Surface Pasteurisation of Fresh Chicken Meat using UV-C Technology

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Abstract

Fresh chicken meat is highly susceptible to contamination by spoilage and pathogenic microorganisms due to its high-water activity and rich nutrients. Following processing, aerobic mesophilic count (AMCs) on the surface of fresh chicken samples ranges from 3.00 to 4.00 log CFU/cm^2. The New Zealand food safety guidelines stipulate that aerobic mesophilic counts (AMCs) present on surfaces of fresh chicken portion should be <6 log CFU/cm^2 by end of shelf-life (6-7 days) when stored at 4°C. Hence, the safety and shelf-life of fresh chicken meat pose challenges for the industry. The UV-C technology, is a novel food processing technique that has lethal germicidal capability at 280-290 nm. Therefore, the technology has a potential to decontaminate suitable food products including the surfaces of fresh poultry portions.

This study investigated the effect of UV-C light processing on untreated fresh skinless and skin-on chicken portions. The study was conducted in 2 phases to optimise the processing technology and determine its effects on fresh chicken samples during storage (4°C). One day old fresh chicken samples (skinless breast fillet, skinless thigh fillet, skin-on breast fillet, and skin-on thigh fillet) were obtained from a commercial processing factory and transported to Massey University, Auckland Campus, under chilled conditions (4°C) within an hour.

In phase one, the fresh chicken samples were treated with four UV-C dosages (50, 100, 200, and 300 mJ/cm^2) at ambient temperature (20°C) using a commercial UV disinfection system. AMCs were determined by swabbing the fresh chicken samples using swabs and 5-cm^2 templates. Suitable dilutions (10^{-1} up to 10^{-6}) of the swabbed samples were enumerated on standard plate agar with incubation at 30°C/72 h and grown colonies were expressed as log CFU/cm^2. Temperature of the chicken samples before and after UV-C treatments was measured using a 20-cm probe thermometer. Treatment time was recorded automatically by the UV-C equipment. Phase one results showed that 50 mJ/cm^2 was capable of maximum microbial reduction (skinless: 1.69 log CFU/cm^2; skin-on: 0.21 log CFU/cm^2) with minimal temperature changes (skinless: 3.14°C; skin-on: 3.32°C) and lowest exposure times (skinless: 2.17 minutes; skin-on: 2.22 minutes.). Therefore, 50 mJ/cm^2 was selected as the optimum dosage for skin-on and skinless fresh chicken samples.

In phase 2, the effect of optimised UV-C light dosage (50 mJ/cm^2) on fresh chicken samples stored at 4°C/7 days was investigated. Instrumental color analysis, AMCs and lipid oxidation were determined at 4 different time points (day 0, 3, 5, 7) during storage (4°C). AMCs were analysed as previously described. The detection of *E.coli, S. aureus, L. monocytogenes, Campylobacter* spp. and *Salmonella* spp. were conducted at 0 and 7 days of storage using standard methods, while colour was measured by a colorimeter. Lipid oxidation was analysed by the thiobarbituric acid (TBA) method. Consumer sensory evaluation was carried out to evaluate raw and cooked chicken samples during storage. Raw chicken samples were evaluated by a focus group consisting of 5 semi-trained panelists at days 1, 5, and 7 while cooked samples were evaluated on days 1 and 7 by 30 panelists using a 9-scale hedonic test. For cooked chicken portions, samples were cooked to an internal temperature of 75°C using

a convection oven. The cooked chicken samples were cooled to between 30 – 40°C before being served to the sensory panelists.

The result of phase 2 showed that the initial mean AMCs were 3.31 ± 0.11 (skin-on) and 3.80 ± 0.35 (skinless) log CFU/cm^2. After UV-C treatment, the AMCs of UV-treated chicken samples were reduced to 1.87 ± 0.98 (skinless) and 3.07 ± 0.34 (skin-on) log CFU/cm^2, indicating that the AMCs for skinless and skin-on chicken samples decreased by 1.93 log and 0.24 log CFU/cm^2 after UV-C (50 mJ/cm^2) treatment, respectively. At the end of storage, the AMCs on skin-on chicken breast samples were 8.57 ± 0.34 (untreated) and 7.48 ± 0.07 (UV-treated) log CFU/cm^2. Whereas, AMCs on skinless breast fillet were 8.62 ± 0.35 (untreated) and 6.73 ± 1.10 (UV-treated) log CFU/cm^2, respectively. The results indicated that the growth of AMCs on untreated chicken samples exceeded the recommended limit on day 5, while UV-treated chicken samples were higher than the recommended limit on day 6 (skin-on) and day 7 (skinless). In addition, the AMCs results suggested that UV-C treatment was more effective on skinless chicken portion. Furthermore, pathogenic bacteria (*E.coli, S. aureus, L. monocytogenes, Campylobacter* spp., and *Salmonella* spp.) were not detected on untreated and UV-treated chicken samples on days 0 and 7 of storage, indicating the effectiveness of the chlorinated chilling processing step. Based on the Hunter L*, a*, b* colour readings and TBA (TBARS) results, the applied UV-C dose (50 mJ/cm^2) had minimal impact on the color and lipid oxidation of both skin-on and skinless chicken samples during storage. However, a faint burnt odor was detected by sensory panelists during evaluation of UV-C treated fresh (raw) chicken samples stored (4°C) for day 1. The panelists did not detect any unpleasant odor from the cooked chicken samples during storage. Therefore, the results suggested that UV-C light may offer good prospects for shelf-life extension of fresh chicken samples. In addition, the results also indicated that UV-C light surface pasteurisation was more effective for skinless chicken samples, compared to its skin-on counterparts.

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Abbreviation

AMCs	=	Aerobic Mesophilic Count
BPA	=	Baird-Parker Agar
CFU	=	Colony Forming Unit
DNA	=	Deoxyribonucleic Acid
EFSA	=	European Food Safety Authority
FSANZ	=	Food Standards Australia New Zealand
HAV	=	Hepatitis A Virus
HPP	=	High-Pressure Processing
mCCDA	=	Modified Charcoal-Cefoperazone-Deoxycholate
mJ	=	millijoule
NoV	=	Norovirus
PIANZ	=	Poultry Industry Association New Zealand
RNA	=	Ribonucleic Acid
RPET	=	Recycled Polyethylene Terephthalate
SLBF	=	Skinless Breast Fillet
SLTF	=	Skinless Thigh Fillet
SOBF	=	Skin-on Breast Fillet
SOTF	=	Skin-on Thigh Fillet
TBA	=	2-thiobarbituric acid
TBARS	=	Thiobarbituric Acid Reactive Substance
TCA	=	Trichloroacetic Acid
TEP	=	1,1,3,3-tetra-ethoxypropane
USFDA	=	United States Food and Drug Administration
UV	=	Ultraviolet
VRBA	=	Violet Red Bile Agar
XLD	=	Xylose Lysine Deoxycholate

1. Introduction

Fresh chicken meat product is one of the important sources of protein worldwide. In 2018, the annual world poultry production reached 123 million tons, and is predicted to continue to rise in the following years (McLeod et al., 2018). The consumption of chicken meat is about 40 kg per capita in New Zealand, higher than any other animal meat product. (PIANZ, 2018). Fresh chicken meat is highly susceptible to surface contamination by spoilage and pathogenic microorganism due to their rich nutritional content and high-water activity. Microorganisms are already present on the skin of the birds and gastrointestinal tract since before slaughter. Therefore, there is a high possibility for these microorganisms to spread and contaminate the fresh meat product through cross-contamination during handling and processing. Food contamination and spoilage by microorganism presents serious problems for consumer safety. There have been numerous cases of food poisoning, pathogen outbreak, and product recalls worldwide (Bardon, Kolar, Cekanova, Hejnar, & Koukalova, 2009; Castaneda, 2017; Premarathne et al., 2017; Scheinberg, Doores, & Cutter, 2013). *Campylobacter jejuni*, *Salmonella* spp., *Listeria monocytogenes*, and *Escherichia coli* are the main pathogenic microorganism found on the surface of chicken meat (Castaneda, 2017; Cunningham, 2012; Premarathne et al., 2017; Scheinberg et al., 2013). These bacteria can infect human through consumption of cross-contaminated or undercooked chicken meat (Devleesschauwer, Bouwknegt, Mangen, & Havelaar, 2017; Pasquali et al., 2017; Premarathne et al., 2017).

The presence of spoilage bacteria on the surface of fresh poultry meat after processing is the main reason in determining the shelf-life of the product (Octavian & Octavian, 2010; Petracci & Fletcher, 2002; Russell, Fletcher, & Cox, 1995). The growth of the spoilage microorganisms during cold-storage can lead to quality defects such as discoloration, development of off-odor, and development of off-flavor (James, 2005; Mead, 2004; Pearson & Dutson, 1994; Shall, 2013). Once the growth of the spoilage microorganisms reaches high numbers ($>10^5$ CFU/cm^2), they start to produce metabolites that cause the defects to become more noticeable. The shelf-life of fresh poultry meat products ultimately end when the consumer is able to notice and identify these defects (Carvalho, Shimokomaki, & Estévez,

2017; Parrott & Walley, 2017). Therefore, international food safety authorities such as USFDA and FSANZ recommended that AMCs present on the surface of fresh chicken meat should be $< 5 \times 10^6$ CFU/cm^2 at the end of shelf-life (FSANZ, 1995; Hasell & Salter, 2003).

Different food preservation methods have been developed and applied in food processing to control or reduce contamination thereby extending the shelf-life of food products. Heat and chemical treatment are the most common methods of microorganism inactivation (Huang, Wu, Lu, Shyu, & Wang, 2017; Tewari & Juneja, 2007). Despite being highly effective, heat treatment and chemical antimicrobial agent often destroy sensory properties and valuable nutrients such as protein and vitamins (Koutchma, 2008, 2009; Tewari & Juneja, 2007).

Alternative non-thermal and non-chemical preservation methods have been investigated for food processing application. Ultraviolet (UV) light technology, high pressure processing (HPP), high voltage processing, and gamma irradiation, are some of the examples of alternative preservation methods (Gould, 2001; Gunter-Ward et al., 2018; Lynch, 2016; Seemeen, 2011; Tewari & Juneja, 2007). UV-C light is a part of the electromagnetic spectrum that possess germicidal capabilities (Ahmad, Christensen, & Baron, 2017; Gabriel, Ballesteros, Rosario, Tumlos, & Ramos, 2018; Gunter-Ward et al., 2018; Koutchma, 2008, 2009; Unluturk & Atilgan, 2014). UV light technology has several advantages over other alternative technologies including ease of operation and cost efficiency (Baysal, Molva, & Unluturk, 2013; Gunter-Ward et al., 2018).

The United States Food and Drug Administration (USFDA) and European Food Safety Authority (EFSA) have recently approved the application of UV-C light (100-280 nm) for the treatment of various types of food such as bread, juice and dairy products (Forney & Moraru, 2009). UV-C light was first applied as a substitute for heat treatment for the pasteurisation of liquid food products such as fruit juice and milk (Ahmad et al., 2017; Gabriel et al., 2018; Gunter-Ward et al., 2018). Successful applications of UV-C light have also been reported for surface pasteurisation of fruit, vegetables, raw meat, and cooked meat (Baysal et al., 2013; Butot et al., 2018; Gamage, 2015; Heinrich, Zunabovic, Varzakas, Bergmair, & Kneifel, 2016; Semi, 2016) .

UV-C light technology has a huge potential for poultry processing application. The germicidal capabilities paired with minimal impact on sensory properties of the meat product make UV-C technology a suitable processing aid in the poultry industry. UV-C light processing can reduce the presence of spoilage bacteria on the surface of fresh chicken product directly after processing, resulting in the extension of shelf-life. Increasing the shelf-life of fresh chicken meat product will lead to the increase in food safety, economic value, as well as a decrease in food waste production. Despite the advantages of UV-C application in the food industry, implementation of the technology has been generally been slow worldwide, including in New Zealand (Koutchma, 2008, 2009). Therefore, the aim of this study was to investigate the potential of UV-C light processing for surface pasteurisation of fresh chicken meat portion.

1.1. Objectives

The main objective of this study was to develop an effective surface pasteurisation process for fresh chicken meat using UV-C light technology.

1.2. Specific objectives

The specific objectives of this research were to:

- Evaluate the efficacy of UV-C light technology on reducing the microbial load of fresh chicken meat.
- Optimise the UV-C surface pasteurisation process for fresh skinless and skin-on chicken meat.
- Determine the effect of UV-C light treatment on microbial survival, physicochemical attributes, and sensory characteristics of fresh chicken meat during refrigerated storage (4°C).

2. Literature Review

2.1. Introduction

Industrial food processing aims to transform and increase the value to raw plant or animal material by converting them into safe and acceptable food products (Boziaris, 2014; Grumezescu & Holban, 2018; Hui & Aalhus, 2012). The main purpose food processing is to prolong the shelf-life with minimal effect on the characteristics and nutritional composition of the food products.

From the consumer's perspective, sensory characteristics and nutritional value are the most important aspects to be considered in the selection of a food product. Characteristics such as appearance (color), texture, odor (smell), and flavor (taste) as well as nutritional content such as protein and fats play an important part in determining the quality of the food products for subsequent purchase. Thus, food industries must implement processing technologies that is capable of preserving these sensory attributes and nutritional values while at the same time maintaining the safety of the food products.

Traditional food preservation methods that are commonly implemented for food processing are based on physical (heat treatment, drying, chilling, and freezing) and chemical (preservatives, acid) treatments. The most common preservation method for the mass food production is heat treatment (canning, pasteurisation, cooking). Although it is a very effective method for food preservation, these traditional food processing practice significantly affects the sensory characteristics and nutritional value (Tewari & Juneja, 2007). The fundamental side effect of heat treatment on food products is the substantial impact on sensory characteristics and nutritional value due to the denaturation of protein and destruction of vitamins. In addition, chemical preservation methods may leave undesirable residues on the food product (Grumezescu & Holban, 2018). These chemical residues have been known to cause health implication and have a considerable effect on sensorial attributes such as appearance, odor, and taste (Koutchma, 2009; Seemeen, 2011; Semi, 2016).

Consumer demand for safe and minimally processed food products have presented a new challenge and opportunity for food manufacturers. Therefore there is a need for processing technique that is not only able to keep food safe from contamination and spoilage, but also retains the freshness and nutrient content of the food product (Banerjee & Verma, 2015).

Novel or alternative food preservation techniques are currently being investigated as a solution to the problems posed by traditional preservation techniques. These alternative processing techniques possess the potential to provide safe food products while retaining the sensory characteristics. Amongst the alternative to the traditional treatment methods are high-pressure processing, gamma irradiation, pulsed electric field, and ultraviolet (UV-C) light (Soni, Oey, Silcock, & Bremer, 2016; Tewari & Juneja, 2007).

Ultraviolet (UV) light is one of the alternative preservation methods that possesses high potential for food processing application. UV technology has been used in medical application such as water decontamination, air decontamination, and surface decontamination. UV light possesses germicidal capabilities that are very suitable for food application. In addition, studies conducted on UV light application on food product indicated that UV has minimal impact on sensory quality of food product (Cilliers et al., 2014; Hyun, Jin, Sun, Sook, & Bin, 2010). Thus, UV light has a tremendous potential to be an efficient and effective processing technique for the food industry.

2.2. Traditional food preservation techniques

Elimination or reduction of bacteria calls for an effective and efficient preservation technique. A lot of effective preservation technique has been developed. Preservation by heat is the most effective and widely used preservation technique. It is simple and cost-efficient. Heat effectively reduce the number of bacteria on the meat but at the same time destroy valuable nutrition (Morgan, Radewonuk, & Scullen, 1996). Heat causes the degradation of vitamins and denaturation of protein as well as the development of “cooked” appearance, which are highly undesirable (James, Göksoy, Corry, & James, 2000). Research has been carried out to find out the shortest amount of time that is effective to kill bacteria without

destroying too much nutrition and make it appear less “cooked”. This technique is called pasteurisation. Pasteurisation does not necessarily eliminate all presence of pathogen; it only reduces the number of bacteria to a “safe” level. Since bacteria are commonly found on the surface of the meat, the pasteurisation in meat is referred to as surface pasteurisation. Research has investigated a lot of different technique of surface pasteurisation using steam. One of the latest technologies is using supersaturated steam at 140-150°C to pasteurise meat quickly (Hassan, Skjerve, Bergh, & Nesbakken, 2015). Another study was done by Osiriphun, Tuitemwong, Koetsinchai, Tuitemwong, and Erickson (2012) applies scalding (immersion in hot water) technique to pasteurise chicken. The study concluded that scalding is effective to reduce the number of pathogens in chicken but it developed “cooked” appearance to the chicken meat.

Another common preservation technique is chemical preservatives. The common chemical agent used as preservation on chicken meat is chlorine, potassium sorbate, trisodium hydroxide and sodium hydroxide, and lactic acid and sodium benzoate (Gould, 2001). Chemical preservatives are losing popularity due to the chemical residue it left on the meat product, which results in a change in sensorial quality such as taste and smell. Some of the residues is also harmful to health when ingested by the human body (Chun et al., 2010). Therefore, novel food processing techniques are being explored to find a solution to enhance the quality and safety of food products.

2.3. Ultraviolet light

UV (ultraviolet) light is categorized as electromagnetic radiation with wavelength ranging from 100 to 400 nm (Figure 2.1), between visible light and X-ray (Thompson, 2003). It is present naturally in sunlight or can be generated artificially using special light sources (Ahmad et al., 2017). A UV light is divided into three different types based on their wavelength: UV-A, at 320-400 nm; UV-B, at 290 – 320 nm; and UV-C at 200 – 290 nm. UV-A and UV-B are not utilized in food decontamination process due to their minimal germicidal capabilities. UV-C light is the only wavelength that possess potent germicidal capabilities, therefore it is applied as a sanitizing tool (Ahmad et al., 2017; Koutchma, 2009).

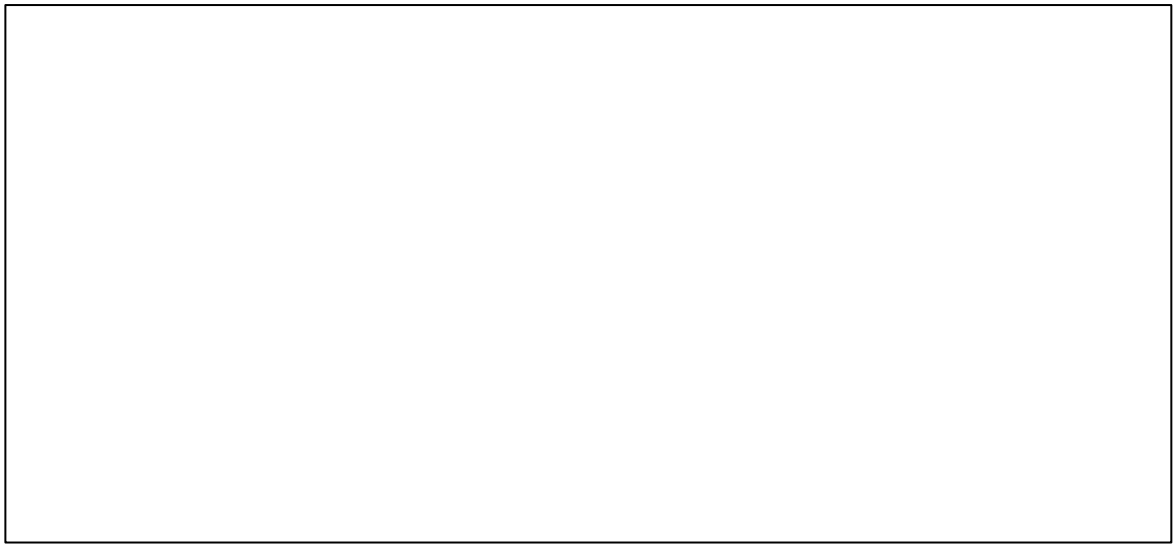

Figure 2.1. Electromagnetic spectrum with an expanded scale of UV radiation.
Source: Thompson (2003).

Exposure to sufficient dosage of UV-C light results in lethal damage to most microorganisms, including those that are the main source of contamination in raw and processed food. Figure 2.2 summarises how the absorption of UV light at 280-290 nm (UV-C region) in the nucleic acid of *Escherichia coli* effectively inactivate the microorganism through prevention of replication and reproduction. The lethality of UV-C exposure comes from its capability of molecular rearrangements in the DNA and RNA, i.e. the genetic material of microorganism. The molecular rearrangements in the genetic material incapacitate the ability of reproduction (Guerrero-Beltran & Barbosa-Canovas, 2004; Koutchma, 2008). The UV-C light being absorbed by the genetic material creates pyrimidine dimers which prevents the replication of the microorganism, ultimately nullifying their ability to further contaminate the food (Koutchma, 2009).

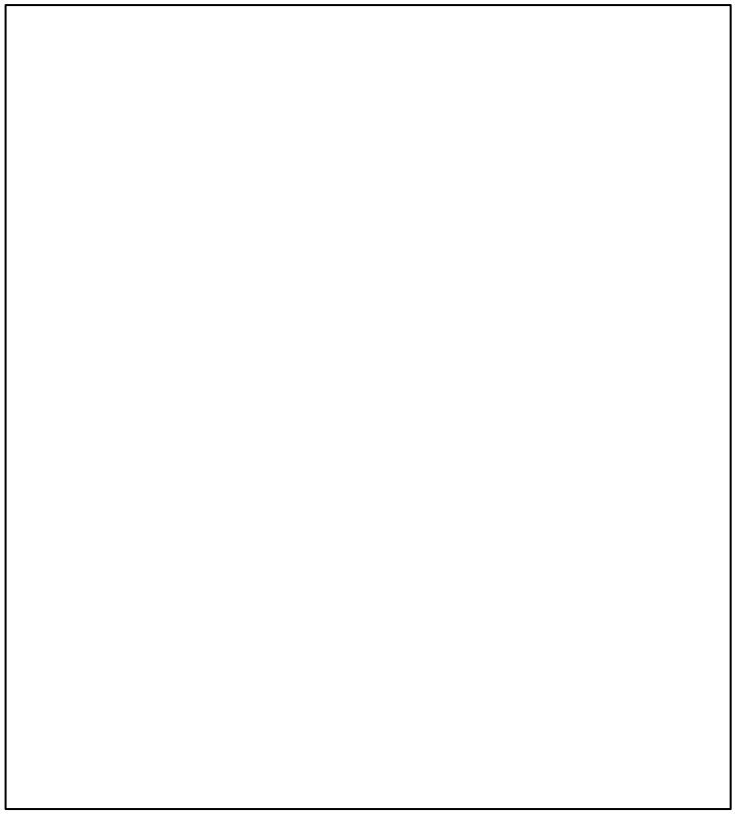

Figure 2.2. Matching action spectrum between nucleic acid absorption and inactivation of *E.coli* cells.
Source: Thompson (2003).

Successful disinfection using UV irradiation depends on several factors. Ultraviolet intensity, duration of exposure, and distance from a light source to object are important factors in determining the dosage (transmitted energy) in a UV irradiation system (Semi, 2016; Thompson, 2003). With that in mind, the dosage of continuous UV light system can be quantified using an equation from Semi (2016):

$$Dc = \frac{S}{4\pi d^2}\ x\ t \qquad (1)$$

where *Dc* is the total dose of UV light expressed in J/cm^2, *S* is the power output from the source of light expressed in Watt, *d* is the distance of an object from the power source expressed in cm, and *t* is exposure time expressed in seconds.

When a pulsed UV light source is used, the total dose will be altered due to the "pulsing" nature of the lamp source. Heinrich et al. (2016) provided the equation to quantify dosage of pulsed UV light system:

$$Dc = n\ x \frac{S}{4\pi d^2}\ x\ t \tag{2}$$

where *Dc* is the total dose of UV light (J/cm^2), *n* is the number of pulses applied during exposure, *S* is the power output from source of light (Watt), *d* is the distance of an object from the power source (cm), and *t* is the duration of one pulse or pulse width (second).

The required effective dose of UV is different from one microorganism to another. The dosage is adjusted to D_{10} value which is the energy needed (killing power) to reduce 1 log concentration of a microorganism (Semi, 2016). For example, the D_{10} value for *Clostridium tetani* in water is 4.9 mJ/cm^2. This means that to reduce 1 log of *Clostridium tetani,* water must be exposed to UV light at 4.9 mJ/cm^2 dosage.

