	40.7	36.3	42.0	41.9
35	34.2	33.8	39.2	37.4
42	27.6	24.9	32.3	31.1

Table B13: Raw Data for Extended Distance for Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under MA Packaging over a 42-day Storage

Storage Time (Day)	Extended Distance (mm)			
	Control	Control in Duplicate	110 mJ/cm^2 MAP	110 mJ/cm^2 MAP in Duplicate
0	-26.0	-27.5	-27.8	-26.0
7	-23.0	-29.2	-27.3	-25.7

14	-22.1	-21.2	-24.6	-23.9
21	-16.7	-25.3	-20.7	-23.6
28	-18.4	-22.0	-23.1	-20.1
35	-15.9	-15.9	-21.4	-19.5
42	-12.0	-12.6	-11.0	-11.1

Note: The extended distance was recorded as a negative value in the software; therefore, the unit is indicated as "-".

B14: ANOVA test results for pH measurements of samples

Type III Sum of Squares analysis (pH):

Source	DF	Sum of squares	Mean squares	F	Pr > F	p-values significati on codes
Sample	1.000	0.002	0.002	1.398	0.257	°
Days	6.000	0.036	0.006	3.787	**0.019**	*
Sample*Days	6.000	0.004	0.001	0.401	0.866	°

*Signification codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*

B15: ANOVA Test Result for A_w Measurements between Control Samples and Samples Treated with a UV-C Dosage ff 110 mJ/cm² under MAP Conditions

Type III Sum of Squares analysis (aw):

Source	DF	Sum of squares	Mean squares	F	Pr > F	p-values significat ion codes
Sample	1.000	0.000	0.000	4.524	0.052	.
Days	6.000	0.000	0.000	7.255	**0.001**	**
Sample*Days	6.000	0.000	0.000	0.289	0.933	°

*Signification codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*

B16: ANOVA Test Results for Tensile Force Measurement between Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

Type III Sum of Squares analysis (Tensile Force):

Source	DF	Sum of squares	Mean squares	F	Pr > F	p-values significat ion codes
Sample	1.000	150.197	150.197	91.142	**<0.0001**	***
Days	6.000	2036.601	339.433	205.974	**<0.0001**	***
Sample*Days	6.000	20.196	3.366	2.043	0.127	°

*Signification codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*

B17: ANOVA Test Results for Extended Distance Measurement between Control Samples and Samples Treated with a UV-C Dosage of 110 mJ/cm² under Modified Atmosphere Packaging over a 42-day Storage at 4˚C

Type III Sum of Squares analysis (Extended Distance):

Source	DF	Sum of squares	Mean squares	F	Pr > F	p-values significat ion codes
Sample	1.000	11.804	11.804	2.131	0.166	°
Days	6.000	643.111	107.185	19.351	**<0.0001**	***
Sample*Days	6.000	20.951	3.492	0.630	0.704	°

*Signification codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*

Appendix C: HACCP Plan for the Processing of Commercial Hokkien Noodles

The Hazard Analysis and Critical Control Points (HACCP) plan identifies, evaluates, and controls the potential food safety hazards throughout the production process. The goal is to ensure that the final Hokkien noodle product is safe for consumption and meets the highest quality standards. Hazards will be considered as either physical, biological or chemical. The hazards will be identified taking into account the likely occurrence of the hazard in animal products in New Zealand. Associated hazards as identified by the Ministry for Primary Industries Hazard Database (https://www.foodsafety.govt.nz/re.g.isters-lists/hazards/index.htm).

C1. Receipt of Raw Materials and Packaging Materials of Hokkien Noodles

Potential Hazards:

Biological hazards: Pathogenic microorganisms and spoilage bacteria that could compromise food safety and quality.

Chemical hazards: The presence of allergens or harmful chemical substances that may pose a risk to consumers.

Physical hazards: Foreign materials, such as glass, metal, or plastic, that could lead to contamination.

Control Measures:

Verify the supplier certifications: all the incoming materials were purchased from local supermarkets, which should comply with food safety standards as regulated by the Ministry for Primary Industries (MPI). Additionally, conduct a thorough visual inspection of all incoming materials to detect any potential contaminants.

Ensure proper storage conditions: for all raw materials and finished products, adhering to the required guidelines to prevent contamination and ensure food safety.

C2. Ingredients Weighing and Preparation

Potential Hazard: Inaccurate measurement of ingredients, which could result in inconsistent product quality and potential deviations from established food safety and production standards.

Control Measures: Calibrate weighing equipment to ensure precise ingredient measurements so as to maintain consistency in product quality.

C3. Mixing, Kneading, and Extruding by Noodle Making Machine

Potential Hazards:

Cross-contamination due to improper handling of equipment or ingredients.

Inconsistent dough texture may affect the final product quality.

Control Measures:

Ensure thorough sanitization of the noodle-making machine and utensils used in the mixing, kneading and extruding process to prevent cross-contamination.

Regularly monitor the parameters such as time and speed to ensure consistency in dough texture and product quality.

Conduct regular inspections of extruded noodles to ensure consistency in shape, texture, and overall quality, ensuring that they meet the required production standards.

C4. Cooking

Potential Hazards:

Physical hazard: Overcooking can lead to negative effects on the texture of the noodles.

Control Measures:

Continuously monitor the cooking time to ensure Hokkien noodles are cooked for the appropriate duration, preserving their desired texture and quality.

C5. Rinsing and Cooling

Potential Hazards:

Biological hazard: The growth of pathogens due to slow cooling, which may allow bacteria to proliferate.

Control Measures:

Rapidly cool noodles to room temperature 25°C to prevent bacterial growth.

Use RO water for rinsing and cooling to ensure food safety and prevent contamination.

C6. Acidifying

Potential Hazard:

Biological hazard: The growth of pathogenic microorganisms if the noodles are not acidified properly.

Chemical Hazards: The introduction of excessive acidulant (lactic acid) may lead to undesired chemical reactions that affect flavour.

Control Measures:

Ensure that the noodles are acidified to the correct pH level to inhibit microbial growth.

Use a calibrated pH meter to measure the acidity.

Accurately measure and control the quantity of acidulant added, ensuring that it complies with the production standard.

Conduct batch testing of pH to confirm that the acidification process is effective and the pH is about 4 to 5.

C7. Packing

Potential Hazards:

Biological hazard: Contamination during the packaging process.

Physical hazard: Presence of foreign objects in the packaging.

Control Measures:

Ensure clean and sanitary conditions throughout the packaging process to prevent contamination.

Use high-quality, food-safe packaging materials to safeguard against physical contamination and ensure product integrity.

C8. Refrigerated Storage

Potential Hazards:

Biological hazard: The growth of microorganisms if Hokkien noodles are stored at improper temperatures.

Control Measures:

Store noodles at temperatures below 4°C to prevent the growth of harmful microorganisms.