2.3.1. Ultraviolet (UV-C) light sources

There are various types of UV sources that have been developed and have the potential to be applied for food processing. The natural source of UV radiation, the sun, is not able to be utilized as food preservation technique since the ozone in our atmosphere blocks most of the damaging short-wavelength (UV-C) radiation (Ahmad et al., 2017). However, UV can be artificially generated using man-made lamp (Thompson, 2003). They can be divided into two main types, continuous and pulsed UV source. Excimer lamp technologies, continuous UV low-pressure and medium-pressure mercury lamps are categorized as a continuous source, while pulsed xenon UV-light is used as a pulsed-UV light source (Guerrero-Beltran & Barbosa-Canovas, 2004; Koutchma, 2008, 2009).

The most commonly used source of UV-C light is continuous UV source. They are mainly used for water treatment and sanitation (Ahmad et al., 2017; Koutchma, 2008, 2009). The typical lamp sources are the low-pressure and medium pressure mercury lamp. Low-pressure

lamps are mainly used for surface disinfection since they are very efficient at generating UV light (Ahmad et al., 2017; Koutchma, 2008). The weakness of low-pressure lamps is that it can only generate low UV output. Medium-pressure mercury lamps, on the other hand, can generate higher output than its low-pressure counterpart (up to 30 times). Medium pressure lamps allow the treatment of high flow rates using fewer light sources. They are mainly used for large scale water and fluid treatment and sanitation (Ahmad et al., 2017; Thompson, 2003).

Excimer lamps and pulsed UV light are recently being studied further in their application in food processing (Heinrich et al., 2016; Hierro et al., 2011; McLeod et al., 2018). Excimer lamps or excilamps produces monochromatic light which can be set to the desired wavelength by the formation of rare gas, halogen excimers, or rare gas halide exciplexes (Koutchma, 2009). Other advantages of this type of lamp are that it can produce very low output and can be used in surface with low temperatures, which is perfect for application in liquid disinfection (Koutchma, 2008; Warriner, Kolstad, Rumsby, & Waites, 2002).

Pulsed UV-C light is also being investigated on its effectiveness for food processing. Pulsed UV-C light works by pulsing a high-power xenon lamp for about 0.1 to 3 millisecond or 10 to 100 millisecond per source, depending on the type of source (Sharma & Demirci, 2003). Studies on pulsed UV light shows promising results in reducing the number and eliminating pathogens such as *Aspergillus niger* on cornmeal (Jun, Irudayaraj, Demirci, & Geiser, 2003), *Escherichia coli* O157:H7 on alfalfa seeds (Sharma & Demirci, 2003), and yeast (Takeshita et al., 2003).

2.3.2. Ultraviolet (UV-C) light application in food processing

UV light application for food processing has been around for a period of time. It has been used for water disinfection, air disinfection, and surface disinfection in food production plants (Koutchma, 2008). The USFDA (2017) has declared the use of UV light as a safe way to reduce the number of microorganisms present in a food product. Nowadays, it is used for

much more application throughout the food production process in various different food products.

UV-C light is gaining popularity as a preservation technology due to its effective germicidal properties and cost-efficiency in addition to its suitability to meet the recent demand in food processing. Recent trend in food processing calls for minimally processed product, fresh and free from chemical residue (Banerjee & Verma, 2015; Heinrich et al., 2016). UV as a treatment in food processing has no effect on the sensorial quality of food, such as color, appearance, and odor. UV-C light treatment also has no significant effect on the nutritional quality of the food and left no residue. This is an enormous advantage compared to popular chemical preservatives such as chlorine or popular physical preservation technique such as the application of heat. The use of chlorine left an obvious residue on the food product in the form of chloroform, which drastically affects the odor of food (Gamage, 2015). Heat treatment, despite being effective, destroys some valuable nutrition in food. Denaturation of protein in heat treatment of meat is one of the examples of the destruction of nutrition by heat treatment (Tewari & Juneja, 2007). Heat treatment also results in "cooked" appearance which does not agree with consumer's demand for minimally processed food product (Banerjee & Verma, 2015).

The first food-related UV-C light application is in water treatment (Azimi, Allen, & Farnood, 2012). Water is a clear liquid, able to be fully penetrated by light. Even dispersion of UV-C light in water resulted in a very effective and efficient decontamination process. After that, research began on disinfection or pasteurisation of other liquid food, such as fruit juices and milk (Koutchma, 2009). Studies have been conducted on the effectiveness of UV-C light treatment for liquid food disinfection. The effectiveness of UV-C treatment in liquid foods depends on the turbidity of the liquid food (Koutchma, 2009). The UV system is based on the light spectrum and the germicidal efficacy highly depends on the capability of UV-C light to penetrate the liquid food (Gunter-Ward et al., 2018). Several studies that have been carried out on various product, such as bovine milk (Cilliers et al., 2014; Gunter-Ward et al., 2018), apple and grape juice (Baysal et al., 2013), orange juice (Rodríguez, Oteiza, Giannuzzi, & Zaritzky, 2017), and pumelo fruit juice (Shah, Shamsuddin, Rahman, & Adzahan, 2014),

shows significant efficacy of UV-C light on reducing the number of microorganisms in the liquid food product without compromising sensory and nutritional quality.

The UV light has also been used effectively for the disinfection of surfaces that come in contact with food material during production (Gabriel, Ballesteros, Rosario, Tumlos, & Ramos, 2018). It has been used in dairy food, bakery, and meat production plant (Gabriel et al., 2018). Recently, UV technology is applied for direct disinfection or pasteurisation on the surface of a food product. The surface of food has been established to be the first entry point for microorganism to grow and, later on, penetrate the inside of the food (Isohanni & Lyhs, 2009). Studies have been carried out to determine the effectiveness of UV irradiation on fruit skin and vegetable surface. A study was done by Gamage (2015) on the application of UV-C technology for the treatment of fresh broccoli. The study shows a significant decrease in a number of the pathogen (*Listeria monocytogenes*) on the surface of broccoli that has been exposed to UV light with a dosage of 5.2 kJ/m². Another study was done by Semi (2016), successfully create a system for decontamination of fruit surface (skin) using UV-C light treatment. Both studies also concluded that UV-C light treatment in fruit and vegetable surface does not significantly alter the sensorial and nutritional qualities of the food product.

2.3.3. Ultraviolet (UV-C) light application in poultry products

Fresh poultry meat product is highly susceptible to microbiological contamination resulting in a short shelf-life (McLeod et al., 2018). The slaughter process of poultry includes skinning, cutting, boning and portioning for easier processing (Barbut, 2002; Owens, Alvarado, & Sams, 2010). During these processes, bacteria from the skin and carcass cavity of chicken can be a major source of contamination (Chun et al., 2010). Contamination also occurs during processing and handling of chicken meat. There are four major pathogens that are recognized as a major contaminant in chicken: *Escherichia coli, Salmonella spp., Listeria monocytogenes,* and *Campylobacter jejuni* (Alter, 2017; Bardon, Kolar, Cekanova, Hejnar, & Koukalova, 2009; Chun et al., 2010). When chicken meat contaminated with dangerous level of pathogen is not cooked properly prior to consumption, the consumer can experience fatal disease such as salmonellosis by infection of *Salmonella spp.* and listeriosis by infection

of *Listeria monocytogenes* (Chun et al., 2010). Hence, it is important to control and eliminate the presence of pathogenic bacteria on the fresh poultry meat product.

Furthermore, the microorganism can compromise the quality of poultry product by spoilage (Castaneda, 2017; Cunningham, 2012; Demirok et al., 2013). Spoilage microorganism is present all over the processing steps. It is a major challenge to eliminate the presence of all the spoilage microorganisms during processing. Handling has been established as the main entry point for spoilage microorganism to infect the surface of raw meat (Cunningham, 2012; Curtis, 2005). Although being mostly harmless for human health, the high presence of spoilage microorganism is an indicator of the presence of pathogens. Moreover, the presence of spoilage microorganism alters the freshness and sensory characteristics of fresh poultry meat product. Spoilage microorganisms such as *Pseudomonas* spp. and *Acinetobacter* spp. are capable of producing a biochemical byproduct that can affect the freshness of poultry meat (Barbut, 2002; Cunningham, 2012). Studies reported that at 1.0×10^5 CFU/ml, spoilage bacteria will start producing off odor (Pearson & Dutson, 1994; Russell, Fletcher, & Cox, 1995). Furthermore, at 1.0×10^7 CFU/ml, spoilage bacteria will begin to produce slime on the surface of fresh chicken meat (Russell et al., 1995). The presence of slime and development of off-odor are two main defects for raw poultry meat product. Thus, any reduction in the initial number of spoilage microorganism will significantly delay their growth during storage, improving the quality and shelf-life of fresh poultry product. The current established shelf-life of chicken meat was 6 to 7 days when stored under refrigeration temperature (4°C) (Jiménez et al., 1997; Lu, Sun, Huang, Guo, & Memon, 2019; McMeekin, 1975, 1977; Russell et al., 1995).

The threat of contamination thereby forced the food industry to find a way to reduce the number of bacteria that is present in chicken meat during slaughter, handling, and processing. Regulation and standard on bacterial count are established to control the contamination. New Zealand and Australian food authority, the Food Standards Australia New Zealand (FSANZ), has set the standard for a chicken product in Australia and New Zealand. The standard mentions *Campylobacter* spp. and *Salmonella* spp. as their main concern in a chicken product. The maximum number of Campylobacter present must be lower than ten thousand CFU (Colony Forming Unit) per whole chicken carcass (FSANZ, 2018). The maximum

number for *Salmonella* spp., however, is not mentioned. In addition, FSANZ also recommended the number of aerobic mesophilic count (AMCs) on fresh chicken meat to be lower than 5 x 10^6 CFU/cm^2 at the end of shelf-life.

UV-C light has a lot of advantages compared to heat and chemical preservation techniques. The UV light does not alter the sensory or nutritional quality of meat. It also does not leave any residue on the meat product. In addition, UV-C light system is inexpensive and easy to operate (Gamage, 2015; Koutchma, 2009). This is the main advantage of UV light system compared to other popular non-thermal system such as high-pressure processing and pulsed electric field. High-pressure processing and pulsed electric field system display similar disinfection efficacy as well as maintaining nutritional and sensorial quality but they are expensive and require a lot of care and attention to operate (Huang, Wu, Lu, Shyu, & Wang, 2017).

Research has been conducted to investigate the efficacy of UV light application on the preservation of chicken meat. A study by Chun et al. (2010) on the effect of UV-C light on chicken breast shows that UV light was capable of reducing a significant number of *L.monocytogenes, Salmonella spp*., and *C.jejuni* during chilled storage. Another more recent study was done by McLeod et al. (2018), where chicken fillets were exposed to UV-C (254 nm) light using two different types of UV-C lamp sources (continuous and pulsed). The study reported that treatment of fresh skinless chicken breast using pulsed and continuous UV-C light successfully reduced in the number of pathogens.

2.3.4. Effect of UV-C light treatment on microorganisms

The efficacy of a food preservation technology is determined by its capability to reduce or eliminate spoilage and pathogenic microorganism that is present on the food product and its effect on the sensory characteristics and nutritional value (Grumezescu & Holban, 2018; Mead, 2004; Seemeen, 2011). UV-C has been widely applied in the food industry for shelf-life extension and sterilization purposes. Moreover, UV-C light treatment is gaining popularity due to the recent demand for minimally processed food product. Previous studies reported that UV-C is capable of inactivating various different microorganisms, such as

bacteria, virus, and spores in different types of food products (Butot et al., 2018; Cilliers et al., 2014; Gabriel et al., 2018; Gamage, 2015; Gunter-Ward et al., 2018; Semi, 2016; Unluturk & Atilgan, 2014).

UV ray absorption by the DNA and RNA of microorganism has been established as the key killing mechanism of UV-C light treatment (Chun, Kim, Lee, Yu, & Song, 2010; Haughton et al., 2011b; Koutchma, 2009). The germicidal process starts with the absorption of UV ray by the DNA, which leads to the formation of cross-linked pyrimidine nucleotide bases that causes mutation in the DNA. This mutation blocks the transcription and replication ability of DNA, consequently preventing cell reproduction which ultimately leads to cell death (Gabriel et al., 2018).

There are several factors influencing the efficacy of UV-C light in the inactivation of microorganisms on a food product. Exposure time and UV-C light dose are the main technical factors that affect the efficacy of UV-C light decontamination (Heinrich et al., 2016; Koutchma, 2008; Semi, 2016). Generally, increasing UV light dose resulted in higher germicidal capability. However, high dosage and long exposure duration might induce changes in sensory qualities and nutrient content of the food product (Gunter-Ward et al., 2018; Heinrich et al., 2016; Rodríguez, Oteiza, Giannuzzi, & Zaritzky, 2017).

The target microorganism also has an important impact on the efficacy of UV-C light decontamination process (Cilliers et al., 2014; Koutchma, 2009; Park, Kim, Lee, & Ha, 2015). The inactivation of microorganism using UV-C light depends on the size of their cells. Higher UV-C light dose is required for the inactivation of microorganism with larger cell size (Azimi et al., 2012; Soni et al., 2016). UV-C light has been proven to be effective against most spoilage and pathogenic bacteria in their vegetative form in different types of food product (Butot et al., 2018; McLeod et al., 2018; Park & Ha, 2015; Unluturk & Atilgan, 2014). UV-C light has also been proven to successfully inactivate viruses in different types of food contact surfaces and product (Butot et al., 2018; Gunter-Ward et al., 2018; Park et al., 2015). On the other hand, bacterial spores were found to be more resistant to UV-C treatment (Gayán, Álvarez, & Condón, 2013; Soni et al., 2016).

In addition, the efficacy of direct UV-C light decontamination for surfaces (food or non-food) depends on the topography of the surface itself. As the inactivation of microorganism using UV-C light relies on direct exposure on the target microorganism, any obstruction caused by the surface topography of the UV-C light may reduce the efficacy of the inactivation process (Haughton et al., 2011b; Koutchma, 2008, 2009). Studies have been conducted to test the efficacy of UV-C light treatment on the inactivation of microorganism on surfaces with different surface topography. The result of these studies suggested that UV-C light treatment on the same type of microorganism was more effective on smoother surface such as stainless steel compared to rougher surface such as chicken skin or chicken meat (Park & Ha, 2015; Park et al., 2015). Rough surfaces such as chicken skin harbors cracks and cervices which provide shielding to microorganisms from UV-C light exposure (McLeod et al., 2018).

2.3.4.1. Effect of UV-C light treatment on bacteria

Bacteria are classified as prokaryotes, which are simple, single-celled microorganism (Atwill, 2017; Castaneda, 2017; Grumezescu & Holban, 2018). Bacteria is an important microorganism for the food industry as it serves a dual purpose, as a food processing aid (cheese, beer, yoghurt) and as a parameter for food safety (Grumezescu & Holban, 2018). The presence of bacteria at a large number on the food product will lead to spoilage and food-borne diseases. Spoilage of food by bacteria reduces the shelf-life of the product and ultimately, the value of the product. Food-borne disease is a very serious health risk for consumer and can lead to a massive loss for the food industry.

Spoilage bacteria

The common type of bacteria that causes spoilage in poultry product is psychrophilic bacteria (Barbut, 2002; Jiménez et al., 1997; McMeekin, 1975, 1977). Although their optimum growth temperature was between 20°C up to 35°C, these bacteria can grow at refrigeration temperature, at or less than 7°C (Arnold, 2005; Curtis, 2005; Kelly, 2005; Mead, 2004). Their presence in fresh poultry product is marked by a characteristic odor described as ‘dirty

dishrag' or 'wet dog' odor (Barbut, 2002; Mead, 2004). After the development of the off-odor, colonies will start forming on the surface of the chicken meat and form slime. This presence of slime and development of off-odors indicates that the number of spoilage bacteria is higher than 1.0 x 10^5 CFU/cm^2 (Owens et al., 2010; Pasquali et al., 2017). Therefore, the growth of psychrophilic bacteria is usually used as an indicator to determine the spoilage level and shelf-life of fresh poultry product.

The psychrophilic bacteria species commonly found on fresh chicken products are *Pseudomonas* spp. and *Acinetobacter* spp. (Arnold, 2005; Owens et al., 2010). UV-C technology has been investigated for their capability to reduce and suppress the growth of these spoilage bacteria. Haughton et al. (2011b) in his study on the efficacy of UV-C light towards food and non-food surfaces reported that up to 1.76 log CFU/g reduction was achieved for the total viable count. In a more recent study by McLeod et al. (2018), UV-C treatment on raw chicken fillet was reported to reduce the presence of *Pseudomonas* spp. by 2.5 log CFU/cm^2. Based on these studies, UV-C light processing was proven to be effective in inactivating and reducing the presence of spoilage bacteria. However, the effect of UV-C light treatment on the remaining spoilage bacteria during storage has not yet been investigated.

Pathogens

Bacteria can also pose a health risk by causing disease upon consumption. These food-borne diseases are commonly caused by the consumption of poorly cooked contaminated poultry product. The common bacteria that are responsible for these food-borne diseases in poultry products are *Campylobacter jejuni*, *Salmonella* spp, *Listeria monocytogenes*, and *Escherichia coli* (Alter, 2017; Castaneda, 2017). These species of bacteria are found in the gastrointestinal tract of live poultry and have a high possibility of contaminating the carcass during slaughter and processing (Kelly, 2005; MacDonald, 2005; Owens et al., 2010; Qian, 2015). Ingestion of these bacteria can lead to severe health complications. The efficacy of UV-C technology against these bacteria on fresh poultry meat has been investigated in

numerous studies. Table 2.1 summarizes the result of various study regarding the application of UV-C light technology for direct surface pasteurisation of fresh poultry meat.

Table 2.1. Summary of UV-C light treatment on fresh chicken meat.

UV-C System	Target Microorganism	Dosage	Reduction	Source
Continuous	*Campylobacter jejuni*	9.4 – 32.9 mW/s.cm^2	0.7 log CFU/g	Isohanni and Lyhs (2009)
Continuous	*Campylobacter jejuni, Listeria monocytogenes, Salmonella enterica*	5 kJ/m^2	1.26, 1.29, 1.19 log CFU/g respectively	Chun et al. (2010)
Continuous	*Campylobacter jejuni, Escherichia coli, Salmonella enterica*, total viable count, *Enterobacteraceae*	0.192 J/cm^2	0.76, 0.98, 1.34, 1.76, 1.29 log CFU/g respectively	Haughton et al. (2011b)
Pulsed	*Campylobacter jejuni, Escherichia coli, Salmonella* Enteritidis	7.08 J/cm^2	0.96, 1.13, 1.35 log CFU/g respectively	Haughton et al. (2011a)
Continuous	*Listeria monocytogenes*	5 mJ/cm^2	36.4 MPN/fillet	Lyon, Fletcher, and Berrang (2007)
Continuous	Hepatitis A virus & murine norovirus-1	600 – 1200 mWs/cm^2	1 log CFU/g	Park and Ha (2015)
Continuous & Pulsed	*Salmonella* Enteritidis, *Listeria Monocytogenes, Staphylococcus aureus, Escherichia coli, Pseudomonas* spp., *Bronchotrix thermospacta, Carnobacterium divergens*	Continuous: 0.05 – 3.0 J/cm^2 Pulsed: 1.25 – 18 J/cm^2	Continuous: 1.1 – 2.8 log CFU/cm^2 Pulsed: 0.9 – 3 log CFU/cm^2	McLeod et al. (2018)

Recent studies on UV-C technology indicated that UV-C light is very effective in controlling both spoilage and pathogenic bacteria. However, further work must be carried out to optimise the UV-C light processing technology for direct surface pasteurisation application in the poultry industry.

Bacterial spores

Bacterial spores, commonly referred to as endospores, are tough, dormant, and non-reproductive structures formed as a response to unfavorable and hostile environmental conditions (Gayán et al., 2013). Due to their highly tolerant nature, the elimination of bacterial endospores represents a challenge to the food industry (Heinrich et al., 2016; Soni et al., 2016). Bacterial spores are highly resistant to most conventional and novel food preservation and processing technology (Soni et al., 2016). Spores have been known to be

highly resistant to heat treatment, dehydration, and chemical treatments (Baysal et al., 2013; Blatchley III, Meeusen, Aronson, & Brewster, 2005; Soni et al., 2016). Spores are not killed at boiling temperature (100°C) but are destroyed at 121°C (Bermúdez-Aguirre, Dunne, & Barbosa-Cánovas, 2012). Furthermore, bacterial spores are also highly resistant to irradiation and high-pressure processing. A high degree of pressure (>800 MPa) was needed to successfully inactivate bacterial spores (Gayán et al., 2013; Seemeen, 2011).

Bacillus and *Clostridium* are two examples of bacteria that are capable of forming spores. These two bacteria are also the main concern in food processing. *Bacillus cereus* has been found to contaminate various food products such as rice, eggs, milk, and raw meat around the globe (Gayán et al., 2013; Soni et al., 2016). The main concern for *bacillus cereus* is its toxin-producing ability, which leads to food poisoning when ingested. *Clostridium botulinum* also poses a threat to the food industry. *C. botulinum* readily grows in places where oxygen levels are low such as canned food, modified atmosphere packaged food, and vacuum packaged foods (Gayán et al., 2013). Similar to *B. cereus*, *C. botulinum* also produces a toxin that causes botulism when ingested. Botulism is a severe illness with symptoms include vertigo, nausea, vomiting, and muscle weakness that can lead to paralysis and death (Gayán et al., 2013).

Spores have an altered DNA conformation caused by the presence of small acid-soluble proteins that binds to the DNA (Soni et al., 2016). This unique altered DNA conformation combined with the presence of a thick spore protein coating provided formidable protection towards UV-C exposure (Gayán et al., 2013). Moreover, spores have been known to be capable of repairing itself after UV-C exposure. This happens mainly due to the activity of enzymes called photolyases, which bind to the dimers formed by the UV-C treatment and use energy from visible light to reverse the formation of dimers (Heinrich et al., 2016; Soni et al., 2016). Both *C. botulinum* and *B. cereus* have shown to be highly resistant to UV-C treatment. A high dosage of UV-C is required to inactivate the bacterial spores as compared to the vegetative stage. Soni et al. (2016) reported in their study that the UV-C treatment D-values for *B.anthracis sterne* spores was 810 J/m^2, which is significantly higher compared to 60 J/m^2 for its vegetative cells.

In order to overcome this problem, the efficacy of UV-C combined with other conventional preservation method to inactivate bacterial spores was investigated. Gayán et al. (2013) reported that the combination of UV (27.10 J/ml) and heat treatment (60°C) increase the inactivation efficacy against *B. coagulans* by 2 logs. Despite this revelation, the resistance of each species of *Bacillus* towards the combination of UV and heat treatment is different. Therefore, the efficacy of UV treatment alone combined with other preservation method towards the inactivation of bacterial endospores is still uncertain.

2.3.4.2. Effect of UV-C light treatment on virus

Aside from bacteria, some species of virus also poses a threat to food safety (Butot et al., 2018; Cantlay, Ingram, & Meredith, 2017; Gunter-Ward et al., 2018). Several cases of food-borne illness outbreak caused by the virus were reported around the world (Jean, Morales-Rayas, Anoman, & Lamhoujeb, 2011; Park et al., 2015). Norovirus (NoV), hepatitis A virus (HAV), rotavirus, sapovirus, and astrovirus are all major viral pathogen that has been causing food-borne illnesses (Seemeen, 2011). Among these enteric viruses, norovirus and hepatitis A virus are the leading cause of non-bacterial foodborne illness (Park et al., 2015). In both developing and developed countries, 80 to 90% reported foodborne viral outbreak is caused by NoV and HAV (Jean et al., 2011; Park & Ha, 2015; Park et al., 2015).

Norovirus is comprised of a genetically diverse group of single-stranded, positive-sense, non-enveloped RNA virus (Romalde, 2017). Transmission of NoV is mainly through the oral-fecal route. Hepatitis A virus consists of a group of non-enveloped, icosahedral RNA viruses (Cao et al., 2019). HAV is the main cause of non-bacterial food-borne illness in developing countries (Jean et al., 2011). Similar to NoV, HAV is also transmitted through oral-fecal route, either by direct person-to-person contact or by consumption of contaminated food or water.

NoV and HAV have been reported to contaminate raw meat through handling during processing or distribution/transport (Butot et al., 2018; Park & Ha, 2015). Fresh poultry meat

provided a very suitable and strong candidate as a vector for both NoV and HAV transmission. The amount of hand to meat handling as well as inadequate hygiene standard increases the possibility of contamination.

The efficacy of UV-C treatment to inactivate NoV and HAV have been explored and investigated recently. Jean et al. (2011) and Park et al. (2015) both investigated the effectiveness of UV-C treatment against NoV and HAV on stainless steel food contact surface. Both studies reported complete inactivation of both species of viruses on the stainless-steel surface using UV-C light. Furthermore, the capability of UV-C light to inactivate both NoV and HAV was investigated on direct food product surface decontamination application. Park and Ha (2015) studied the inactivation of human norovirus and hepatitis A virus on fresh chicken meat. The study concluded that chicken breast treated with UV-C light at 60 – 1200 mWs/cm^2 was capable of reducing 1 log (90%) of both NoV and HAV counts without any damage to the physicochemical and sensory qualities of the fresh meat product.

2.4. Effect of UV-C light treatment on food quality

Aside from safety and shelf-life, food sensory characteristics is also regarded as an important factor for consumer's perception of the food product. Consumer sensory perception is influenced by biochemical reactions, physicochemical properties, enzymatic reactions, and structural changes that are occurring on the food product (Genç, Esteves, & Diler, 2016; Grumezescu & Holban, 2018; Hui & Aalhus, 2012). The rate of these changes or reactions is heavily influenced by how the product is processed and stored. Most conventional food processing technique involves heat treatment. This means heating the food up to a desired (safe) temperature and letting it cool down slowly before packaging and chilled storage. The heat treatment induces changes in sensory characteristics due to off-flavor and off-odor generation, textural changes, and denaturation of protein and vitamins (Morgan, Radewonuk, & Scullen, 1996; Tewari & Juneja, 2007).

On the other hand, UV-C light as a processing aid has been established to have a minimal impact on sensory qualities. A number of studies have been conducted to investigate the impact of UV-C processing towards psychochemical qualities and sensory qualities of fresh chicken meat. These studies reported that UV-C light processing on fresh chicken meat product had minimal to negligible impact (Chun et al., 2010; Haughton et al., 2011b; McLeod et al., 2018; Park & Ha, 2015).

2.4.1. Effect of UV-C light treatment on sensory characteristics

UV-C light treatment has been reported to have minimal impact on the appearance, texture, flavor, and odor of various different food product such as dairy, bakery, vegetables, and meat (Butot et al., 2018; Gamage, 2015; Gunter-Ward et al., 2018; Heinrich et al., 2016; Semi, 2016). The extent of sensory quality changes depends on the applied dose of UV-C light and the composition of the food product (Heinrich et al., 2016; Koutchma, 2008). The influence UV-C have on sensory quality typically increases as the dose increases (Heinrich et al., 2016; McLeod et al., 2018).

2.4.1.1.Appearance

Color of food is one of the primary attributes for a consumer to judge the quality of a product for its appearance. Color has a very important role in determining the quality of raw meat. Consumer primarily determines the quality and the freshness of fresh meat by its appearance and color. In general, the consumer prefers fresh poultry meat to be pink or slightly pink in color and have no slime presence on the surface of the meat (Octavian & Octavian, 2010). Any defect such as the presence of visible slime or change in color will affect the consumer perception on the quality of the fresh chicken meat.

Color of fresh meat is mainly associated with myoglobin. Myoglobin is the primary pigment in meat. Changes in myoglobin such as denaturation, heme displacement, and ferrous atom oxidation generally lead in changes in the color of the meat (Carvalho, Shimokomaki, & Estévez, 2017; Owens et al., 2010). These changes are induced by processing, packaging,

and storage conditions. Moreover, spoilage bacteria were reported to have an effect on the changes in color on fresh chicken meat. The presence of spoilage bacteria such as *Pseudomonas* spp. increase the rate of oxygen consumption (Barbut, 2002; Owens et al., 2010). The increased oxygen consumption accelerates the transformation of myoglobin to metmyoglobin, resulting in discoloration (Carvalho et al., 2017). Furthermore, some species of *Pseudomonas* spp. such as *Pseudomonas mephitica* has been reported to be capable of producing H_2S. The production of H_2S converts myoglobin to sulfmyoglobin, resulting in green discoloration (Owens et al., 2010).

The effect of UV-C light processing towards the color of fresh poultry meat has been investigated in several studies. These studies agree that UV-C light has minimal impact on the color of fresh poultry meat, regardless of the dose. Isohanni and Lyhs (2009) reported that UV-C illumination did not have a significant effect on the color of fresh chicken meat. Chun et al. (2010) investigated the effect of UV-C exposure on the color of fresh broiler meat during storage. A study by Haughton et al. (2011b) detected some changes in the color of UV treated chicken compared to untreated chicken samples. Similar to the previous study, they also deemed that the changes are not significant enough to affect the overall appearance quality of a fresh chicken product. A more recent study by Park and Ha (2015) reported a similar conclusion that UV-C treatment did not induce any significant changes towards the appearance of fresh chicken meat.

2.4.1.2.Odor

The odor is also an important quality attribute for food products. Consumer judges a food product by smell after judging its appearance. In poultry product, the odor is one of the main parameters for the consumer to judge the quality of the fresh meat. Consumers expect clean and fresh odor from a poultry product. Any slight change in odor is going to give the impression that the product has lost its freshness and close to being spoiled.

Odor changes in a fresh chicken product are contributed by a various different factor, with the main causes being microbial spoilage, oxidative rancidity, and processing induced off-

odors (Kilcast, 2013; Owens et al., 2010). Spoilage microorganism such as *Pseudomonas* spp. and *Acinetobacter* spp. are capable of producing off-odors through the chemical byproduct of their metabolism. The breakdown of sulfur by spoilage bacteria produces volatile compounds that contribute towards the development of off-odors (Barbut, 2002; Mead, 2004; Owens et al., 2010). The utilization of UV-C light processing has been reported to be capable of inactivating or reducing the presence of these spoilage bacteria. A study by Haughton et al. (2011b) has concluded that UV-C light was capable of reducing the presence of spoilage bacteria (total viable count) by 1 log CFU/g on the fresh skinless chicken fillet. A more recent study by McLeod et al. (2018) indicated that UV-C treatment at 3 J/cm^2 on fresh skinless chicken fillet was capable of reducing *Pseudomonas* spp. up to 2.5 log CFU/cm^2. However, the UV-C treatment left a slight "sun-burnt" odor on the fresh chicken fillets.

Processing induced off-odors and oxidative rancidity are closely related to each other. Oxidative rancidity is usually caused by processing. Exposure of fresh poultry product towards mild temperature causes lipid oxidation to accelerate, leading to rancid flavors and aroma. In addition, lipid oxidation also occurs during storage. The rate of the oxidation reaction is generally slower at lower storage temperature. The effect of irradiation, whether through gamma irradiation or UV-C irradiation, have been reported to affect the rate of lipid oxidation. The source of irradiation-induced off-odors development was believed to be sulfur. Irradiation exposure on fresh meat resulted in sulfur development from the derivation of protein. Increased dosage of gamma or UV-C irradiation has been shown to increase the rate of lipid oxidation (Chun et al., 2010; McLeod et al., 2018; Park & Ha, 2015).

2.4.1.3.Flavor

In fresh poultry product, the flavor is also the main attribute for quality. However, the concern for flavor arises after the purchase of the fresh product. The quality attribute for flavor is far more complex than the odor, since there is a huge variation on how consumer process or cook the product for consumption.

Irradiation application for fresh chicken products arises concern as for the flavor profile of the product. Irradiated fresh meat product has been reported to develop off-odors as mentioned above. However, studies showed that after cooking, there are no significant off-flavors detected from products treated with UV-C light. A recent study by McLeod et al. (2018) indicated that after being cooked using a various different method, no residual flavor was detected on the UV-C treated chicken meat.

2.4.2. Effect of UV-C light treatment on food yield and processing cost

Yield and processing cost are very important parameters for the business side of food manufacture. Any lost in yield and increase in cost could be the defining factor between making profit and loss. Therefore, it is crucial that manufacturers conduct a proper calculation before applying any processing technology.

Conventional food processing technology such as heat is very effective in killing microorganism, promoting a high degree of safety. However, the denaturation of protein, destruction of vitamins, and degradation of quality attributes such as color greatly reduce the value of the food product. Furthermore, growing trends in consumer demands call for minimally processed product, free from chemical residue and over-processing (Banerjee & Verma, 2015). Therefore, manufacturers need to start investing in novel alternative technology for the preservation the food product to stay in line with the current and upcoming trend.

In contrast, UV-C processing technology had no effect on the yield of food during manufacture. UV-C processing is essentially exposing food products towards a ray of light, which will not have an effect on the yield of manufacture (Heinrich et al., 2016). In addition, UV-C treatment has minimal effect on sensory characteristics and nutritional value of food while demonstrating potent germicidal capabilities (Cilliers et al., 2014; Heinrich et al., 2016). Furthermore, UV-C systems are cost-efficient and easy to operate. Thus, the UV-C light processing system is a very suitable candidate for food processing aid application.

2.5. UV-C light regulations

The production of food is currently regulated by strict laws to ensure ethical conduct and safety. Before any new or novel food processing technology can be applied and the resulting product can be marketed, they must be thoroughly assessed and evaluated for their safety by regulatory agencies. Potential hazards whether it be microbiological, toxicological, or nutritional concerns must be evaluated. Currently, there are two main food safety agencies that have made a comprehensive law regarding the use of UV-C light technology. The United States Food and Drugs Administration (US FDA) control the use of UV-C light technology based on their CFR 21 part 179, while the European Union through their European Food Safety Authority (EFSA) regulate the application of UV-C light technology in their recent Novel food regulation (EFSA, 2016; USFDA, 2017).

As mentioned before, UV-C technology has been applied for the disinfection of various different food-related object and food product such as surface and potable water, juice products, dairy products, and bakery products. The US FDA uses food additive approach to control and regulate the use of UV-C technology. The FDA considers UV-C light as a source of radiation to treat food and define UV-C as a food additive. The regulation produced by the FDA stated that UV radiation at 253.7 nm is safe to use for reducing human pathogen and other microorganisms in food products such as juices, baking yeasts, and dairy products. Currently, there is no maximum or minimum limit set by the FDA as to the dosage of UV-C exposure towards food products. However, the maximum and minimum dose limit was set to agree with a good manufacturing practice. This includes initial microbial load, the effect of UV towards the sensory and nutritional quality, and cost of UV-C technology operation (USFDA, 2017). Therefore, it is up for the manufacturers to set its dosage limitation in order to achieve their specific decontamination goals.

In 2018, novel food regulation came to effect in the European Union. The regulation stated that a food product should be considered novel food when it is the result of production processed that is not used within the EU before 15 May 1997, and which develop changes in the composition or structure of food that ultimately affect its nutritional quality, metabolism, and undesirable substances (EFSA, 2016). Based on this definition, food product treated with

UV-C light technology was categorized as a novel food. The EFSA approved the application of UV-C treatment for bread in 2014. The approved UV treatment parameter is within the wavelength of 240 to 315 nm for a maximum duration of 5 s with a dosage of 10 to 50 mJ/cm^2. A more recent approved UV-C treatment in the EU is for application in dairy products. In 2016, EFSA permitted the application of UV-C treatment for milk as a post-pasteurisation treatment in order to extend the shelf-life of the product (EFSA, 2016).

The application of UV-C light treatment for direct surface pasteurisation of fresh meat product has not received enough attention yet from the regulatory agencies. Therefore, no regulation or laws are yet to be created to control the usage of UV-C light technology for surface pasteurisation purposes. The UV-C surface pasteurisation process needs to be optimised first before it can be applied for real industrial application.

2.6. Summary

Studies suggested that UV-C light technology has a huge potential for poultry processing application due to its germicidal capabilities paired with minimal impact on sensory characteristics and nutritional value of the meat product. UV-C light processing has the ability to reduce the presence of spoilage bacteria on the surface of fresh chicken product directly after processing, resulting in the extension of shelf-life. Increasing the shelf-life of fresh chicken meat product will lead to better food safety, economic value, as well as the decrease in food waste. However, application of the technology has been generally been slow worldwide despite the advantages of UV-C application in the food industry. Moreover, the efficacy of UV-C light treatment on the shelf-life of fresh chicken meat during storage have not been studied in detail.

Before the UV-C light technology can be applied for industrial poultry processing, the whole process must be optimised to maximise the efficacy and efficiency of the processing technique. As mentioned previously, prolonged UV-C light exposure on food product might have a negative impact on the sensory characteristics. Therefore, a suitable UV-C light dose that posess potent germicidal capability while having minimal impact on physicochemical

and sensory characteristic must be selected. This study aims to optimise the UV-C light treatment process and investigate its effect on the shelf-life of fresh chicken meat during refrigerated storage (4°C).

3. Material and Methods

3.1. Experimental overview

The surface pasteurisation of fresh chicken meat using UV-C light technology was studied in two phases. The objective of phase 1 was to select an optimum UV-C dosage capable of delivering maximum microbial (AMCs) reduction with minimum temperature increase and lowest exposure time. Each type of the fresh chicken samples (skinless breast fillet (SLBF), skin-on breast fillet (SOBF), skinless thigh fillet (SLTF), and skin-on bone-in thigh (SOTF)) was treated with four doses of UV-C light (50, 100, 200, and 300 mJ/cm^2). Aerobic mesophilic count (AMCs), temperature increase, and exposure time were measured on the fresh chicken samples after each UV-C cycle. Baseline data were also collected before the experiments.

Phase 2 investigated the effect of optimised UV-C dosage on the stability of fresh chicken meat samples stored at 4°C. The effect of optimised UV-C dose on the physicochemical and sensorial changes was analysed on untreated and UV-C treated samples. The fresh chicken samples were analysed for color, microbial survival, degree of lipid oxidation, and sensory evaluation over a 7-day storage at refrigeration temperature (4°C).

3.2. Phase 1: UV-C light surface pasteurisation optimisation

The goal of the optimisation was to select an optimum UV-C dosage for surface pasteurisation with the maximum bacterial reduction of AMCs, minimum temperature increase, and the lowest exposure time. A factorial experiment consisting of 2 factors (UV-C light dosages and chicken meat type) with 4 levels was generated to determine the optimum dosage for continuous UV-C light surface pasteurisation process on fresh chicken meat portions (Table 3.1). The UV-C dosages were set at 50, 100, 200 and 300 mJ/cm^2 based on previous studies (Chun et al., 2010; Haughton et al., 2011b; McLeod et al., 2018). The selected types of chicken meat samples used in this study were skinless breast fillet (SLBF), skin-on breast fillet (SOBF), skinless thigh fillet (SLTF), and skin-on thigh (SOT). The effect

of UV-C light treatment was analysed in parallel to the control samples in order to determine microbial reduction, temperature increase, and exposure time.

Table 3.1. Randomized factorial design for the optimisation of UV-C light surface pasteurisation process.

Run Number	Block	UV Dosage (mJ/cm^2)	Meat Type
1	2	50	SLTF
2	2	50	SOBF
3	2	100	SOT
4	2	100	SLTF
5	2	100	SLBF
6	2	200	SLBF
7	2	50	SOT
8	2	200	SOBF
9	2	200	SLTF
10	2	300	SOT
11	2	300	SLBF
12	2	300	SOBF
13	2	300	SLTF
14	2	50	SLBF
15	2	200	SOT
16	2	100	SOBF
17	1	100	SOBF
18	1	50	SLBF
19	1	200	SLBF
20	1	200	SOBF
21	1	300	SLTF
22	1	300	SOBF
23	1	300	SOT
24	1	50	SOBF
25	1	100	SOT
26	1	100	SLTF
27	1	200	SOT
28	1	50	SLTF
29	1	300	SLBF
30	1	50	SOT
31	1	100	SLBF
32	1	200	SLTF

Notes: Design consisted of 2 factors, each with 4 levels. experiment was replicated twice using 2 different batches. Block was introduced to negate the effect caused by the different batches. The design was generated using Minitab 17 (Minitab Inc., USA, 2009). SLBF = Skinless Breast Fillet; SOBF = Skin-On Breast Fillet; SLTF = Skinless Thigh Fillet; SOT = Skin-On Thigh

3.2.1. Chicken samples

Fresh chicken portions (150 – 300 g) were collected from a commercial poultry processing factory. Each type of chicken meat portion was packed in 5-kg cardboard boxes. During sample collection, the 5-kg boxes were placed in a chilly bin containing ice packs to maintain temperature (4 ± 1°C). The samples were transported to Massey University, Auckland within one hour of collection.

3.2.2. UV-C light surface pasteurisation treatment

The UV-C light surface pasteurisation was conducted using the Joulesafe® UV disinfection system (21A0043, Radiant UV, USA) (Figure 3.1). The UV equipment comprised of the main chamber (30 x 50 x 50 in cm) which contained UV emitting lamps and a rack for custom-built removable, transparent trays made out of special plastic polymer material provided by the manufacturer (Figure 3.2A). The trays and reflective walls of the chamber enabled complete exposure of food samples to UV-C light from all directions (360°) (RadiantUV, 2016). In addition, the equipment was also equipped with a built-in air conditioning system that provide stable temperature inside the UV chamber. Low-pressure mercury lamps, located at the top (six) and bottom (six), each emitting 254 nm UV light, were produced constant uniform beam of UV-C light. Built-in touch-screen control panel controlled the UV treatment process and temperature (set to 20°C). The equipment recorded the exposure time of each cycle of the UV-C light treatment process. The chicken samples were held on the custom-made trays and then placed inside the UV chamber followed by the UV-C treatment (Figure 3.2B and Figure 3.3).

Figure 3.1. JouleSafe® UV-C light processing equipment (21A0043, Radiant UV, USA)

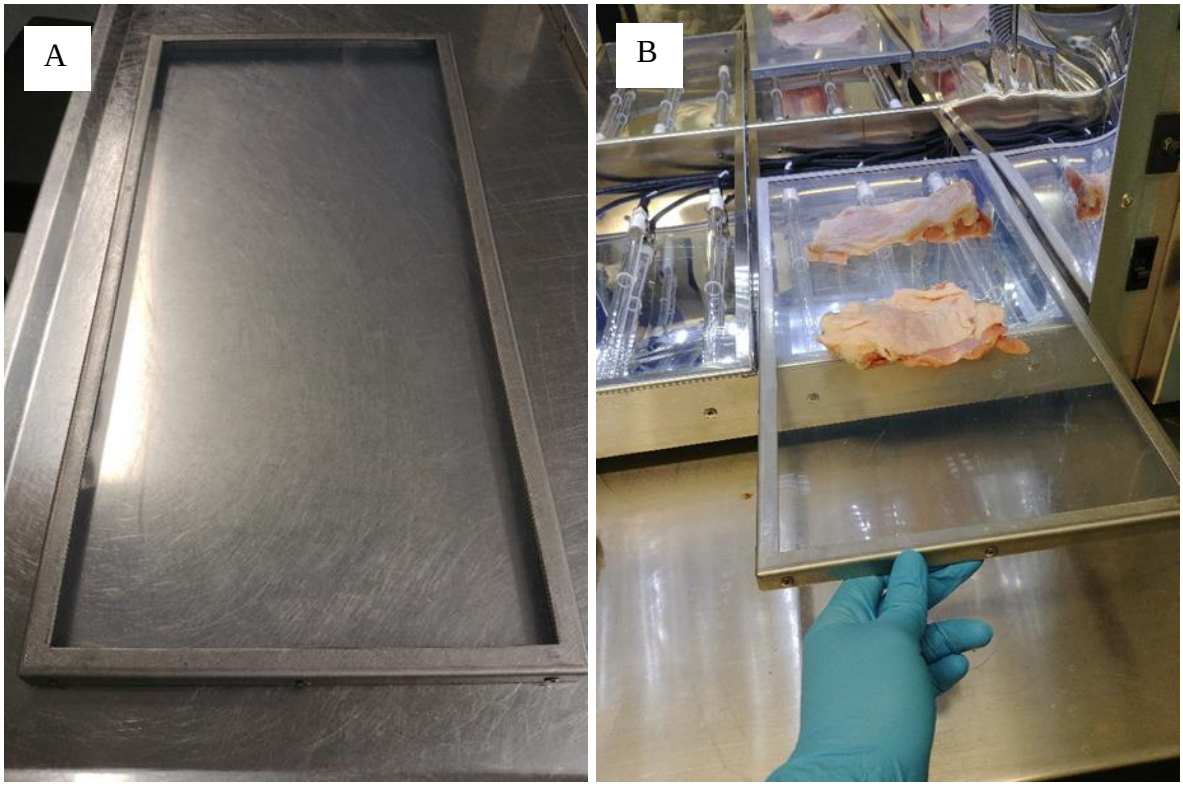

Figure 3.2. Custom-made UV-C Tray (A). UV trays and chicken samples being loaded into the UV-C chamber (B).

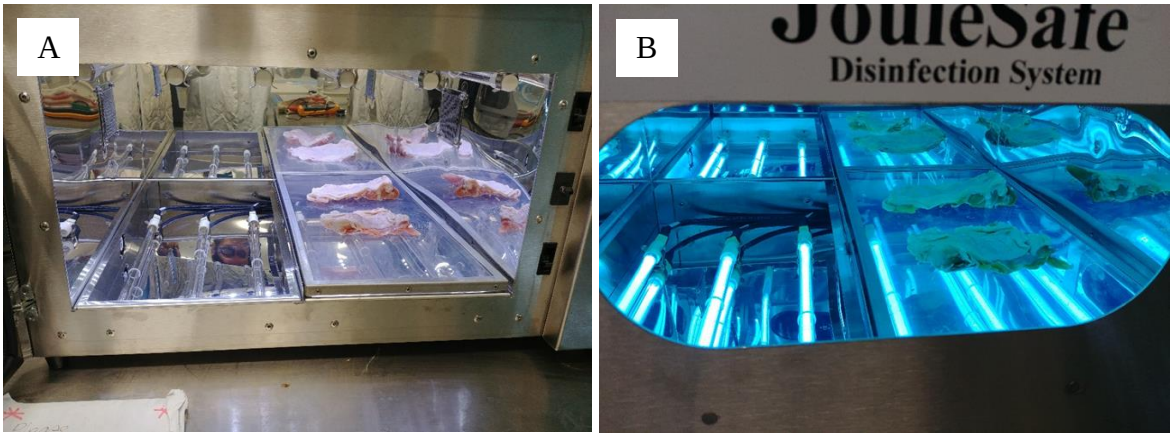

Figure 3.3. UV-C trays loaded inside the equipment (A). Samples being treated with UV-C light (B).

3.2.3. Measurement of temperature and exposure time

Temperature of untreated (control) and UV-treated fresh chicken samples were measured before and after UV-C light treatment with a thermometer (RS PRO RS-41, RS Components Ltd., UK) equipped with a 20-cm probe. Preliminary experiments were conducted to determine the impact UV-C light treatment (100 mJ/cm²) on the temperature change of fresh chicken samples. Preliminary tests showed that temperature increase was appreciable up to 1 – 2-cm depth. Therefore, for the UV-C light generated temperature change inside the chicken was measured at about 1 – 2-cm depth. The exposure time of each UV-C cycle was recorded and the data downloaded to an external computer.

3.2.4. Microbial enumeration

Following UV-C light treatment, microbial enumeration was conducted on the samples. Wet and dry swab sampling procedure of ISO 18593 was adopted to collect swab samples (Castaneda, 2017). The surface of each sample was swabbed with three sterile cotton swabs (Nanjing Luster Medical & Healthcare Products, China) and a 5-cm^2 sterile template (Fort Richard, NZ). Firstly, the first swab was pre-moistened using 0.1% (w/w) maximum recovery diluent (MRD) (Oxoid, NZ). The pre-moistened swab was used to collect swab samples from the surface of the chicken samples for 30 seconds. The tips of the swabs were aseptically broken and placed into 10-mL sterile peptone water. The second and third swabs were used to swab the same surface to ensure maximum recovery of microbial cells from the surface of the sample. The glass bottle containing the swab samples and maximum recovery diluent (MRD) were mixed thoroughly using a vortex mixer (VM-96B JEIO TECH, Korea). One milliliter of the suspension from the glass bottle was withdrawn and added into 9 ml of MRD to produce a 10^{-2} dilution. Series of dilutions of the samples were prepared up to a 10^{-6} dilution.

Plate count agar (Oxoid, NZ) was used for the enumeration of AMCs as described by Haughton et al. (2011b) and Seemeen (2011). The media were prepared following the manufacturer's protocol (Oxoid, 2019). Each dilution was aseptically transferred (0.1 mL) to

the surface of the solidified media (plate count agar) and spread evenly. The inoculated samples were allowed to diffuse into the solidified agar and then the plates were stacked together and transferred into and incubator set at 30°C for 72 hours. Developed colonies were counted after incubation and expressed as $\log_{10}$ CFU/cm^2.

3.3. Phase 2: Effect of UV-C light surface pasteurisation during storage

Following the optimisation of UV-C light treatment, an optimum dosage obtained in phase 1 was selected. In phase 2, the effect of the selected UV-C light dosage on the microbial survival, physicochemical properties, and sensory attributes of fresh chicken meat (skin-on and skinless) during 4°C storage for 7 days was investigated. The experimental framework of phase 2 is shown in Figure 3.4.

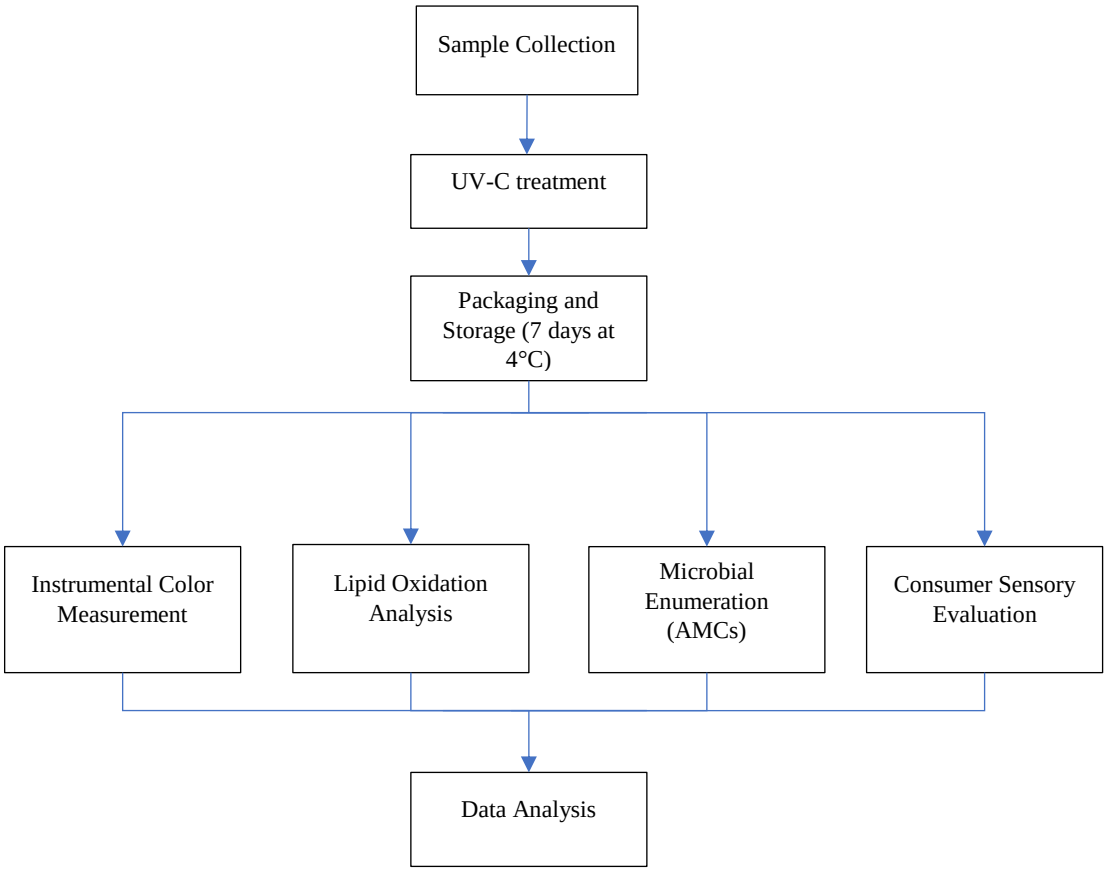

Figure 3.4. Phase 2 experimental framework.

UV-C light treatment was conducted as described in sub-chapter 3.2.2. Following the UV-C treatment, the chicken samples (UV-treated and untreated) were individually packed in food grade recycled polyethylene terephthalate (RPET) tray (22.4 x 17.2 x 4 cm) with a polyethylene sealant layer (Figure 3.5) and stored for 7 days at refrigeration temperature (4°C). The RPET tray used in this experiment have a barrier top web 25 micron with an oxygen transfer rate of 16cc/m²/24hour at 23°C.

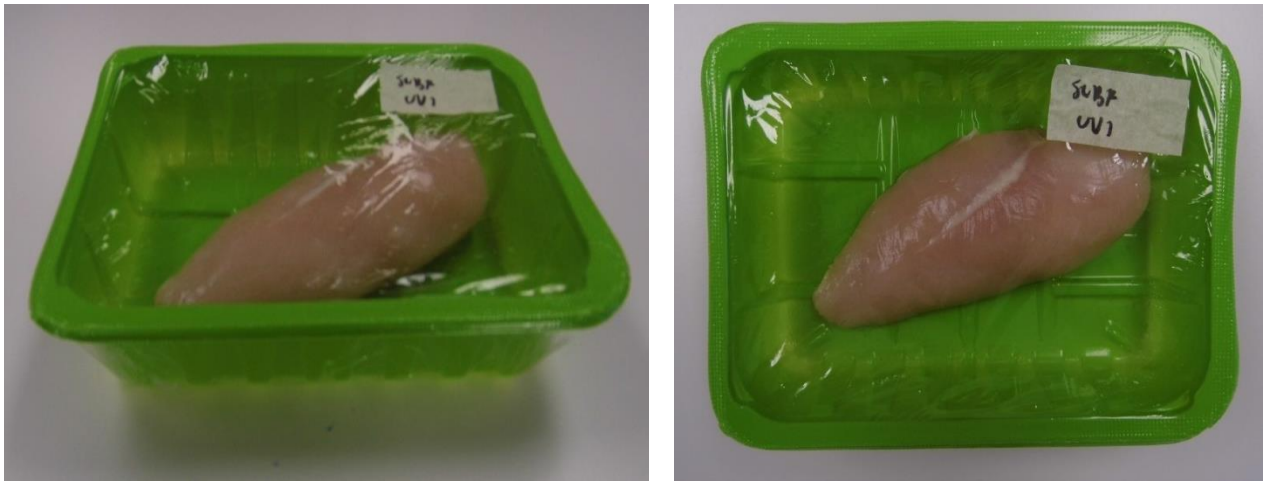

Figure 3.5. Fresh chicken samples packed in recycled polyethylene terephthalate (RPET) tray with a polyethylene sealant layer.

3.3.1. Microbial enumeration

Enumeration of AMCs was conducted on untreated (control) and UV treated chicken samples (skinless and skin-on) during storage at 4°C. An overview of the treatment of each swab sample in phase 2 is shown in Figure 3.6. Collection of swab samples was described in sub-chapter 3.2.4. AMCs of the chicken samples were enumerated on days 0, 3, 5, and 7 during storage using the method described in sub-chapter 3.2.4.

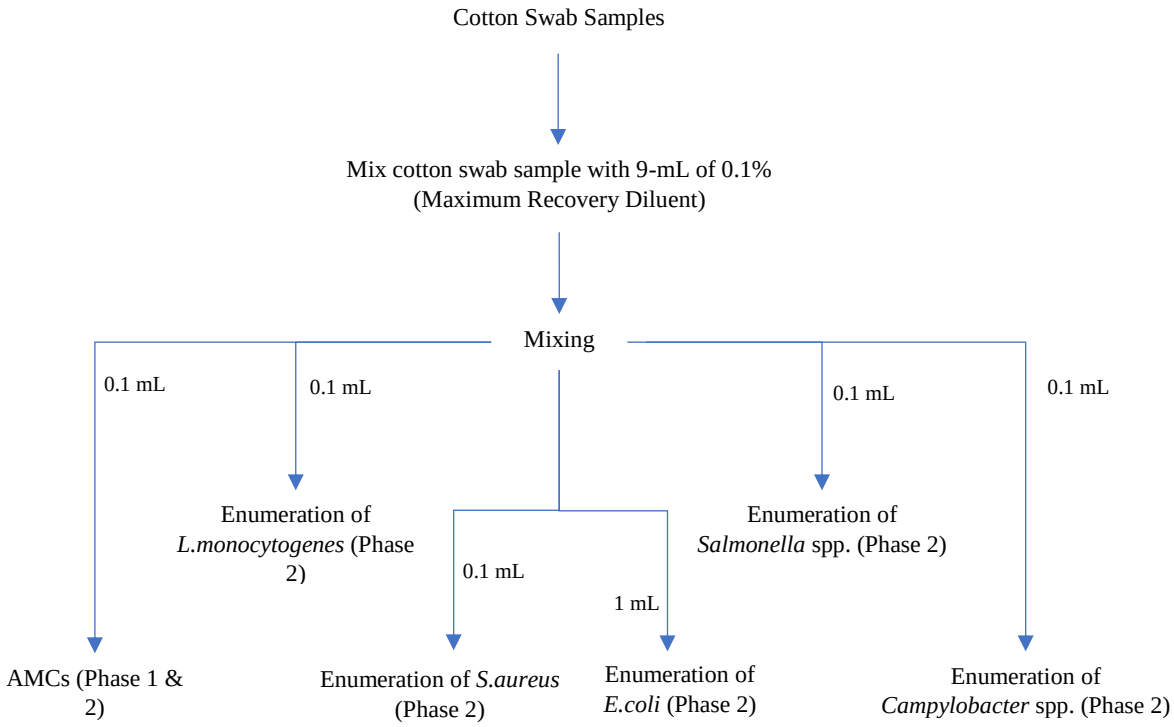

Figure 3.6. Overview of preparation of samples for microbial analysis.

In addition to the enumeration of AMCs; *Listeria monocytogenes.*, *Salmonella* spp., *Campylobacter* spp., *Staphylococcus aureus*, and *Escherichia coli* were also enumerated on the fresh chicken samples on days 0 and 7 during storage. Each species of bacteria was enumerated using its appropriate pre-made medium:

- Xylose Lysine Deoxycholate (XLD) agar (Fort Richard, NZ) was used for the enumeration of *Salmonella* spp. (Chun et al., 2010).
- *Listeria monocytogenes* was enumerated using Oxford Agar (Ford Richards, NZ) (Chun et al., 2010).
- *Campylobacter* spp. was enumerated in modified charcoal-cefoperazone-deoxycholate agar (mCCDA) (Castaneda, 2017).

- Enumeration of *Staphylococcus aureus* was conducted using Baird-Parker Agar (BPA) (ThermoFischer Scientific, USA) infused with egg yolk tellurite (Fort Richard, NZ) (Castaneda, 2017).
- *Escherichia coli* was enumerated using Violet Red Bile Agar (VRBA). VRB agar was prepared following the manufacturer's instruction on the day of experiment and was kept at 48°C (Castaneda, 2017; Chun, Kim, Lee, Yu, & Song, 2010). One ml of each dilution was pour-plated on the VRB agar. The solidified plates were incubated at 35°C for 24 h. Developed colonies were counted after incubation and expressed as $\log_{10}$ CFU/cm².

Plates for the detection of *Salmonella* spp., *Staphylococcus aureus,* and *Listeria monocytogenes* were incubated at 35°C for 24 hours. For *Campylobacter* spp., the mCCDA plates were stacked inside an airtight rectangular plastic container (Castaneda, 2017). Two CampyGen™ (ThermoFischer Scientific, USA) sachets were placed inside the container to create microaerophilic conditions (84% N_2, 10% CO_2, and 6% O_2). The plates were then incubated at 42°C for 48 hours. Developed colonies were counted after incubation and expressed as $\log_{10}$ CFU/cm^2.

3.3.2. Measurement of color

The appearance (color) of fresh poultry product is an important attribute for consumer's perception (Carvalho et al., 2017; Chun et al., 2010; Owens et al., 2010). Therefore, the effect of UV-C treatment on the color of chicken samples was determined. A Minolta CR-300 Colorimeter (Minolta Company, Tokyo, Japan) equipped with illuminant light source (D65) was used to measure the color of the samples (Chun et al., 2010; Seemeen, 2011). The measuring head of the CR-300 uses diffuse illumination/0^0 viewing geometry to measure the color of the samples as seen under diffuse lighting conditions. The colorimeter was calibrated using a standard white calibration plate supplied by the manufacturer with L* value of 94.01, a* value of 0.29, and b* value of 1.77. The Hunter's color values (L*, a*, b*) of the samples were measured in five determinations on days 0, 3, 5, and 7 during storage.

3.3.3. Lipid oxidation analysis

Lipid oxidation is one of the major non-microbial, psychochemical reaction that affects the quality of fresh meat product during storage (Ahn et al., 1998; Ashton, 2002; Carvalho et al., 2017; Chun et al., 2010). The most widely used method to measure the extent of lipid oxidation in meat products including poultry is the 2-thiobarbituric acid (TBA) method (Al-Hijazeen, Lee, Mendonca, & Ahn, 2016; Reitznerová et al., 2017; Ulu, 2004). Malonaldehyde (principal product of lipid oxidation) reacts with 2-thiobarbituric acid to produce pink reddish color (Reitznerová et al., 2017; Ulu, 2004). Therefore, the intensity of color produced from the reaction determines the amount of malonaldehyde present in the food sample, which indicates the extent of lipids oxidation in the food product.

In this study, the degree of lipid oxidation of the untreated and UV-C treated fresh chicken samples was measured using the TBA method described by Chun et al. (2010) and Ahn et al. (1998). Five grams of sample were homogenized using a blender (BFP 100, Breville Inc, Australia) in 15 mL of distilled water. A sample of the meat homogenate (1 mL) and 20mM 2-thiobarbituric acid/15% trichloroacetic acid (TBA/TCA) solution (2 mL) was transferred into a test tube. The mixture was mixed using a vortex mixer (VM-96B JEIO TECH, Korea) for 30 seconds and incubated in boiling water for 15 minutes to develop color (pink-reddish). The mixture was cooled to room temperature (20°C) and then centrifuged (6-16KS, Sigma, Germany) at 2000 *g* for 15 minutes to separate coagulated protein (from the reaction with 15% trichloroacteic acid) and supernatant. The degree of oxidation was assessed by measuring the absorbance of the supernatant using a spectrophotometer (UV-1601, Shimadzu, Japan) at 531 nm. Thiobarbituric acid reactive substances (TBARS) values represented the degree of lipid oxidation and were calculated using a malonaldehyde standard curve (Appendix H). The degree of lipid oxidation (TBARS) was expressed as a ratio of malonaldehyde (mg) to one kilogram of meat sample (MDA/kg). The lipid oxidation measurement was conducted 3 times.

The malonaldehyde standard curve graph was prepared using 1,1,3,3-tetra-ethoxypropane (TEP) as described by Reitznerová et al. (2017) and Degala, Mahapatra, Demirci, and

Kannan (2018). TEP solution with concentrations of 2 µM, 4 µM, 6 µM, 8 µM, and 10 µM including a blank (control) containing distilled water. One mL of each TEP and blank solution was mixed with 20 mM TBA/TCA solution (2 mL) in a test tube using a vortex mixer for 30 seconds. The mixtures were incubated in boiling water for 15 minutes to develop a pink-reddish color. After the color had developed, the mixture was cooled to room temperature and centrifuged (2000 *g* for 15 minutes). The absorbance of the supernatant was measured in two replicates using a spectrophotometer at 531 nm. The standard curve graph was generated using the absorbance readings in Microsoft® Excel (Microsoft®, USA).

3.3.4. Sensory evaluation

The sensory evaluation chicken meat samples were conducted in two parts to evaluate the UV-C effect on the sensory attributes of raw and cooked samples. The former (raw chicken samples) were evaluated during storage for seven days by a focus group comprising five panelists. The panelists evaluated the samples for appearance, texture, and odor. Focus group was conducted on days 1, 5, and 7 of storage. Four samples (untreated skin-on chicken breast, UV treated skin-on chicken breast, untreated skinless chicken breast, and UV treated skinless chicken breast) were presented to the focus group panelists.

Cooked chicken samples were evaluated at days 1 and 7 of storage by sixty consumer sensory participants (n = 60) using the 9-point hedonic scale (McLeod et al., 2018; Seemeen, 2011). To mimic the industrial preaparation of cooked chicken products, the samples were roasted in a convection oven (Bakbar Turbofan 32 Max, Moffat, Australia) until the center temperature of the chicken sample reached 75°C. No seasoning was added to the chicken samples. The internal temperature of the samples during the cooking process was monitored using a temperature probe (16002, Sensing Devices Limited, UK) connected to a probe log. The cooked products were cooled to 30 – 40°C at ambient conditions and sliced into uniform portions (2 x 2 cm) for sensory evaluation. Four different cooked chicken samples (untreated skinless breast, UV-treated skinless breast, untreated skin-on breast, and UV-treated skin-on breast) were coded with random three-digit numbers and then presented to the panelist for evaluation. Sensory panelists were provided with crackers and still bottled water to rinse their

palates during sensory evaluation. The samples were evaluated for appearance, odor, texture, flavor, freshness, and overall liking on a 9-point hedonic scale. The category definition was: 9-like extremely; 8-like very much; 7-like moderately; 6-like slightly; 5-neither like nor dislike; 4-dislike slightly; 3-dislike moderately; 2-dislike very much; 1-dislike extremely (Seemeen, 2011).

3.4. Statistical analysis of data

The data obtained in this study were analysed using Minitab Statistical Software version 17.0 (Minitab Inc., USA, 2009). Data on the optimisation of UV-C light surface pasteurisation dosage were analysed using the General Linear Model. Data on microbial cell counts, TBARS, Hunter L*, a*, b* values, and sensory evaluation obtained during storage were analysed by one-way analysis of variance (ANOVA) and significant means were separated by Tukey's post-hoc test.

4. Results and Discussion

4.1.Phase 1 – Selection of optimum UV-C light surface pasteurisation dosage

The efficacy of UV-C technology for the inactivation of surrogate microorganisms on the surface of fresh chicken meat have been well studied (Chun et al., 2010; Haughton et al., 2011b; McLeod et al., 2018). However, there are limited studies on the efficacy of UV-C technology for the surface pasteurisation of aerobic mesophilic bacterial load on fresh chicken meat samples. Therefore, the effectiveness of UV-C technology for the surface pasteurisation of fresh chicken samples without inoculation was investigated in this study. In phase 1, the goal of UV-C light surface pasteurisation to select a UV-C light dosage capable of maximum reduction of AMCs with minimum temperature increase and exposure time. Therefore, reduction of AMCs, temperature changes, and exposure times were determined in this phase.

Aerobic mesophilic counts (AMCs) were analysed to determine the efficacy of different UV-C light doses (50, 100, 200, 300 mJ/cm²) on the surface of fresh chicken meat samples. The microbial (AMCs) reduction of UV-C light at 50 to 300 mJ/cm^2 ranged from 1.69 - 2.98 log CFU/cm^2 and 0.21 - 0.86 log CFU/cm^2 for skinless (SLBF and SLTF) and skin-on (SOBF and SOTF) chicken samples, respectively (Table 4.1). The results indicated that increasing the UV-C light dosage from 50 to 300 mJ/cm^2 did not increase the reduction of AMCs significantly ($p>0.05$). Furthermore, UV-C light treatment was more effective on reducing the load of microflora on the surface of fresh skinless chicken meat samples compared to skin on samples, which is in agreement with previous studies (Haughton et al., 2011b; Isohanni & Lyhs, 2009). UV-C light treatment on the surface of fresh chicken meat samples using dosages ranging from 50 - 200 mJ/cm² reduced the AMCs by 1.41 - 1.76 log CFU/cm² and 0.05 - 0.14 log CFU/cm² for skinless and skin-on chicken breast fillet respectively (Haughton et al., 2011b). The previous studies also reported that increasing the UV-C light dosage from 50 up to 200 mJ/cm² did not increase the microbial reduction efficacy on both skinless and skin-on chicken meat samples ($p>0.05$) (Haughton et al., 2011b; Isohanni & Lyhs, 2009).

Table 4.1. Means (± standard deviation) of microbial log reductions (log CFU/cm²)* on fresh chicken meat samples treated with 4 different UV-C dosages (mJ/cm²)

Chicken meat type	UV-C dosage (mJ/cm²)	Microbial Reduction (log CFU/cm²)
Skinless Breast Fillet	50	$^{a}1.69 \pm 0.74^{a}$
	100	$^{a}1.90 \pm 0.17^{a}$
	200	$^{a}1.82 \pm 0.38^{a}$
	300	$^{a}2.98 \pm 0.47^{a}$
Skin-on Breast Fillet	50	$^{b}0.57 \pm 0.28^{a}$
	100	$^{b}0.42 \pm 0.23^{a}$
	200	$^{b}0.86 \pm 0.13^{a}$
	300	$^{b}0.28 \pm 0.26^{a}$
Skinless Thigh Fillet	50	$^{a}1.81 \pm 0.17^{a}$
	100	$^{a}2.55 \pm 0.62^{a}$
	200	$^{a}2.64 \pm 0.20^{a}$
	300	$^{a}2.46 \pm 0.09^{a}$
Skin-on Thigh Fillet	50	$^{b}0.21 \pm 0.26^{a}$
	100	$^{b}0.58 \pm 0.04^{a}$
	200	$^{b}0.54 \pm 0.03^{a}$
	300	$^{b}0.48 \pm 0.44^{a}$

Notes: Means* of microbial log reduction (CFU/cm²) followed by standard deviation (±). Within rows, different superscripts in front of mean values indicate significance ($p<0.05$). Within rows of each chicken meat type, mean values followed by different superscripts are significantly different ($p<0.05$); $n = 2$.

DNA damage is established as the mechanism of microbial reduction induced by UV-C light treatment (Gabriel et al., 2018; Gunter-Ward et al., 2018; Heinrich et al., 2016). Absorption of UV-C light by the DNA causes mutation that blocks the ability to replicate, effectively killing the cells. As the method relies on direct exposure of light on the microorganisms residing on the surface, factors such as surface topography, UV-C light dosage and equipment, affect the inactivation efficiency (Chun et al., 2010; Gayán et al., 2013; Heinrich et al., 2016). The surface topography of chicken skin is highly irregular, which shelters the microorganisms from UV-C light (Haughton et al., 2011b; Petracci & Fletcher, 2002).

Compared to the skin-on chicken meat samples, the surface skinless chicken meat samples are smoother, providing more access for UV-C light. Therefore, UV-C light surface pasteurisation is more effective on the surface of skinless chicken meat compared to its skin-on counterparts.

In this study, the results (Table 4.2) indicated that UV-C light dosage and chicken meat type had a significant impact on the increase of temperature and time of exposure ($p<0.05$). Temperature increased by 2.43 - 15.77°C and 2.93 - 12.83°C for skinless and skin-on chicken samples respectively, when treated with UV-C light at 50 - 300 mJ/cm². The exposure duration ranged from 2.16 - 12.58 minutes (skinless) and 2.16 - 13.03 minutes (skin-on) for samples treated with 50 - 300 mJ/cm². The UV-C equipment (Joulsafe®, RadiantUV, USA) used in this study automatically adjusted the exposure time based on the selected UV-C dosage and size of the food sample (RadiantUV, 2016). Thus, the size variation of the type of chicken meat (SLBF, SOBF, SLTF, and SOTF) resulted in significant differences of exposure time and temperature increases ($p<0.05$). However, 50 mJ/cm² demonstrate the least exposure time and temperature increase irrespective of type of chicken meat.

Optimising temperature changes and exposure duration were intended to minimize the impact of UV-C light on the characteristics of the fresh meat product and increase the efficiency of the process. Conventional continuous UV-C light lamp system produces heat during treatment and as the applied UV-C light dosage increases, exposure time also increases along with the dosage (Ahmad et al., 2017; Gamage, 2015; Koutchma, 2008, 2009; Semi, 2016). As mentioned earlier, prolonged UV-C light exposure results in the increase in temperature and might have undesirable effects on the food product (Barbut, 2002; Carvalho et al., 2017; Mead, 2004; Owens et al., 2010; Ulu, 2004). Therefore, it is vital that temperature change and exposure duration are kept at minima to reduce undesirable effect on the food product as well as keeping production cost low in industrial/commercial settings.

Based on our results, the UV-C dose of 50 mJ/cm² was therefore selected as the optimum UV-C dose. The dosage of 50 mJ/cm² showed similar microbial reduction capability with the

other dosages (100, 200, and 300 mJ/cm²) with minimal impact on temperature and exposure time.

Table 4.2. Temperature changes (°C)* and exposure time (minutes)* of fresh chicken meat with 4 different UV-C dosages (mJ/cm²)

Chicken Meat Type	UV-C Dosage (mJ/cm²)	Temperature Increase (°C)	Exposure Time (minutes)
Skinless Breast Fillet	**50**	**2.43 ± 0.05**	**2.16 ± 0.00**
	100	6.32 ± 0.40	4.50 ± 0.05
	200	10.55 ± 0.40	8.44 ± 0.40
	300	13.60 ± 1.74	12.58 ± 0.04
Skin-on Breast Fillet	**50**	**3.70 ± 0.66**	**2.28 ± 0.16**
	100	5.55 ± 0.97	4.53 ± 0.30
	200	9.53 ± 0.71	8.51 ± 0.82
	300	12.10 ± 1.84	13.03 ± 0.70
Skinless Thigh Fillet	**50**	**3.83 ± 0.94**	**2.18 ± 0.06**
	100	7.52 ± 0.54	4.31 ± 0.04
	200	11.87 ± 0.80	7.81 ± 0.20
	300	15.77 ± 2.36	11.46 ± 0.59
Skin-on Thigh Fillet	**50**	**2.93 ± 0.57**	**2.16 ± 0.04**
	100	5.98 ± 0.87	4.28 ± 0.39
	200	9.73 ± 1.18	7.88 ± 0.02
	300	12.83 ± 1.93	11.30 ± 0.92

Notes: Means* of temperature increase (°C) and exposure time (minutes) followed by standard deviation (±); UV-C light dosage of 50 mJ/cm² was selected as the optimum dosage for demonstrating the lowest exposure time and temperature increase; n = 2.

4.2. Phase 2 – Shelf-life analysis

Previous studies have focused on the efficacy of UV-C light (50 mJ/cm²) for reducing inoculated microorganisms on the surface of fresh poultry meat (Chun et al., 2010; Haughton et al., 2011b; McLeod et al., 2018; Park & Ha, 2015). However, the effect of UV-C treatment

on the microbial and overall quality of fresh poultry meat during refrigerated storage have not been studied in detail. The second phase of this study investigated the effect of selected UV-C light dosage (50 mJ/cm²) on the microbial survival, physicochemical characteristics, and sensory attributes of fresh chicken meat during refrigerated storage (4°C). Microbial enumeration, measurement of color, lipid oxidation analysis, and sensory evaluation were conducted on untreated (control) and UV-C treated (50 mJ/cm²) fresh chicken sample (skinless and skin-on) during refrigerated storage at 4°C for seven days.

4.2.1. Microbial enumeration

The data on the effect of selected (optimum) UV-C light dosage (50 mJ/cm²) on the growth of AMCs during refrigerated storage (4°C) are shown in Table 4.3. The initial AMCs present on the surface of the fresh chicken meat sample were 3.31 ± 0.11 and 3.80 ± 0.35 log CFU/cm² for skin-on and skinless chicken meat samples, respectively. The initial AMCs were reduced to 3.07 ± 0.22 and 1.87 ± 0.98 log CFU/cm², thus, giving microbial log reductions of 0.24 and 1.93, respectively. The results also suggested that the microbial log reductions on fresh skin-on samples were not significant ($p>0.05$), whereas significant microbial log reductions were observed on the skinless samples when the two types of meat were treated with UV-C light at 50 mJ/cm² ($p<0.05$).

Microbial enumeration was also conducted on untreated and UV-C treated fresh chicken samples (skinless and skin-on) on days 3, 5, and 7 during refrigerated storage (4°C). The results are shown in Figure 4.1. UV-C treatment (50 mJ/cm²) appeared to delay the growth of aerobic mesophilic cells on the surface of both skin-on and skinless fresh chicken samples. The difference in the microbial counts were significant ($p<0.05$) throughout the storage period between untreated and UV-C treated skinless chicken meat samples. However, there was no significant difference ($p>0.05$) on the microbial count of skin-on chicken meat samples treated with UV-C (50 mJ/cm²) during refrigerated storage period.

FSANZ (1995) guidelines recommend that the AMCs on fresh chicken meat product should be $<10^6$ CFU/cm² at the end of the shelf-life. The results suggested that the AMCs on skin-on fresh chicken samples exceeded the recommended limit on day 5 (untreated) and day 6

(UV-C treated) of storage, while the AMCs on skinless fresh chicken samples exceeded the recommended limit on day 5 (untreated) and day 7 (UV-C treated) of storage. These results indicated that UV-C light surface pasteurisation was more effective on delaying the growth of microorganisms on the surface of skinless fresh chicken meat compared to its skin-on counterparts. The latter outcome was not unexpected due to the irregularity of the surface topography of skin-on chicken meat. In addition, the low efficacy microbial reduction of UV-C light treatment on the surface of skin-on chicken meat was reported by previous studies (Haughton et al., 2011b; Isohanni & Lyhs, 2009).

Table 4.3. Mean values (± standard deviation) of AMCs* (log CFU/cm²) of untreated and UV-C treated (50 mJ/cm²) fresh chicken meat samples during storage at 4°C.

Chicken Meat Type	Storage Period (day)	Control	UV-C Treated
Skin-On Breast Fillet	0	$^{a}3.31 \pm 0.11^{a}$	$^{a}3.07 \pm 0.22^{a}$
	3	$^{a}4.75 \pm 0.27^{a}$	$^{ab}4.31 \pm 0.32^{a}$
	5	$^{b}6.74 \pm 0.34^{a}$	$^{b}5.14 \pm 1.31^{b}$
	7	$^{c}8.57 \pm 0.34^{a}$	$^{c}7.48 \pm 0.07^{a}$
Skinless Breast Fillet	0	$^{a}3.80 \pm 0.35^{b}$	$^{a}1.87 \pm 0.98^{a}$
	3	$^{a}5.01 \pm 0.32^{b}$	$^{b}3.34 \pm 0.86^{a}$
	5	$^{b}6.54 \pm 0.11^{b}$	$^{b}4.37 \pm 0.20^{a}$
	7	$^{c}8.62 \pm 0.35^{b}$	$^{c}6.69 \pm 0.24^{a}$

Notes: Means* of AMCs followed by standard deviation (±). Within columns of each chicken meat type, different superscripts in front of mean values indicate significance ($p<0.05$). Within rows of each chicken meat type, mean values followed by different superscripts letters are significantly different ($p<0.05$). $n = 3$.

As mentioned previously, there are limited published data on the effect of UV-C treatment on the microbiological quality of fresh chicken meat during refrigerated storage. Chun et al. (2010) investigated the effect of UV-C treatment on the microbiological and overall quality of skinless chicken breast fillet inoculated with pathogens. The study showed that UV-C light (50 mJ/cm²) successfully suppressed the growth of inoculated *Campylobacter jejuni*, *Listeria*

monocytogenes, and *Salmonella Typhimurium* on skinless chicken breast fillet during 6 days of storage at 4°C. These data agree with the results obtained in the current study.

Presence *Campylobacter* spp., *Salmonella* spp., *E.coli, S.aureus,* and *Listeria monocytogenes* in the beginning (day 0) and at the end (day 7) of storage were not detected in both untreated and UV-treated fresh chicken portion (skinless and skin-on) samples. These results suggested that the acidified sodium chlorite immersion chilling step (4°C) applied by the commercial poultry processing factory was effective in the inactivation of the pathogenic bacteria (Demirok et al., 2013; James, Vincent, de Andrade Lima, & James, 2006; Zhang, Jeong, Janardhanan, Ryser, & Kang, 2011). The chilling step combines low pH (2.3 – 3.2) and the presence of chlorine to oxidise the cell wall of microorganisms, ultimately leading to cell death (Demirok et al., 2013; James et al., 2006).

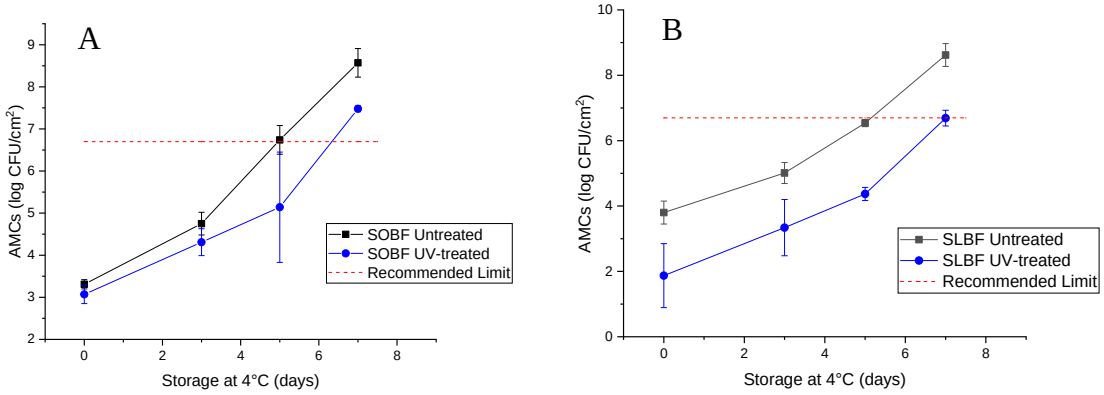

Figure 4.1. Aerobic mesophilic counts (AMCs) of untreated and UV-C treated (50 mJ/cm²) fresh chicken meat samples.
Notes: SOBF = Skin-on Breast Fillet (A); SLBF = Skinless Breast Fillet (B); Broken horizontal line = FSANZ (1995) microbiological criteria for foods recommended AMCs (6 log CFU/cm²) on fresh chicken meat product at the end of shelf-life. Error bars represent the standard deviation of the mean values; n = 3.

4.2.2. Instrumental color

Color is an important attribute for the appearance of fresh meat product. The color of fresh meat product is highly unstable due to the sensitivity of myoglobin (main pigment in fresh

meat) against temperature, oxygen, and the activity of microorganisms (Cunningham, 2012; Mead, 2004; Petracci & Fletcher, 2002). It is therefore important for any poultry processing technology to have minimal impact on the color of fresh poultry product (Carvalho et al., 2017; Owens et al., 2010; Seemeen, 2011).

The color of the fresh chicken meat samples was measured using the colorimeter to investigate the effect of UV-C light treatment on the color of fresh chicken samples. Hunter L* values represent the lightness of the surface of the sample. The lightness of untreated and UV-C treated chicken samples are shown in Figure 4.2. The lightness (L* value) for both skin-on and skinless chicken samples decreased steadily during the storage period irrespective of the UV-C treatment. The decrease in the lightness could be attributed to the activity of spoilage microorganisms, oxidation of pigment in meat, and the storage conditions. Spoilage microorganisms are capable of protein and lipid breakdown, thereby decreasing the lightness of the fresh chicken meat product (Carvalho et al., 2017; Chun et al., 2010; Petracci & Fletcher, 2002). The oxidation of meat pigment (myoglobin) changes the color of the meat (Barbut, 2002). The rate of oxidation is dependent on the oxygen levels and storage temperature (Arvanitoyannis & Stratakos, 2012; Carvalho et al., 2017).

Significant differences were observed on the third, fifth, and seventh day of storage between the lightness (L* values) of UV-C treated and untreated skin-on chicken breast ($p<0.05$). However, there were no differences between the lightness of untreated and UV treated skinless chicken breast throughout the storage period ($p>0.05$). The results suggested that UV-C light treatment had more significant impact on the lightness (L* values) of skin-on fresh chicken sample compared to its skinless counterparts. A study by Chun et al. (2010) on the effect of UV-C light treatment on skinless chicken breast fillet during storage reported that L* values of UV-C treated chicken remained stable during storage at 4°C. In addition, the study also reported that UV-C light treatment had no significant effect on the lightness of skinless chicken breast fillet. Other studies also reported that after initial UV-C exposure on skinless chicken meat, there were no significant changes in the lightness between UV-C treated and untreated samples (McLeod et al., 2018; Park & Ha, 2015). However, there are limited data on the effect of UV-C treatment on the lightness of skin-on chicken meat during

refrigerated storage. Haughton et al. (2011b) reported that UV-C treatment had no effect in the initial lightness value of skin-on chicken breast fillet, which is in agreement with the results obtained in this study.

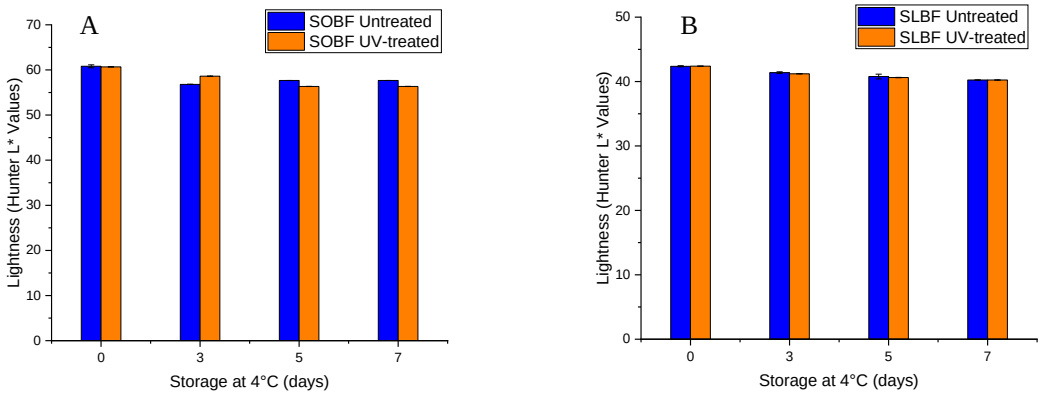

Figure 4.2. Hunter's L* values of untreated and UV-C treated fresh chicken meat samples during storage.
Notes: L* = degree of lightness (0 – 100 = black – white); SOBF = Skin-on Breast Fillet (A); SLBF = Skinless Breast Fillet (B); Error bars represent the standard deviation of the mean values; n = 5.

Hunter a* values represented the redness/greenness of the surface of fresh chicken meat. Similar to the lightness, the redness/greenness of both skin-on and skinless chicken breast decreased during storage irrespective of UV-C treatment. As mentioned previously, the decrease could be attributed to the activity of spoilage microorganisms, meat pigment oxidation, and storage conditions (Carvalho et al., 2017; Petracci & Fletcher, 2002). The results for the redness/greenness (a* values) for untreated and UV-C treated chicken samples are shown in Figure 4.3. The negative values indicated that the color of both UV-C treated and untreated skin-on chicken breast leaned towards green rather than red. Significant differences was detected between the greenness (a* value) of untreated and UV-C treated skin-on breast during storage at 4°C ($p<0.05$). In contrast, no differences were observed between the redness (a* values) of untreated and UV-C treated skinless chicken breast throughout storage period ($p>0.05$). The result suggested that UV-C treatment had a significant impact on the redness of skin-on fresh chicken sample ($p<0.05$), while the a* values of skinless fresh chicken samples was not affected by UV-C treatment ($p>0.05$). These

results are in agreement with studies conducted by Park and Ha (2015) and Haughton et al. (2011b), who reported no significant differences in the initial a* values between UV-C treated (50 mJ/cm²) and untreated skinless chicken breast.

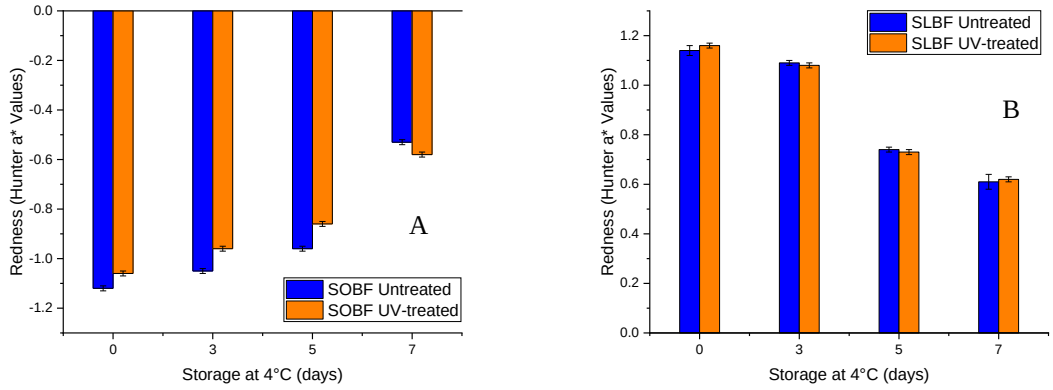

Figure 4.3. Hunter's a* values of untreated and UV-C treated fresh chicken meat samples during storage.
Notes: a* = degree of redness ((-80) – (+100) = green – red); SOBF = Skin-on Breast Fillet (A); SLBF = Skinless Breast Fillet (B); Error bars represent the standard deviation of the mean values; n = 5.

Yellowness was represented by hunter b* values. The yellowness (b* values) of untreated and UV-C treated chicken samples are shown in Figure 4.4. The yellowness (b* values) of both skin-on and skinless breast decreased during storage. Throughout storage (4°C), the difference of the yellowness between UV-C treated and untreated skin-on chicken breast was significant ($p<0.05$). Whereas, the differences between the b* values of untreated and UV treated skinless breast was not significant ($p>0.05$) during storage except for day 0. It therefore seems that the yellowness (b* value) of fresh skin-on chicken meat is more sensitive towards UV-C light treatment compared to their skinless counterparts.

As discussed previously, the activity of microorganisms and the rate of oxidation may lead to discoloration, resulting in the decrease of the yellowness of both skin-on and skinless chicken breast sample (Barbut, 2002; Mead, 2004). Petracci and Fletcher (2002) reported that the yellowness decreased steadily for both untreated skinless and skin-on breast fillet during storage. However, there are limited published data on the effect of UV-C light

treatment on the yellowness of skin-on fresh chicken meat during refrigerated storage. Haughton et al. (2011b) and Park and Ha (2015) reported that UV-C treatment had no considerable impact on the initial yellowness (b* values) skinless chicken breast fillet. Chun et al. (2010) reported that UV-C treatment had no substantial impact on the skinless chicken breast samples during storage at 4°C for 6 days. These results are in agreement with the results obtained in this study.

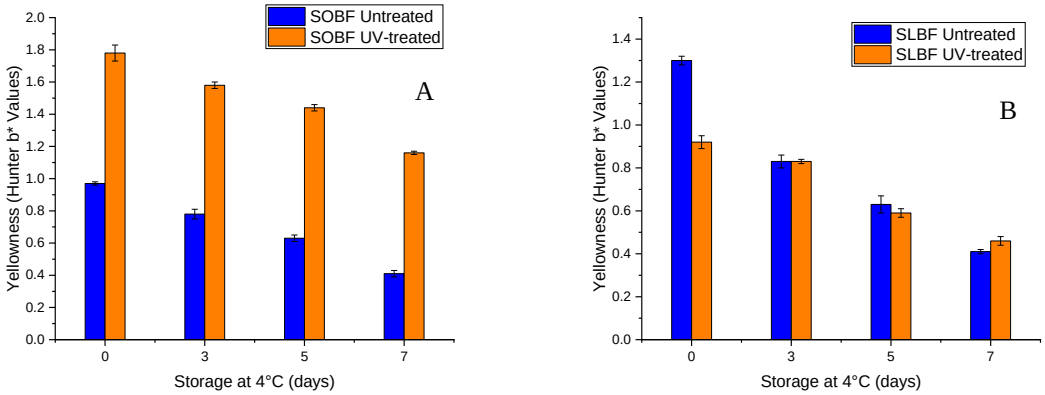

Figure 4.4. Hunter's b* values of untreated and UV-C treated fresh chicken meat samples during storage.
Notes: b* = degree of yellowness ((-80) – (+70) = blue – yellow); SOBF = Skin-on Breast Fillet (A); SLBF = Skinless Breast Fillet (B); Error bars represent the standard deviation of the mean values; n = 5.

4.2.3. Lipid oxidation

Lipid oxidation is one of the most important non-microbial quality attributes in fresh meat product (Carvalho et al., 2017; Reitznerová et al., 2017; Secci & Parisi, 2016). Excessive oxidation of lipid leads to quality defects such as development of off-flavors and aroma (Carvalho et al., 2017; Gao, Zhuang, Yeh, Bowker, & Zhang, 2019). Therefore, the degree of lipid oxidation of untreated and UV-C treated fresh chicken samples during refrigerated storage (4°C) was analysed. Data on thiobarbituric acid reactive substances (TBARS) represent the degree of lipid oxidation of the samples (Lu et al., 2019; Park & Ha, 2015). The TBARS results (Table 4.4) suggested that UV-C light treatment had no significant effect on the lipid oxidation rate of both skinless and skin-on fresh chicken samples during refrigerated

storage at 4°C ($p>0.05$). The rate of lipid oxidation is mainly affected by temperature, thus minimal exposure time and temperature increase ensure UV-C treatment at 50 mJ/cm² had minimal effect on the lipid oxidation of both skinless and skin-on chicken meat (Gao et al., 2019; Reitznerová et al., 2017).

Chun et al. (2010) reported that UV-C treatment had no significant effect on the lipid oxidation of skinless chicken breast samples stored at 4°C for 6 days. Park and Ha (2015) also reported that UV-C treatment had no considerable impact on the lipid oxidation of fresh skinless chicken breast fillet samples. Furthermore, Degala et al. (2018) reported that UV-C treatment at 100 mJ/cm² had no effect on the TBARS of goat meat samples. The results obtained in the current study was clearly in agreement with previous studies, indicating that UV-C light treatment at 50 mJ/cm² had minimum effect on the degree of lipid oxidation of skinless chicken meat. However, there are limited published data on the effect of UV-C treatment on skin-on chicken meat samples.

Table 4.4. TBARS (MDA/kg) values* of chicken breast fillet samples during storage at 4°C.

Chicken Meat Type	Storage (day)	Untreated (Control)	UV-C Light Treated (50 mJ/cm²)
Skin-on breast fillet	0	$^{a}1.72 \pm 0.56^{a}$	$^{a}3.09 \pm 0.70^{a}$
	3	$^{a}1.24 \pm 0.36^{a}$	$^{a}2.14 \pm 1.38^{a}$
	5	$^{a}1.40 \pm 0.08^{a}$	$^{a}2.22 \pm 0.27^{a}$
	7	$^{a}3.23 \pm 1.39^{a}$	$^{a}2.46 \pm 0.83^{a}$
Skinless breast fillet	0	$^{a}2.11 \pm 0.75^{a}$	$^{a}1.34 \pm 0.89^{a}$
	3	$^{b}0.58 \pm 0.14^{a}$	$^{a}0.22 \pm 0.21^{a}$
	5	$^{ab}1.03 \pm 0.06^{a}$	$^{a}1.61 \pm 0.64^{a}$
	7	$^{a}2.14 \pm 0.35^{a}$	$^{a}1.43 \pm 0.65^{a}$

Notes: Means* of TBARS followed by standard deviation (±). Within columns of each sample type, different superscripts in front of mean values indicate significance ($p<0.05$). Within rows of each sample type, mean values followed by different superscript are significantly different ($p<0.05$); MDA = Malonaldehyde; n = 3.

4.2.4. Focus group

A focus group comprised of five panelists evaluated UV-C treated (50 mJ/cm²) raw chicken meat samples (skin-on and skinless) at 3 different data point (days 0, 5, 7) during storage at 4°C for its sensory characteristics (appearance, odor, and texture). The appearance of the samples was evaluated visually by the panelists. There were no differences in the appearance between untreated and UV-C treated chicken samples (skin-on and skinless) until day 5 of storage, when discolorations on the surface of untreated chicken samples were observed. Meanwhile, the discoloration on UV-C treated chicken samples was barely noticeable. By day 7, major greenish/grayish discolorations were spotted by the panelists on the surface of untreated chicken samples during storage, while minor greenish discolorations were observed on the surface UV-treated chicken samples.

The odor of the samples was evaluated by direct smelling by the panelists. The odor of both UV-C treated and untreated chicken samples (skinless and skin-on) was fresh and chickeny on the initial (day 0) storage day. A slight "burnt" odor was detected on the UV-C treated fresh chicken samples (skin-on and skinless). On the fifth day of storage, the odor of untreated chicken samples was described as ammoniacal and sulphorous with a tint of chicken smell (Octavian & Octavian, 2010). The "burnt" odor was no longer detectable on day 5 of storage on UV-C treated chicken samples. At the end of storage, off-odor (rancid and rotten) had developed from the untreated chicken samples (skin-on and skinless) and was stronger compared to its UV-C treated counterparts.

The texture of both skin-on and skinless chicken breast samples were determined through its muscular elasticity. Both UV-C treated and untreated fresh chicken samples (skin-on and skinless) showed loss of muscle elasticity at the same time (day 5) during storage. The evaluations indicated that UV-C treatment at 50 mJ/cm² did not have an impact on the texture on fresh chicken samples (skinless and skin-on).

The sensory characteristics (appearance, texture, and odor) of fresh chicken meat deteriorated during storage. The rate of deterioration is mainly attributed to the storage temperature, presence of oxygen, and spoilage microorganisms (Barbut, 2002; Mead, 2004; Owens et al.,

2010). Storage temperature influences the activity of spoilage microorganisms and the rate of physicochemical and enzymatic reactions on the fresh meat products. The biochemical activity (proteolysis and lipolysis) of spoilage microorganisms such as *Pseudomonas* spp. and *Acinetobacter* spp. (both capable of surviving at refrigeration temperature), produces metabolites that develops slime and off-odor (ammoniacal or sulphorous), discoloration (greenish), and loss of muscle elasticity (Cunningham, 2012). Proteolysis and lipolysis also occur enzymatically, in which the rate of the reactions are mainly affected by the storage temperature, contributing to further loss in muscle elasticity (Barbut, 2002; Pearson & Dutson, 1994). The presence of oxygen affects myoglobin, the primary pigment in fresh meat. The activity of spoilage microorganisms increase the rate of oxygen consumption which accelerates the transformation of myoglobin to metmyoglobin, resulting in the discoloration (Carvalho et al., 2017). Some species of *Pseudomonas* spp. such as *Pseudomonas mephitica* are capable of producing H_2S (hydrogen sulfide) which converts myoglobin to sulfmyoglobin, resulting in the green discoloration (Owens et al., 2010).

The results of focus group correlated with the microbial enumeration (AMCs) during storage, which indicated the suppression of microbial growth on the surface UV-C treated fresh chicken samples. Spoilage microorganisms begin to show considerable signs of sensory defects (discoloration, slime development, off-odor generation) when their presence (AMCs) reached $\geq 10^5$ CFU/cm² (Barbut, 2002; Cunningham, 2012; Mead, 2004). Untreated fresh chicken samples showed signs of deterioration (discoloration and off-odor development) at day 5 of storage, when their AMCs were 6.74 ± 0.34 (skin-on) and 6.54 ± 0.11 (skinless) CFU/cm². Meanwhile, UV-C treated fresh chicken samples did not show any signs of considerable deterioration on day 5, when their AMCs were 5.14 ± 1.31 and 4.37 ± 0.20 CFU/cm² for skin-on and skinless respectively. Thus, it may be assumed that UV-C light treatment successfully delayed and suppressed the activity of spoilage microorganism (McLeod et al., 2018; Park & Ha, 2015). In addition, UV-C treatment may be presumed to have no considerable effect on the natural enzymatic proteolysis and lipolysis, thus having no substantial effect on the texture of the fresh chicken meat samples. Overall, the results of the focus group suggested that UV-C treatment had minimal impact on the sensory

characteristics (appearance, odor, texture) of the fresh chicken samples (skinless and skin-on) during refrigerated storage (4°C) for 7 days.

4.2.5. Consumer sensory evaluation

Consumer sensory evaluation was conducted on days 1 and 7 of storage. Sixty (60) panelists evaluated cooked UV-C treated and untreated skinless and skin-on chicken breast. The samples were evaluated for appearance, odor, flavor, texture, juiciness, and overall acceptance using a 9-point hedonic scale. The samples were cooked (roasted) to mimic preparation of the products before consumption.

Mean values for each sensory attribute of skin-on and skinless chicken breast are shown in Table 4.4. The results suggested that appearance, odor, flavor, texture, juiciness and overall acceptance were not affected by UV-C treatment ($p>0.05$). However, the odor of UV-C treated skin-on breast fillet decreased from 6.83 ± 0.95 at day 1 to 5.70 ± 1.51 at day 7 of storage ($p<0.05$). Meanwhile, the result suggest that the sensory attributes of skinless breast fillet samples were not affected by UV-C treatment and storage time ($p>0.05$).

Park and Ha (2015) applied UV-C treatment at 60 mJ/cm² on skinless chicken breast and reported no effect on color, flavor, texture, appearance, and overall acceptability scores. McLeod et al. (2018) investigated the effect of UV-C treatment on the sensory acceptance of both raw and cooked skinless chicken breast samples and reported that UV-C treatment (50 mJ/cm²) did not have any effect on the sensory acceptance of cooked skinless chicken breast. The results of the previous studies are in agreement with the results obtained in the current study.

Table 4.5. Comparison of the mean consumer sensory scores* chicken breast fillet during storage at 4°C.

Sample Type	Storage Time (day)	Treatment	Appearance	Odor	Flavor	Texture	Juiciness	Overall
Skin-on Breast Fillet	1	Control	5.63 ± 1.38^{a}	6.27 ± 1.31^{ab}	6.07 ± 0.91^{a}	5.03 ± 1.10^{ab}	5.03 ± 0.76^{ab}	5.00 ± 1.08^{a}
		UV	6.20 ± 0.71^{a}	6.83 ± 0.95^{a}	6.43 ± 1.19^{a}	5.70 ± 1.26^{a}	5.73 ± 1.20^{a}	5.47 ± 1.14^{a}
	7	Control	5.47 ± 1.61^{a}	5.73 ± 1.39^{b}	5.53 ± 1.41^{a}	4.53 ± 1.76^{b}	4.33 ± 1.81^{b}	4.97 ± 1.43^{a}
		UV	5.53 ± 1.43^{a}	5.70 ± 1.51^{b}	5.53 ± 1.74^{a}	4.77 ± 1.96^{ab}	4.80 ± 1.97^{ab}	5.33 ± 1.45^{a}
Skinless Breast Fillet	1	Control	6.23 ± 1.70^{a}	6.30 ± 1.58^{a}	6.13 ± 1.36^{a}	5.73 ± 1.55^{a}	5.83 ± 1.60^{a}	6.10 ± 1.56^{a}
		UV	6.13 ± 1.70^{a}	6.37 ± 1.13^{a}	6.10 ± 1.42^{a}	6.00 ± 1.46^{a}	6.10 ± 1.65^{a}	6.07 ± 1.44^{a}
	7	Control	6.07 ± 1.39^{a}	6.20 ± 1.61^{a}	5.97 ± 1.22^{a}	5.67 ± 1.37^{a}	5.13 ± 1.85^{a}	5.77 ± 1.28^{a}
		UV	6.07 ± 1.34^{a}	6.20 ± 1.16^{a}	6.00 ± 1.86^{a}	5.63 ± 2.04^{a}	5.13 ± 1.89^{a}	5.70 ± 1.62^{a}

Notes: Means* of sensory attribute scores followed by standard deviation (±). Within columns of each sample type, mean values followed by different superscripts are significantly different ($p<0.05$); n = 60.

5. Conclusions

UV-C light dosage of 50 mJ/cm² showed maximal AMCs log reduction with minimal increase in temperature and exposure time, therefore it was selected as the optimum dosage for the surface pasteurisation of fresh chicken samples. The selected (optimised) UV-C dosage (50 mJ/cm²) was more effective in reducing and delaying the growth aerobic mesophilic microbial load on the surface of fresh skinless chicken meat samples compared to treatment of fresh skin-on chicken meat samples during refrigerated storage (4°C).

UV-C light treatment at 50 mJ/cm² had no significant impact on the lipid oxidation of fresh chicken meat samples (skinless and skin-on) during storage ($p<0.05$). Results indicated that the color of fresh skinless chicken meat samples during storage was not affected by UV-C light treatment. However, the color of fresh skin-on chicken meat was significantly affected by UV-C light treatment ($p<0.05$).

Focus group sensory evaluation showed that UV-C treatment at 50 mJ/cm² delayed the deterioration of sensory characteristics (appearance, odor, and texture) on fresh chicken meat samples (skinless and skin-on) by 1-2 days during storage at 4°C. Consumer sensory evaluation showed that UV-C treatment had no impact on the overall acceptability and sensory attributes of cooked chicken meat samples. In conclusion, the results of this study suggest that UV-C light technology may be applied for the surface pasteurisation of fresh skinless chicken meat portions.

6. Recommendations for future work

Based on the results obtained in this study, a few recommendations can be made for further research:

1. The combination of UV-C light with other processing technologies such as automated packaging system can be explored to increase the efficacy of the surface pasteurisation process.

2. In this study, the UV-C treatments was conducted at ambient temperatures (20 ± 1°C). Research may be conducted on temperature-assisted UV-C light treatments to further enhance the effectiveness of UV-C light surface pasteurisation process (reference).

3. One-day old chicken samples were used in this study. Further studies can be conducted to determine the effect of UV-C light treatment on fresh chicken samples obtained directly ((approximately 3 hours after slaughter) at the end of production line.

4. Very little information is published on the effect of UV-C light treatment on 'skin-on chicken meat. Further in-depth studies are required to increase the efficacy of UV-C light treatment on these chicken samples.

5. Members of the bacterial populations constituting the AMCs analysed in this study were not identified. Further research on identifying the dominant bacteria surviving on the surface of fresh chicken meat after UV-C light treatment are desirable to increase the efficacy and efficiency of the technology.

7. References

Ahmad, S. I., Christensen, L., & Baron, E. (2017). History of UV lamps, types, and their applications. In S. I. Ahmad (Ed.), *Ultraviolet Light in Human Health, Diseases and Environment* (pp. 3-11): Springer International Publishing.

Ahn, D. U., Olson, D. G., Jo, C., Chen, X., Wu, C., & Lee, J. I. (1998). Effect of muscle type, packaging, and irradiation on lipid oxidation, volatile production, and color in raw pork patties. *Meat Science, 49*(1), 27-39. doi:10.1016/S0309-1740(97)00101-0

Al-Hijazeen, M., Lee, E., Mendonca, A., & Ahn, D. (2016). Effects of tannic acid on lipid and protein oxidation, color, and volatiles of raw and cooked chicken breast meat during storage. *Antioxidants, 5*(2), 19.

Alter, T. (2017). Chapter 6 - Prevention and mitigation strategies for Campylobacter with focus on poultry production In *Campylobacter: features, detection, and prevention of foodborne disease* (pp. 111-129): Academic Press.

Arnold, J. W. (2005). 15 - Sanitation in poultry processing. In G. C. Mead (Ed.), *Food Safety Control in the Poultry Industry* (pp. 360-379): Woodhead Publishing.

Arvanitoyannis, I. S., & Stratakos, A. C. (2012). Application of modified atmosphere packaging and active/smart technologies to red meat and poultry: a review. *Food and Bioprocess Technology, 5*(5), 1423-1446. doi:10.1007/s11947-012-0803-z

Ashton, I. P. (2002). 14 - Understanding lipid oxidation in fish. In H. A. Bremner (Ed.), *Safety and Quality Issues in Fish Processing* (pp. 254-285): Woodhead Publishing.

Atwill, E. (2017). Global trends that increase the risk of foodborne illness from consumption of raw produce. *Thai Journal of Vetenary Medicine, 47*, S149.

Azimi, Y., Allen, D. G., & Farnood, R. R. (2012). Kinetics of UV inactivation of wastewater bioflocs. *Water Research, 46*, 3827-3836. doi:10.1016/j.watres.2012.04.019

Banerjee, R., & Verma, A. K. (2015). Minimally processed meat and fish products. In M. W. Siddiqui & M. S. Rahman (Eds.), *Minimally Processed Foods: Technologies for Safety, Quality, and Convenience* (pp. 193-250): Springer International Publishing.

Barbut, S. (2002). *Poultry products processing : an industry guide*: CRC Press.

Bardon, J., Kolar, M., Cekanova, L., Hejnar, P., & Koukalova, D. (2009). Prevalence of *Campylobacter jejuni* and its resistance to antibiotics in poultry in the Czech Republic. *Zoonoses And Public Health, 56*(3), 111-116. doi:10.1111/j.1863-2378.2008.01176.x

Baysal, A. H., Molva, C., & Unluturk, S. (2013). UV-C light inactivation and modeling kinetics of *Alicyclobacillus acidoterrestris* spores in white grape and apple juices. *International Journal of Food Microbiology, 166*(3), 494-498. doi:10.1016/j.ijfoodmicro.2013.08.015

Bermúdez-Aguirre, D., Dunne, C. P., & Barbosa-Cánovas, G. V. (2012). Effect of processing parameters on inactivation of *Bacillus cereus* spores in milk using pulsed electric fields. *International Dairy Journal, 24*(1), 13-21. doi:https://doi.org/10.1016/j.idairyj.2011.11.003

Blatchley III, E. R., Meeusen, A., Aronson, A. I., & Brewster, L. (2005). Inactivation of *Bacillus* spores by ultraviolet or gamma radiation. *Journal of Environmental Engineering, 131*(9), 1245-1252. doi:10.1061/(ASCE)0733-9372(2005)131:9(1245)

Boziaris, I. S. (2014). *Seafood processing : technology, quality and safety*: John Wiley & Sons, Ltd.

Butot, S., Cantergiani, F., Moser, M., Jean, J., Lima, A., Michot, L., . . . Zuber, S. (2018). UV-C inactivation of foodborne bacterial and viral pathogens and surrogates on fresh and frozen berries. *International Journal of Food Microbiology, 275*, 8-16. doi:10.1016/j.ijfoodmicro.2018.03.016

Cantlay, J. C., Ingram, D. J., & Meredith, A. L. (2017). A review of zoonotic infection risks associated with the wild meat trade in Malaysia. *EcoHealth, 14*(2), 361-388. doi:10.1007/s10393-017-1229-x

Cao, L., Liu, P., Yang, P., Gao, Q., Li, H., Sun, Y., . . . Wang, X. (2019). Structural basis for neutralization of hepatitis A virus informs a rational design of highly potent inhibitors. *PLoS Biology, 17*(4), 1-20. doi:10.1371/journal.pbio.3000229

Carvalho, R., Shimokomaki, M., & Estévez, M. (2017). Chapter 6 - Poultry meat color and oxidation. In M. Petracci & C. Berri (Eds.), *Poultry Quality Evaluation* (pp. 133-157): Woodhead Publishing.

Castaneda, K. M. (2017). *Persistent contamination of Salmonella, Campylobacter, Escherichia coli and Staphylococcus aureus at a broiler farm in New Zealand.* (Master of Science), Massey University, 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. doi:https://doi.org/10.1016/j.foodcont.2009.06.006

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 & Emerging Technologies, 23*, 94-106. doi:https://doi.org/10.1016/j.ifset.2014.03.005

Cunningham, F. (2012). *The microbiology of poultry meat products*: Elsevier.

Curtis, P. A. (2005). 16 - HACCP in poultry processing. In G. C. Mead (Ed.), *Food Safety Control in the Poultry Industry* (pp. 380-392): Woodhead Publishing.

Degala, H. L., Mahapatra, A. K., Demirci, A., & Kannan, G. (2018). Evaluation of non-thermal hurdle technology for ultraviolet-light to inactivate *Escherichia coli* K12 on goat meat surfaces. *Food Control, 90*, 113-120.

Demirok, E., Veluz, G., Stuyvenberg, W., Castañeda, M., Byrd, A., & Alvarado, C. (2013). Quality and safety of broiler meat in various chilling systems. *Poultry Science, 92*(4), 1117-1126.

EFSA. (2016). Safety of UV-treated milk as a novel food pursuant to Regulation (EC) No 258/97. *EFSA Journal, 14*(1). doi:10.2903/j.efsa.2016.4370

Forney, L. J., & Moraru, C. I. (2009). *Ultraviolet light in food technology: principles and applications*: CRC press.

FSANZ. (1995). *Microbiological reference criteria for food* (Version 2.0 ed.): Ministry of Health.

FSANZ. (2018). *Compendium of microbiological criteria for food*. New Zealand: Food Standards Australia New Zealand.

Gabriel, A. A., Ballesteros, M. L. P., Rosario, L. M. D., Tumlos, R. B., & Ramos, H. J. (2018). Elimination of *Salmonella enterica* on common stainless steel food contact surfaces using UV-C and atmospheric pressure plasma jet. *Food Control, 86*, 90-100. doi:https://doi.org/10.1016/j.foodcont.2017.11.011

Gamage, G. (2015). *Effectiveness of UV-C irradiation on controlling growth of L. monocytogenes on fresh cut broccoli* (Doctor of Philosophy), Massey University, New Zealand.

Gao, Y., Zhuang, H., Yeh, H.-Y., Bowker, B., & Zhang, J. (2019). Effect of rosemary extract on microbial growth, pH, color, and lipid oxidation in cold plasma-processed ground chicken patties. *Innovative Food Science and Emerging Technologies*. doi:10.1016/j.ifset.2019.05.007

Gayán, E., Álvarez, I., & Condón, S. (2013). Inactivation of bacterial spores by UV-C light. *Innovative Food Science and Emerging Technologies, 19*, 140-145. doi:10.1016/j.ifset.2013.04.007

Genç, I. Y., Esteves, E., & Diler, A. (2016). *Handbook of seafood : quality and safety maintenance and applications*: Nova Science Publishers, Inc.

Gould, G. W. (2001). New processing technologies: an overview. *Proceedings of the Nutrition Society, 60*(4), 463-474. doi:10.1079/PNS2001105

Grumezescu, A. M., & Holban, A. M. (2018). *Food processing for increased quality and consumption*: Academic Press.

Guerrero-Beltran, J. A., & Barbosa-Canovas, G. V. (2004). Advantages and limitations on processing foods by UV light. *Food Science and Technology International, 10*(3), 137-147. doi:10.1177/1082013204044359

Gunter-Ward, D. M., Patras, A., S. Bhullar, M., Kilonzo-Nthenge, A., Pokharel, B., & Sasges, M. (2018). Efficacy of ultraviolet (UV-C) light in reducing foodborne pathogens and model viruses in skim milk. *Journal of Food Processing and Preservation, 42*(2), e13485. doi:10.1111/jfpp.13485

Gunter-Ward, D. M., Patras, A., S. Bhullar, M., Kilonzo-Nthenge, A., Pokharel, B., & Sasges, M. (2018). Efficacy of ultraviolet (UV-C) light in reducing foodborne pathogens and model viruses in skim milk. *Journal of Food Processing & Preservation, 42*(2), 1-1. doi:10.1111/jfpp.13485

Hasell, S. K., & Salter, M. A. J. F. C. (2003). Review of the microbiological standards for foods. *14*(6), 391-398.

Haughton, P. N., Lyng, J. G., Morgan, D. J., Cronnin, D. A., Fanning, S., & Whyte, P. (2011a). Efficacy of high-intensity pulsed light for the microbiological decontamination of chicken, associated packaging, and contact surfaces. *Foodborne Pathogens and Disease, 8*(1), 109-117.

Haughton, P. N., Lyng, J. G., Morgan, D. J., Cronnin, D. A., Fanning, S., & Whyte, P. (2011b). Efficacy of UV light treatment for the microbiological decontamination of chicken, associated packaging, and contact surfaces. *Journal of food protection, 74*(4), 565-572.

Heinrich, V., Zunabovic, M., Varzakas, T., Bergmair, J., & Kneifel, W. (2016). Pulsed light treatment of different food types with a special focus on meat: a critical review. *Critical Reviews in Food Science & Nutrition, 56*(4), 591-613.

Hierro, E., Barroso, E., la Hoz, L. d., Ordóñez, J. A., Manzano, S., & Fernández, M. (2011). Efficacy of pulsed light for shelf-life extension and inactivation of *Listeria monocytogenes* on ready-to-eat cooked meat products. *Innovative Food Science & Emerging Technologies, 12*(3), 275-281. doi:https://doi.org/10.1016/j.ifset.2011.04.006

Hui, Y. H., & Aalhus, J. L. (2012). *Handbook of meat and meat processing*: CRC Press.

Hyun, C. H., Jin, K. H., Sun, W. M., Sook, C. K., & Bin, S. K. (2010). A comparison of kinetic models of foodborne pathogen inactivation by aqueous chlorine dioxide, fumaric acid, and ultraviolet-C. *Journal of the Korean Society for Applied Biological Chemistry, 53*(2), 243-248.

Isohanni, P. M. I., & Lyhs, U. (2009). Use of ultraviolet irradiation to reduce *Campylobacter jejuni* on broiler meat. *Poultry Science, 88*(3), 661-668. doi:10.3382/ps.2008-00259

James, C., Vincent, C., de Andrade Lima, T., & James, S. (2006). The primary chilling of poultry carcasses—a review. *International Journal of Refrigeration, 29*(6), 847-862.

Jean, J., Morales-Rayas, R., Anoman, M.-N., & Lamhoujeb, S. (2011). Inactivation of hepatitis A virus and norovirus surrogate in suspension and on food-contact surfaces using pulsed UV light (pulsed light inactivation of food-borne viruses). *Food Microbiology, 28*(3), 568-572. doi:https://doi.org/10.1016/j.fm.2010.11.012

Jiménez, S., Salsi, M., Tiburzi, M., Rafaghelli, R., Tessi, M., & Coutaz, V. (1997). Spoilage microflora in fresh chicken breast stored at 4 C: influence of packaging methods. *Journal of applied microbiology, 83*(5), 613-618.

Kelly, L. (2005). 11 - Microbial risk assessment in poultry production and processing. In G. C. Mead (Ed.), *Food Safety Control in the Poultry Industry* (pp. 255-272): Woodhead Publishing.

Kilcast, D. (2013). *Instrumental assessment of food sensory quality : a practical guide*. Burlington: Woodhead Publishing.

Koutchma, T. (2008). UV Light for Processing Foods. *Ozone: Science & Engineering, 30*(1), 93-98. doi:10.1080/01919510701816346

Koutchma, T. (2009). Advances in ultraviolet light technology for non-thermal processing of liquid foods. *Food and Bioprocess Technology: An International Journal, 2*(2), 138-155. doi:10.1007/s11947-008-0178-3

Lu, Q., Sun, J., Huang, M., Guo, Y., & Memon, A. (2019). Effect of storage temperatures and duration on quality of prepared chicken breast with paprika oleoresin. *Animal Science Journal = Nihon Chikusan Gakkaiho, 90*(2), 280-287. doi:10.1111/asj.13117

Lynch, S. (2016). *Pulsed electric fields (PEF): Technology, role in food science and emerging applications*: Nova Science Publishers, Inc.

Lyon, S., Fletcher, D., & Berrang, M. (2007). Germicidal ultraviolet light to lower numbers of *Listeria monocytogenes* on broiler breast fillets. *Poultry Science, 86*(5), 964-967.

MacDonald, D. J. (2005). 10 - The HACCP concept and its application in primary production. In G. C. Mead (Ed.), *Food Safety Control in the Poultry Industry* (pp. 237-254): Woodhead Publishing.

McLeod, A., Hovde Liland, K., Haugen, J. E., Sørheim, O., Myhrer, K. S., & Holck, A. L. (2018). Chicken fillets subjected to UV-C and pulsed UV light: Reduction of pathogenic and spoilage bacteria, and changes in sensory quality. *Journal of Food Safety, 38*(1), 1-1. doi:10.1111/jfs.12421

McMeekin, T. (1975). Spoilage association of chicken breast muscle. *Applied and Environmental Microbiology, 29*(1), 44-47.

McMeekin, T. (1977). Spoilage association of chicken leg muscle. *Applied and Environmental Microbiology, 33*(6), 1244-1246.

Mead, G. C. (2004). *Poultry meat processing and quality*. : Woodhead Pub.

Morgan, A. I., Radewonuk, E. R., & Scullen, O. J. (1996). Ultra high temperature, ultra short time surface pasteurization of meat. *Journal of Food Science, 61*(6), 1216-1218. doi:10.1111/j.1365-2621.1996.tb10963.x

Octavian, B., & Octavian, B. (2010). Raw chicken leg and breast sensory evaluation. *Annals : Food Science and Technology*(1), 25.

Owens, C. M., Alvarado, C., & Sams, A. R. (2010). *Poultry meat processing*: CRC Press.

Oxoid. (2019). Standard plate count agar. Retrieved from http://www.oxoid.com/UK/blue/prod_detail/prod_detail.asp?pr=CM0463&c=UK&lang=EN

Park, S. Y., & Ha, S.-D. (2015). Ultraviolet-c radiation on the fresh chicken breast: Inactivation of major foodborne viruses and changes in physicochemical and sensory qualities of product. *Food & Bioprocess Technology, 8*(4), 895-906. doi:10.1007/s11947-014-1452-1

Park, S. Y., Kim, A.-N., Lee, K.-H., & Ha, S.-D. (2015). Ultraviolet-C efficacy against a norovirus surrogate and hepatitis A virus on a stainless steel surface. *International Journal of Food Microbiology, 211*, 73-78. doi:https://doi.org/10.1016/j.ijfoodmicro.2015.07.006

Pasquali, F., De Cesare, A., Meunier, M., Guyard, M., Rivoal, K., Chemaly, M., & Manfreda, G. (2017). Chapter 7 - Current challenges in poultry meat safety. In M. Petracci & C. Berri (Eds.), *Poultry Quality Evaluation* (pp. 159-195): Woodhead Publishing.

Pearson, A. M., & Dutson, T. R. (1994). *Quality attributes and their measurement in meat, poultry and fish products*: Blackie Academic.

Petracci, M., & Fletcher, D. L. (2002). Broiler skin and meat color changes during storage. *Poultry Science, 81*(10), 1589-1597.

PIANZ. (2018). Chicken defies meat consumption trends. Retrieved from https://pianz.org.nz/news/chicken-defies-meat-consumption-trends/

Premarathne, J. M. K. J. K., Rukayadi, Y., Radu, S., Satharasinghe, D. A., Huat, J. T. Y., Basri, D. F., . . . Nishibuchi, M. (2017). Impact of human *Campylobacter* infections in Southeast Asia: The contribution of the poultry sector. *Critical Reviews in Food Science and Nutrition, 57*(18), 3971-3986. doi:10.1080/10408398.2016.1266297

Qian, C. (2015). *Occurrence of Staphylococcus aureus in a commercial poultry plant and poultry farm.* (Master of Food Technology), Massey University, New Zealand.

RadiantUV. (2016). Joulesafe UV surface disinfection system.

Reitznerová, A., Šuleková, M., Nagy, J., Marcinčák, S., Semjon, B., Čertík, M., & Klempová, T. (2017). Lipid peroxidation process in meat and meat products: a comparison study of malondialdehyde determination between modified 2-thiobarbituric acid spectrophotometric method and reverse-phase high-performance liquid chromatography. *Molecules, 22*(11), 1988.

Rodríguez, M., Oteiza, J., Giannuzzi, L., & Zaritzky, N. (2017). Evaluation of mutagenicity associated with *Escherichia coli* inactivation in UV-treated orange juice. *Toxicological & Environmental Chemistry, 99*(2), 315-330. doi:10.1080/02772248.2016.1178752

Romalde, J. L. (2017). *Noroviruses : outbreaks, control and prevention strategies*: Nova Science Publishers.

Russell, S., Fletcher, D., & Cox, N. (1995). Spoilage bacteria of fresh broiler chicken carcasses. *Poultry Science, 74*(12), 2041-2047.

Scheinberg, J., Doores, S., & Cutter, C. N. (2013). A microbiological comparison of poultry products obtained from farmers' markets and supermarkets in Pennsylvania. *Journal of Food Safety, 33*(3), 259-264.

Secci, G., & Parisi, G. (2016). From farm to fork: lipid oxidation in fish products. A review. *Italian Journal of Animal Science, 15*(1), 124-136. doi:10.1080/1828051X.2015.1128687

Seemeen, S. (2011). *Effects of high pressure processing and ethyl lauroyl arginate on the shelf-life of ready-to-eat chicken breast roast* (Master of Food Technology), Massey University, New Zealand.

Semi, M. F. B. (2016). *UV-light treatment of fruit in a rotating drum.* (Bachelor of Engineering), Massey University, New Zealand.

Soni, A., Oey, I., Silcock, P., & Bremer, P. (2016). *Bacillus spores* in the food industry: A review on resistance and response to novel inactivation technologies. *Comprehensive Reviews in Food Science and Food Safety, 15*(6), 1139-1148. doi:doi:10.1111/1541-4337.12231

Tewari, G., & Juneja, V. (2007). *Advances in thermal and non-thermal food preservation*. Hoboken: Wiley-Blackwell.

Thompson, F. (2003). Ultraviolet light In B. Caballero (Ed.), *Encyclopedia of Food Sciences and Nutrition* (pp. 5885-5890): Academic Press.

Ulu, H. (2004). Evaluation of three 2-thiobarbituric acid methods for the measurement of lipid oxidation in various meats and meat products. *Meat Science, 67*(4), 683-687. doi:https://doi.org/10.1016/j.meatsci.2003.12.014

Unluturk, S., & Atilgan, M. R. (2014). UV-C irradiation of freshly squeezed grape juice and modeling inactivation kinetics. *Journal of Food Process Engineering, 37*(4), 438-449. doi:10.1111/jfpe.12099

USFDA. (2017). CFR-code of federal regulations title 21. *Current good manufacturing practice for finished pharmaceuticals Part, 211*.

Zhang, L., Jeong, J. Y., Janardhanan, K. K., Ryser, E. T., & Kang, I. (2011). Microbiological quality of water immersion–chilled and air-chilled broilers. *Journal of food protection, 74*(9), 1531-1535.

8. Appendix

Appendix A: Raw data for microbial counts (AMCs) during UV-C light optimisation

Table A2. Aerobic mesophilic count for four different samples treated with four different UV-C doses.

Sample Type	Batch	UV Dosage (mJ/cm²)	Microbial Count (log CFU/cm²)			Mean	SD
			1	2	3		
Skinless breast Fillet	1	0	3.60	3.57	3.68	3.62	0.06
		50	1.60	2.60	0.00	1.40	1.31
		100	0.00	2.70	2.08	1.59	1.41
		200	2.41	2.20	1.60	2.07	0.42
		300	0.00	1.30	1.60	0.97	0.85
	2	0	3.49	3.31	3.13	3.31	0.18
		50	2.04	2.32	2.08	2.15	0.15
		100	2.45	2.15	0.00	1.53	1.33
		200	2.08	0.00	1.60	1.23	1.09
		300	0.00	0.00	0.00	0.00	0.00
Skin-on breast fillet	1	0	4.69	3.79	3.91	4.13	0.49
		50	3.55	3.38	3.15	3.36	0.20
		100	3.60	3.32	3.73	3.55	0.21
		200	3.13	4.12	2.28	3.18	0.92
		300	3.24	4.59	3.15	3.66	0.81
	2	0	2.48	3.19	3.03	2.90	0.37
		50	2.64	2.30	2.64	2.53	0.20
		100	3.00	2.26	2.66	2.64	0.37
		200	1.60	2.20	2.60	2.14	0.50
		300	2.68	3.15	2.58	2.80	0.30
Skinless thigh fillet	1	0	3.42	3.58	3.57	3.52	0.09
		50	2.08	2.68	0.00	1.59	1.41
		100	0.00	1.60	0.00	0.53	0.92
		200	1.30	1.78	0.00	1.03	0.92
		300	0.00	1.78	1.60	1.13	0.98
	2	0	4.00	3.49	3.76	3.75	0.25
		50	2.00	1.30	2.87	2.06	0.79
		100	2.00	0.00	2.92	1.64	1.49
		200	0.00	1.30	1.60	0.97	0.85
		300	1.78	0.00	1.90	1.23	1.06

Table $A1_{contd}$. Aerobic mesophilic count for four different samples treated with four different UV-C doses.

Sample Type	Batch	UV Dose (mJ/cm^2)	Microbial Count (log CFU/cm^2)			Average	SD
			1	2	3		
Skin-on thigh fillet	1	0	2.62	2.82	2.73	2.73	0.10
		50	2.45	2.62	3.03	2.70	0.30
		100	2.20	1.78	2.56	2.18	0.39
		200	2.20	2.51	1.90	2.20	0.30
		300	1.90	1.60	2.30	1.94	0.35
	2	0	3.19	3.48	3.15	3.27	0.18
		50	2.87	2.97	2.81	2.88	0.08
		100	2.78	2.72	2.51	2.67	0.14
		200	3.03	1.90	3.21	2.72	0.71
		300	3.25	3.33	2.72	3.10	0.34

Notes: SD = Standard Deviation; Experiment was replicated twice with 3 determinations each.

Appendix B: Raw data for microbial log reduction (AMCs), temperature readings, and exposure time during UV-C light optimisation

Table B1. Result of Microbial Log Reduction (AMCs), Temperature Change, and Exposure time for four different samples treated with four different UV-C doses.

Sample Type	Batch	UV Dosage (mJ/cm^2)	Microbial Reduction (log CFU/cm^2)	Temperature (°C)			Exposure Time (Minutes)
				Before	After	Change	
Skinless breast fillet	1	50	2.22	7.90	10.37	2.47	2.16
		100	2.02	8.03	14.63	6.60	4.53
		200	1.54	7.87	18.13	10.27	8.72
		300	2.65	9.30	21.67	12.37	12.61
	2	50	1.17	8.87	11.27	2.40	2.16
		100	1.78	7.47	13.50	6.03	4.47
		200	2.09	6.07	16.90	10.83	8.16
		300	3.31	5.87	20.70	14.83	12.55
Skin-on breast fillet	1	50	0.77	5.17	9.33	4.17	2.39
		100	0.58	6.93	13.17	6.23	4.32
		200	0.95	7.27	16.30	9.03	7.93
		300	0.47	7.33	18.13	10.80	12.53
	2	50	0.37	6.83	10.07	3.23	2.17
		100	0.26	7.47	12.33	4.87	4.74
		200	0.76	7.10	17.13	10.03	9.09
		300	0.10	6.43	19.83	13.40	13.52
Skinless thigh fillet	1	50	1.94	8.87	12.03	3.17	2.13
		100	2.99	8.53	15.67	7.13	4.28
		200	2.50	6.87	19.30	12.43	7.67
		300	2.40	7.67	21.77	14.10	11.04
	2	50	1.69	8.10	12.60	4.50	2.22
		100	2.11	8.47	16.37	7.90	4.33
		200	2.78	7.30	18.60	11.30	7.96
		300	2.52	6.70	24.13	17.43	11.88
Skin-on thigh fillet	1	50	0.03	7.47	10.80	3.33	2.19
		100	0.55	6.77	12.13	5.37	4.01
		200	0.52	5.90	16.47	10.57	7.87
		300	0.79	6.10	17.57	11.47	10.65
	2	50	0.39	8.93	11.47	2.53	2.13
		100	0.61	7.90	14.50	6.60	4.56
		200	0.56	7.30	16.20	8.90	7.89
		300	0.17	6.80	21.00	14.20	11.96

Notes: Experiment was replicated twice with 3 determinations each.

Appendix C: Minitab output of UV-C light optimisation

Microbial log reduction

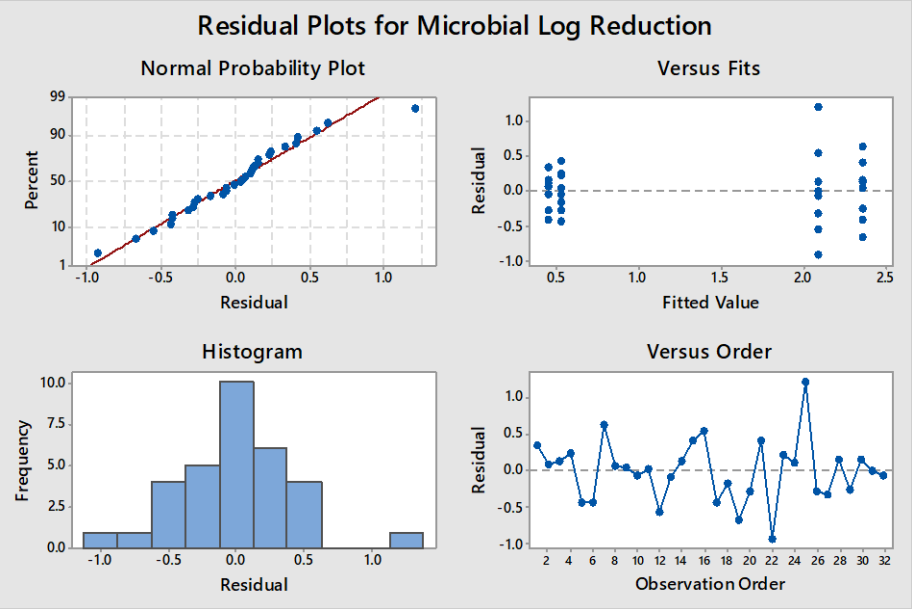

Figure C3. Residual plots for microbial log reduction generated by Minitab 17 (Minitab Inc., USA, 2009).
Note: Experiment was replicated twice with 3 determinations each.

General Factorial Regression: Microbial Log Reduction versus Chicken Meat Type

Factor Information

Factor	Levels	Values
Chicken Meat Type	4	SLBF, SOBF, SLTF, SOTF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	24.518	8.1726	42.54	0.000
Linear	3	24.518	8.1726	42.54	0.000
Chicken Meat Type	**3**	**24.518**	**8.1726**	**42.54**	**0.000**
Error	28	5.379	0.1921		
Lack-of-Fit	12	3.488	0.2906	2.46	0.047
Pure Error	16	1.891	0.1182		
Total	31	29.897			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.438294	82.01%	80.08%	76.50%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.3622	0.0775	17.58	0.000	
Chicken Meat Type					
SLBF	0.735	0.134	5.48	0.000	1.50
SOBF	-0.830	0.134	-6.18	0.000	1.50
SLTF	1.004	0.134	7.48	0.000	1.50

Regression Equation

Microbial Log Reduction = 1.3622 + 0.735 Chicken Meat Type_SLBF
- 0.830 Chicken Meat Type_SOBF
+ 1.004 Chicken Meat Type_SLTF
- 0.910 Chicken Meat Type_SOTF

Fits and Diagnostics for Unusual Observations

Obs	Microbial Log Reduction	Fit	Resid	Std Resid	
22	1.170	2.098	-0.928	-2.26	R
25	3.310	2.098	1.212	2.96	R

R Large residual

Temperature change

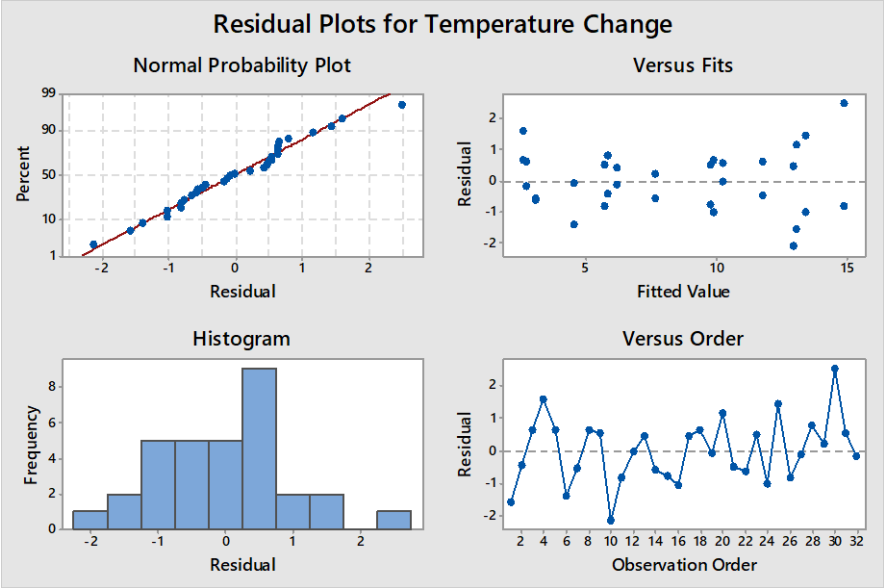

Figure C2. Residual plots for temperature change generated by Minitab 17 (Minitab Inc., USA, 2009).
Note: Experiment was replicated twice with 3 determinations each.

General Factorial Regression: Temperature Change versus Chicken Meat Type, UV Dosage

Factor Information

Factor	Levels	Values
Chicken Meat Type	4	SLBF, SOBF, SLTF, SOTF
UV Dosage	4	50, 100, 200, 300

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	516.436	86.073	70.86	0.000
Linear	6	516.436	86.073	70.86	0.000
Chicken Meat Type	**3**	**20.295**	**6.765**	**5.57**	**0.005**
UV Dosage	**3**	**496.141**	**165.380**	**136.15**	**0.000**
Error	25	30.366	1.215		
Lack-of-Fit	9	7.905	0.878	0.63	0.759
Pure Error	16	22.462	1.404		
Total	31	546.802			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.10211	94.45%	93.11%	90.90%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	8.399	0.195	43.11	0.000	
Chicken Meat Type					
SLBF	-0.174	0.337	-0.51	0.611	1.50
SOBF	-0.645	0.337	-1.91	0.067	1.50
SLTF	1.346	0.337	3.99	0.001	1.50
UV Dosage					
50	-5.174	0.337	-15.33	0.000	1.50
100	-2.057	0.337	-6.10	0.000	1.50
200	2.055	0.337	6.09	0.000	1.50

Regression Equation

Temperature Change = 8.399 - 0.174 Chicken Meat Type_SLBF
- 0.645 Chicken Meat Type_SOBF
+ 1.346 Chicken Meat Type_SLTF
- 0.528 Chicken Meat Type_SOTF
- 5.174 UV Dosage_50 - 2.057 UV Dosage_100
+ 2.055 UV Dosage_200
+ 5.176 UV Dosage_300

Fits and Diagnostics for Unusual Observations

Obs	Temperature Change	Fit	Resid	Std Resid	
10	10.800	12.930	-2.130	-2.19	R
30	17.430	14.921	2.509	2.58	R

R Large residual

Exposure time

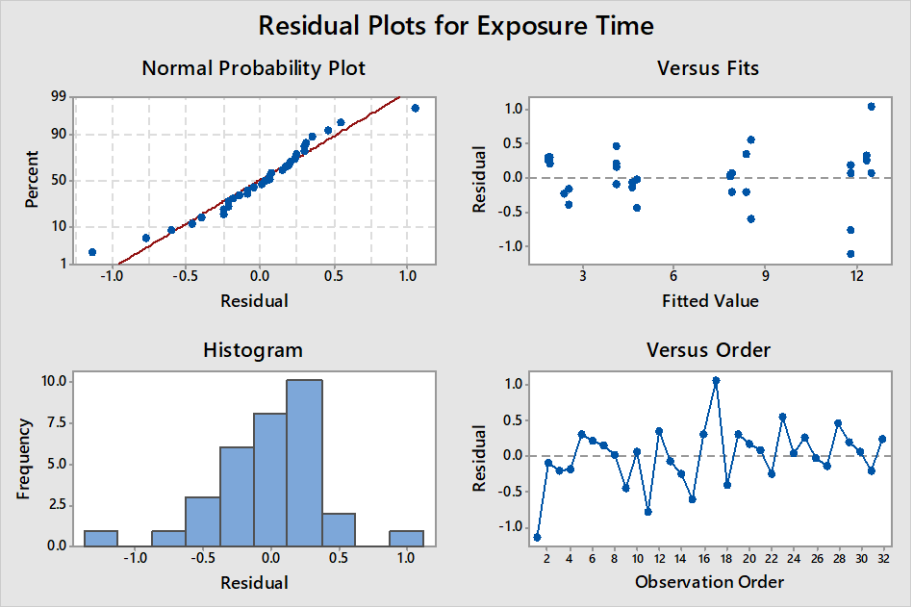

Figure C3. Residual plots for exposure time generated by Minitab 17 (Minitab Inc., USA, 2009).
Note: Experiment was replicated twice with 3 determinations each.

General Factorial Regression: Exposure Time versus Chicken Meat Type, UV Dosage

Factor Information

Factor	Levels	Values
Chicken Meat Type	4	SLBF, SOBF, SLTF, SOTF
UV Dosage	4	50, 100, 200, 300

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	457.101	76.184	365.48	0.000
Linear	6	457.101	76.184	365.48	0.000
Chicken Meat Type	**3**	**2.806**	**0.935**	**4.49**	**0.012**
UV Dosage	**3**	**454.295**	**151.432**	**726.48**	**0.000**
Error	25	5.211	0.208		
Lack-of-Fit	9	2.364	0.263	1.48	0.238
Pure Error	16	2.847	0.178		
Total	31	462.312			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.456559	98.87%	98.60%	98.15%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	6.7131	0.0807	83.18	0.000	
Chicken Meat Type					
SLBF	0.207	0.140	1.48	0.151	1.50
SOBF	0.373	0.140	2.67	0.013	1.50
SLTF	-0.274	0.140	-1.96	0.061	1.50
UV Dosage					
50	-4.519	0.140	-32.33	0.000	1.50
100	-2.308	0.140	-16.51	0.000	1.50
200	1.448	0.140	10.36	0.000	1.50

Regression Equation

Exposure Time = 6.7131 + 0.207 Chicken Meat Type_SLBF
+ 0.373 Chicken Meat Type_SOBF
- 0.274 Chicken Meat Type_SLTF - 0.306 Chicken Meat Type_SOTF
- 4.519 UV Dosage_50 - 2.308 UV Dosage_100 + 1.448 UV Dosage_200
+ 5.379 UV Dosage_300

Fits and Diagnostics for Unusual Observations

Obs	Exposure Time	Fit	Resid	Std Resid	
1	10.650	11.787	-1.137	-2.82	R
17	13.520	12.466	1.054	2.61	R

R Large residual

Appendix D: Microbial enumeration data (AMCs) during shelf-life determination

Table D1. AMCs* (log CFU/cm²) of untreated and UV treated (50 mJ/cm²) fresh chicken meat during storage at 4°C.

Day 0	**log CFU/cm²**	**Day 3**	**log CFU/cm²**	**Day 5**	**log CFU/cm²**	**Day 7**	**log CFU/cm²**
SOBF C1	3.42	SOBF C1	4.75	SOBF C1	7.08	SOBF C1	8.23
SOBF C2	3.20	SOBF C2	5.02	SOBF C2	6.39	SOBF C2	8.57
SOBF C3	3.31	SOBF C3	4.48	SOBF C3	6.74	SOBF C3	8.91
Mean	3.31	Mean	4.75	Mean	6.74	Mean	8.57
STDEV	0.11	STDEV	0.27	STDEV	0.34	STDEV	0.34
SOBF S1	3.29	SOBF S1	4.39	SOBF S1	6.30	SOBF S1	7.53
SOBF S2	3.07	SOBF S2	4.57	SOBF S2	3.72	SOBF S2	7.40
SOBF S3	2.86	SOBF S3	3.95	SOBF S3	5.41	SOBF S3	7.51
Mean	3.07	Mean	4.31	Mean	5.14	Mean	7.48
STDEV	0.22	STDEV	0.32	STDEV	1.31	STDEV	0.07
Reduction	0.24	Reduction	0.44	Reduction	1.60	Reduction	1.09
SLBF C1	3.61	SLBF C1	5.19	SLBF C1	6.55	SLBF C1	8.95
SLBF C2	3.58	SLBF C2	5.20	SLBF C2	6.42	SLBF C2	8.65
SLBF C3	4.20	SLBF C3	4.64	SLBF C3	6.64	SLBF C3	8.26
Mean	3.80	Mean	5.01	Mean	6.54	Mean	8.62
STDEV	0.35	STDEV	0.32	STDEV	0.11	STDEV	0.35
SLBF S1	1.30	SLBF S1	2.34	SLBF S1	4.36	SLBF S1	6.64
SLBF S2	1.30	SLBF S2	3.85	SLBF S2	4.18	SLBF S2	6.48
SLBF S3	3.00	SLBF S3	3.83	SLBF S3	4.57	SLBF S3	6.95
Mean	1.87	Mean	3.61	Mean	4.37	Mean	6.69
STDEV	0.98	STDEV	0.86	STDEV	0.20	STDEV	0.24
Reduction	1.93	Reduction	1.67	Reduction	2.17	Reduction	1.93

Notes: SOBF = Skin-on Breast Fillet; SLBF = Skinless Breast Fillet; STDEV = standard deviation; n = 3.

Appendix E: Minitab output for microbial enumeration (AMCs) during shelf-life determination

Skin-on Breast Fillet (SOBF)

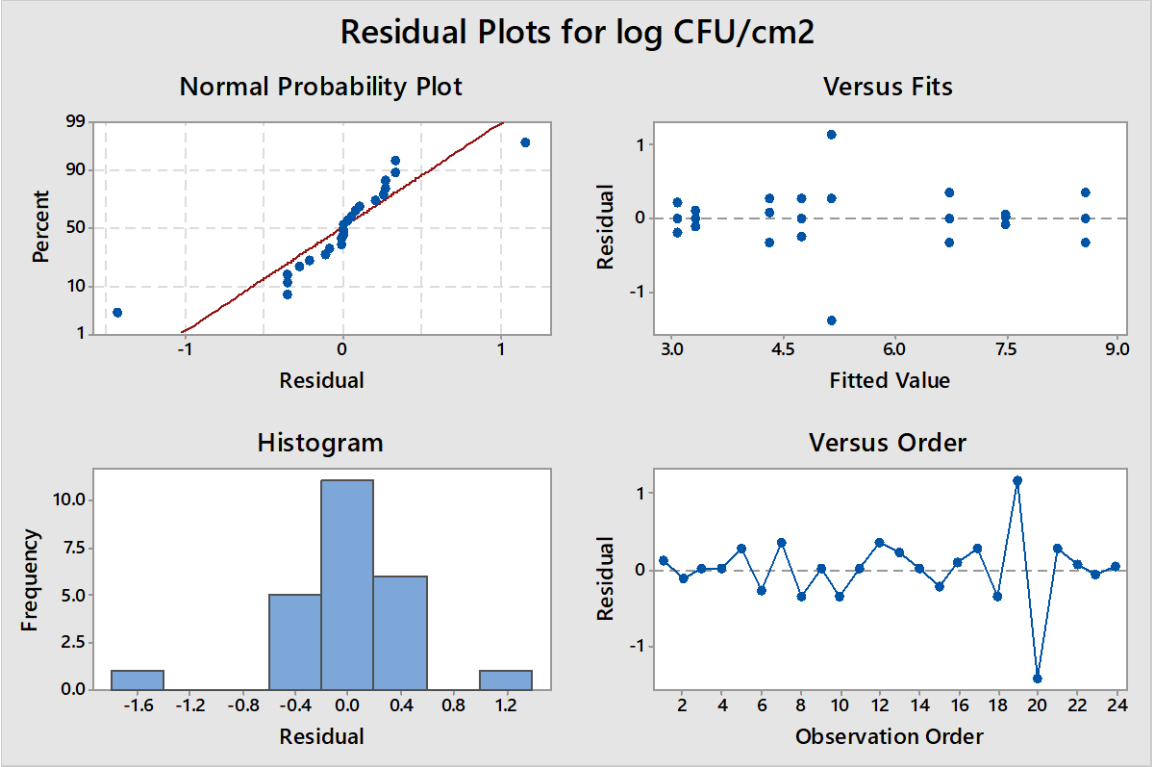

Figure E1. Residual plots for AMCs count (log CFU/cm²) generated by Minitab 17 (Minitab Inc., USA, 2009).
Note: n = 3.

One-way ANOVA: AMCs (log CFU/cm^2) versus Sample SOBF

Method

Null hypothesis All means are equal
Alternative hypothesis At least one mean is different
Significance level α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Sample SOBF	8	Control 0, Control 3, Control 5, Control 7, UV 0, UV 3, UV 5, UV 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Sample SOBF	7	82.817	11.8310	43.11	**0.000**
Error	16	4.391	0.2744		
Total	23	87.207			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.523845	94.97%	92.76%	88.67%

Means

Sample SOBF	N	Mean	StDev	95% CI
Control 0	3	3.3118	0.1088	(2.6706, 3.9529)
Control 3	3	4.749	0.269	(4.108, 5.390)
Control 5	3	6.737	0.344	(6.096, 7.378)
Control 7	3	8.568	0.342	(7.927, 9.209)
UV 0	3	3.072	0.215	(2.431, 3.713)
UV 3	3	4.306	0.318	(3.665, 4.947)
UV 5	3	5.142	1.313	(4.501, 5.783)
UV 7	3	7.4782	0.0707	(6.8370, 8.1193)

Pooled StDev = 0.523845

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Sample SOBF	N	Mean	Grouping
Control 7	3	8.568	A
UV 7	3	7.4782	A B
Control 5	3	6.737	B
UV 5	3	5.142	C
Control 3	3	4.749	C D
UV 3	3	4.306	C D E
Control 0	3	3.3118	D E
UV 0	3	3.072	E

Means that do not share a letter are significantly different.

Skinless Breast Fillet (SLBF)

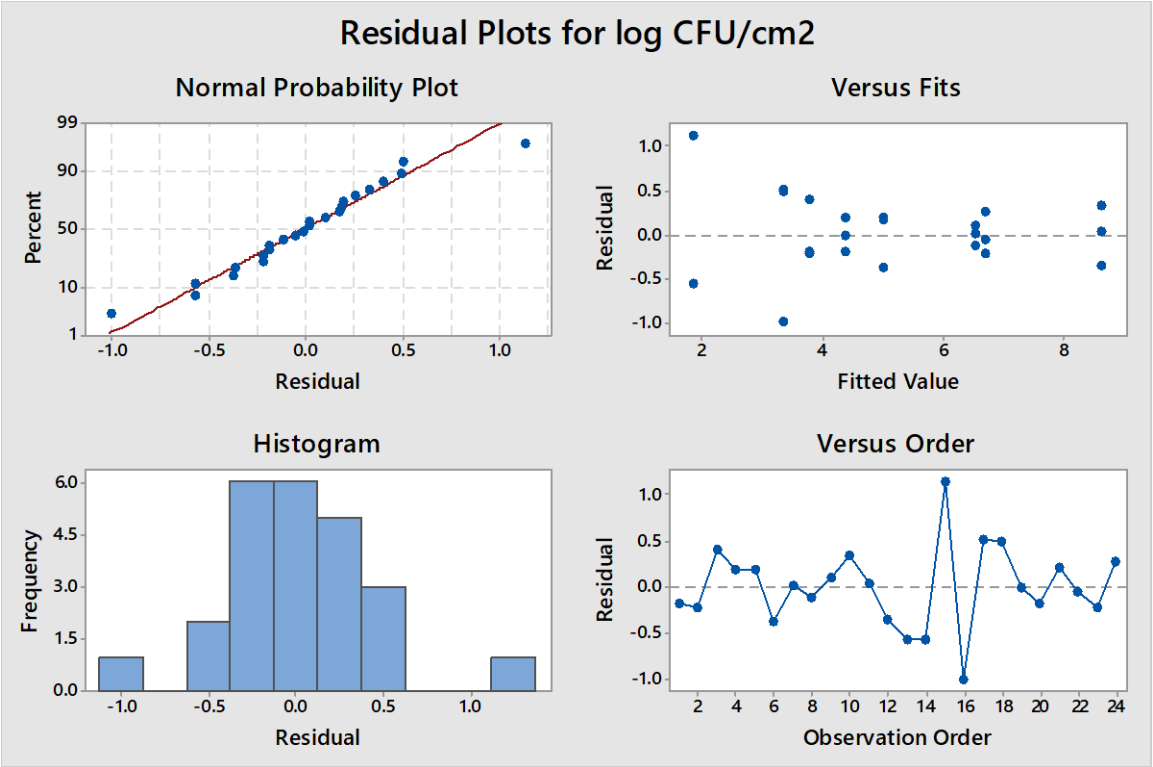

Figure E2. Residual plots for AMCs count (log CFU/cm²) generated by Minitab 17 (Minitab Inc., USA, 2009).
Note: n = 3.

One-way ANOVA: AMCs (log CFU/cm^2) versus Sample SLBF

Method

Null hypothesis All means are equal
Alternative hypothesis At least one mean is different
Significance level α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Sample SLBF	8	Control 0, Control 3, Control 5, Control 7, UV 0, UV 3, UV 5, UV 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Sample SLBF	7	98.212	14.0303	51.83	**0.000**
Error	16	4.331	0.2707		
Total	23	102.543			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.520291	95.78%	93.93%	90.50%

Means

Sample SLBF	N	Mean	StDev	95% CI
Control 0	3	3.799	0.351	(3.162, 4.436)
Control 3	3	5.014	0.321	(4.377, 5.650)
Control 5	3	6.5351	0.1095	(5.8983, 7.1719)
Control 7	3	8.622	0.345	(7.985, 9.259)
UV 0	3	1.867	0.981	(1.231, 2.504)
UV 3	3	3.342	0.865	(2.705, 3.978)
UV 5	3	4.367	0.196	(3.731, 5.004)
UV 7	3	6.692	0.242	(6.055, 7.328)

Pooled StDev = 0.520291

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Sample SLBF	N	Mean	Grouping
Control 7	3	8.622	A
UV 7	3	6.692	B
Control 5	3	6.5351	B
Control 3	3	5.014	C
UV 5	3	4.367	C D
Control 0	3	3.799	C D
UV 3	3	3.342	D
UV 0	3	1.867	E

Means that do not share a letter are significantly different.

Appendix F: Raw data for instrumental color data during shelf-life determination

Table F1. L* values of skin-on breast fillet

Storage Period	Sample	Untreated (Control)	UV-treated
0	1	61.12	60.72
	2	61.13	60.71
	3	60.45	60.68
	4	60.50	60.65
	5	60.85	60.64
	Mean	60.81	60.68
	SD	0.33	0.04
3	1	56.81	58.62
	2	56.80	58.61
	3	56.79	58.61
	4	56.79	58.60
	5	56.80	58.59
	Mean	56.80	58.61
	SD	0.01	0.01
5	1	57.66	56.37
	2	57.67	56.36
	3	57.67	56.35
	4	57.66	56.33
	5	57.66	56.31
	Mean	57.66	56.34
	SD	0.01	0.02
7	1	57.66	56.37
	2	57.67	56.36
	3	57.67	56.35
	4	57.66	56.33
	5	57.66	56.31
	Mean	57.66	56.34
	SD	0.01	0.02

Notes: n = 5.

Table F2. L* values of skinless breast fillet

Storage Period	Sample	Untreated (Control)	UV-treated
0	1	42.45	42.39
	2	42.49	42.39
	3	42.32	42.39
	4	42.31	42.38
	5	42.30	42.38
	Mean	42.37	42.39
	SD	0.09	0.01
3	1	41.55	41.21
	2	41.28	41.20
	3	41.35	41.20
	4	41.20	41.20
	5	41.37	41.23
	Mean	41.35	41.21
	SD	0.13	0.01
5	1	41.07	40.66
	2	41.05	40.64
	3	41.04	40.63
	4	40.39	40.60
	5	40.37	40.60
	Mean	40.78	40.63
	SD	0.37	0.03
7	1	40.25	40.24
	2	40.25	40.23
	3	40.24	40.24
	4	40.24	40.22
	5	40.24	40.25
	Mean	40.24	40.24
	SD	0.01	0.01

Notes: n = 5.

Table F3. a* values of skin-on breast fillet

Storage period	Sample	Untreated (Control)	UV-treated
0	1	-1.13	-1.06
	2	-1.11	-1.07
	3	-1.13	-1.06
	4	-1.12	-1.05
	5	-1.10	-1.05
	Mean	-1.12	-1.06
	SD	0.01	0.01
3	1	-1.07	-0.96
	2	-1.06	-0.96
	3	-1.05	-0.97
	4	-1.04	-0.95
	5	-1.05	-0.94
	Mean	-1.05	-0.96
	SD	0.01	0.01
5	1	-0.96	-0.86
	2	-0.96	-0.87
	3	-0.97	-0.86
	4	-0.95	-0.85
	5	-0.94	-0.85
	Mean	-0.96	-0.86
	SD	0.01	0.01
7	1	-0.53	-0.56
	2	-0.52	-0.58
	3	-0.53	-0.59
	4	-0.54	-0.57
	5	-0.54	-0.58
	Mean	-0.53	-0.58
	SD	0.01	0.01

Notes: n = 5.

Table F4. a* values of skinless breast fillet.

Storage Period	Sample	Untreated (Control)	UV-treated
0	1	1.16	1.16
	2	1.14	1.15
	3	1.12	1.16
	4	1.13	1.14
	5	1.15	1.17
	Mean	1.14	1.16
	SD	0.02	0.01
3	1	1.08	1.09
	2	1.09	1.09
	3	1.08	1.08
	4	1.09	1.08
	5	1.09	1.07
	Mean	1.09	1.08
	SD	0.01	0.01
5	1	0.75	0.75
	2	0.75	0.72
	3	0.73	0.73
	4	0.74	0.72
	5	0.74	0.73
	Mean	0.74	0.73
	SD	0.01	0.01
7	1	0.65	0.61
	2	0.60	0.62
	3	0.58	0.61
	4	0.59	0.62
	5	0.64	0.63
	Mean	0.61	0.62
	SD	0.03	0.01

Notes: n = 5.

Table F5. b* values of skin-on breast fillet.

Storage period	Sample	Untreated (Control)	UV-treated
0	1	0.97	1.83
	2	0.98	1.81
	3	0.98	1.78
	4	0.96	1.74
	5	0.95	1.72
	Mean	0.97	1.78
	SD	0.01	0.05
3	1	0.74	1.56
	2	0.76	1.57
	3	0.79	1.61
	4	0.79	1.58
	5	0.81	1.60
	Mean	0.78	1.58
	SD	0.03	0.02
5	1	0.61	1.47
	2	0.62	1.45
	3	0.63	1.44
	4	0.64	1.43
	5	0.67	1.42
	Mean	0.63	1.44
	SD	0.02	0.02
7	1	0.41	1.17
	2	0.42	1.16
	3	0.42	1.15
	4	0.40	1.16
	5	0.38	1.16
	Mean	0.41	1.16
	SD	0.02	0.01

Notes: n = 5.

Table F6. b* values of skinless breast fillet

Storage Period	Sample	Untreated (Control)	UV-treated
0	1	1.33	0.95
	2	1.29	0.94
	3	1.28	0.93
	4	1.32	0.90
	5	1.29	0.89
	Mean	1.30	0.92
	SD	0.02	0.03
3	1	0.83	0.85
	2	0.85	0.84
	3	0.81	0.83
	4	0.87	0.83
	5	0.80	0.81
	Mean	0.83	0.83
	SD	0.03	0.01
5	1	0.68	0.62
	2	0.64	0.60
	3	0.62	0.58
	4	0.60	0.57
	5	0.59	0.56
	Mean	0.63	0.59
	SD	0.04	0.02
7	1	0.42	0.48
	2	0.42	0.47
	3	0.40	0.45
	4	0.40	0.45
	5	0.40	0.43
	Mean	0.41	0.46
	SD	0.01	0.02

Notes: n = 5.

Appendix G: Minitab output for instrumental color during shelf-life determinations

L* values (lightness) of skin-on breast fillet

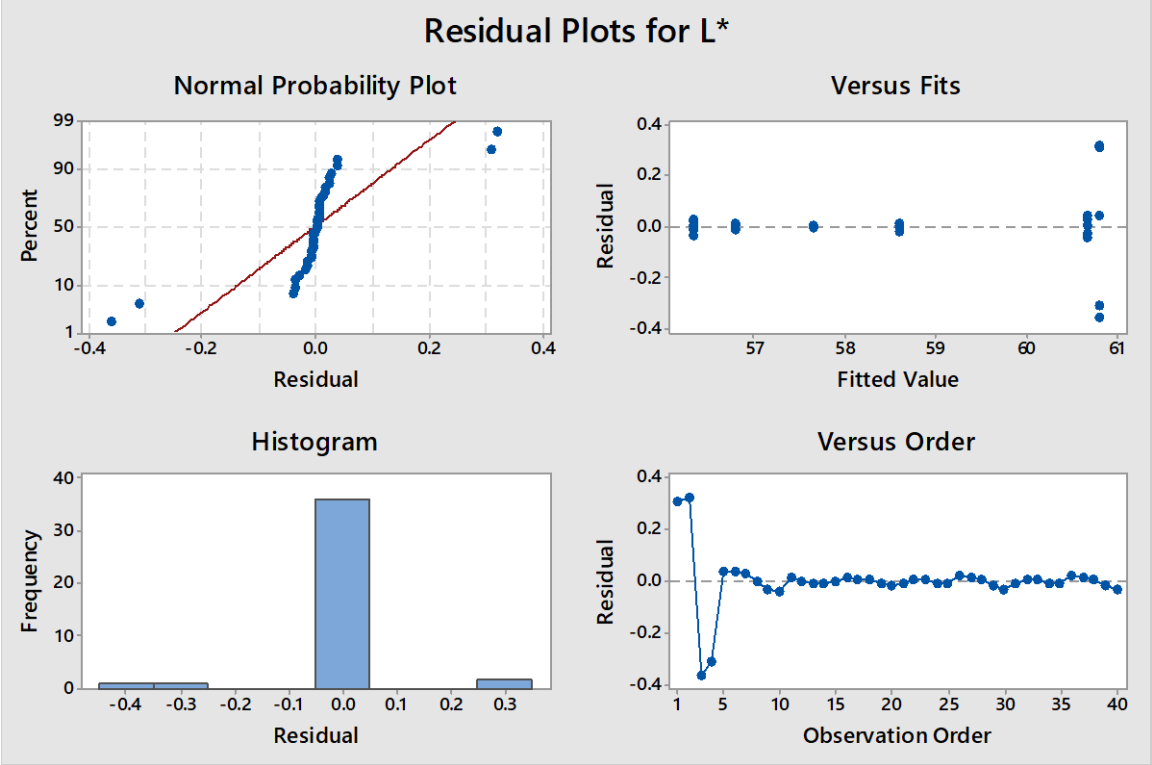

Figure G1. Residual plots for L* values of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).
Notes: n = 5.

One-way ANOVA: L* versus SOBF

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.


Factor Information

Factor  Levels  Values
Sample       8  C0, C3, C5, C7, UV0, UV3, UV5, UV7


Analysis of Variance

Source  DF   Adj SS   Adj MS  F-Value  P-Value
Sample   7  112.487  16.0696  1178.13    0.000
Error   32    0.436   0.0136
Total   39  112.924


Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0.116790  99.61%     99.53%      99.40%


Means

Sample  N     Mean   StDev        95% CI
C0      5   60.810   0.326  ( 60.704,  60.916)
C3      5  56.7980  0.0084  (56.6916, 56.9044)
C5      5  57.6640  0.0055  (57.5576, 57.7704)
C7      5  57.6640  0.0055  (57.5576, 57.7704)
UV0     5  60.6800  0.0354  (60.5736, 60.7864)
UV3     5  58.6060  0.0114  (58.4996, 58.7124)
UV5     5  56.3440  0.0241  (56.2376, 56.4504)
UV7     5  56.3440  0.0241  (56.2376, 56.4504)

Pooled StDev = 0.116790
```

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Sample  N     Mean  Grouping
C0      5   60.810  A
UV0     5  60.6800  A
UV3     5  58.6060    B
C7      5  57.6640      C
C5      5  57.6640      C
C3      5  56.7980        D
UV7     5  56.3440          E
UV5     5  56.3440          E

Means that do not share a letter are significantly different.
```

Note: C = control sample; UV = UV treated sample; 0,3,5,7 = storage period (days).

a* values (redness) of skin-on breast fillet

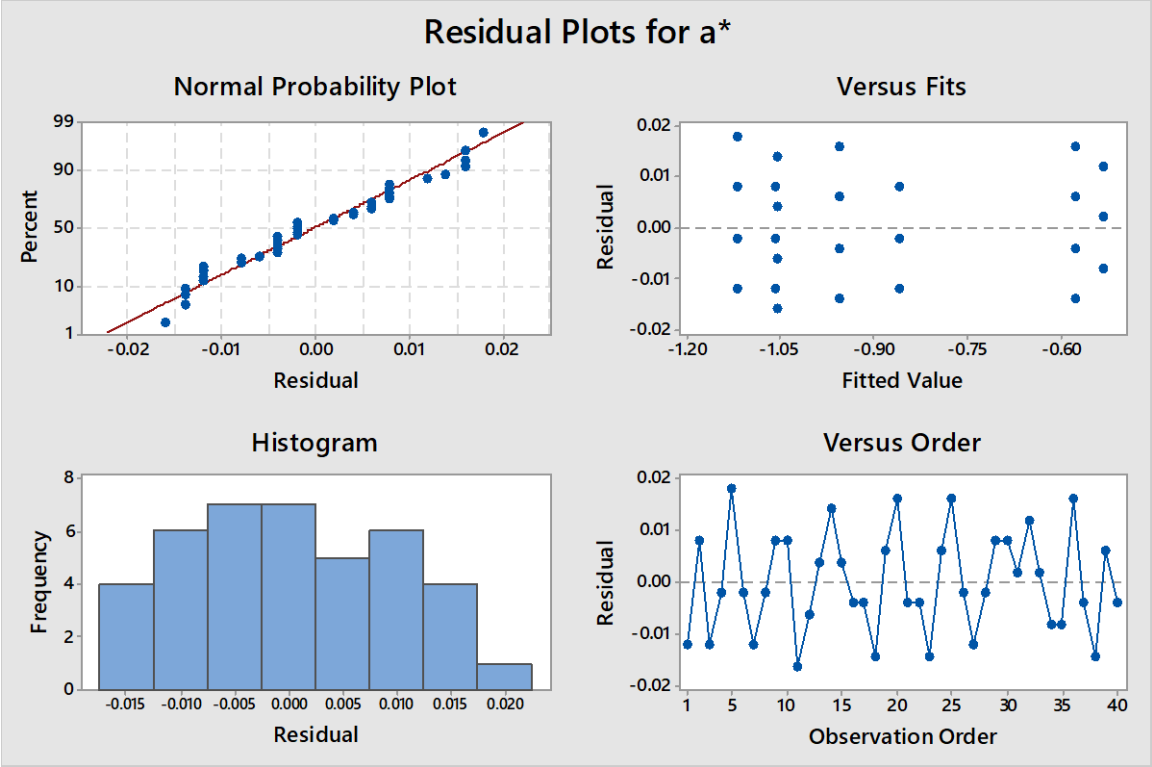

Figure G2. Residual plots for a* values of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).
Notes: n = 5.

One-way ANOVA: a* versus SOBF

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.


Factor Information

Factor  Levels  Values
Sample       8  C0, C3, C5, C7, UV0, UV3, UV5, UV7


Analysis of Variance

Source  DF   Adj SS    Adj MS  F-Value  P-Value
Sample   7  1.71791  0.245416  2181.47    0.000
Error   32  0.00360  0.000112
Total   39  1.72151


Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0106066  99.79%     99.75%      99.67%


Means

Sample  N      Mean    StDev         95% CI
C0      5  -1.11800  0.01304  (-1.12766, -1.10834)
C3      5  -1.05400  0.01140  (-1.06366, -1.04434)
C5      5  -0.95600  0.01140  (-0.96566, -0.94634)
C7      5  -0.53200  0.00837  (-0.54166, -0.52234)
UV0     5  -1.05800  0.00837  (-1.06766, -1.04834)
UV3     5  -0.95600  0.01140  (-0.96566, -0.94634)
UV5     5  -0.85800  0.00837  (-0.86766, -0.84834)
UV7     5  -0.57600  0.01140  (-0.58566, -0.56634)

Pooled StDev = 0.0106066
```

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Sample  N      Mean  Grouping
C7      5  -0.53200  A
UV7     5  -0.57600    B
UV5     5  -0.85800      C
UV3     5  -0.95600        D
C5      5  -0.95600        D
C3      5  -1.05400          E
UV0     5  -1.05800          E
C0      5  -1.11800            F

Means that do not share a letter are significantly different.
```

Note: C = control sample; UV = UV treated sample; 0,3,5,7 = storage period (days).

b* values (yellowness) of skin-on breast fillet

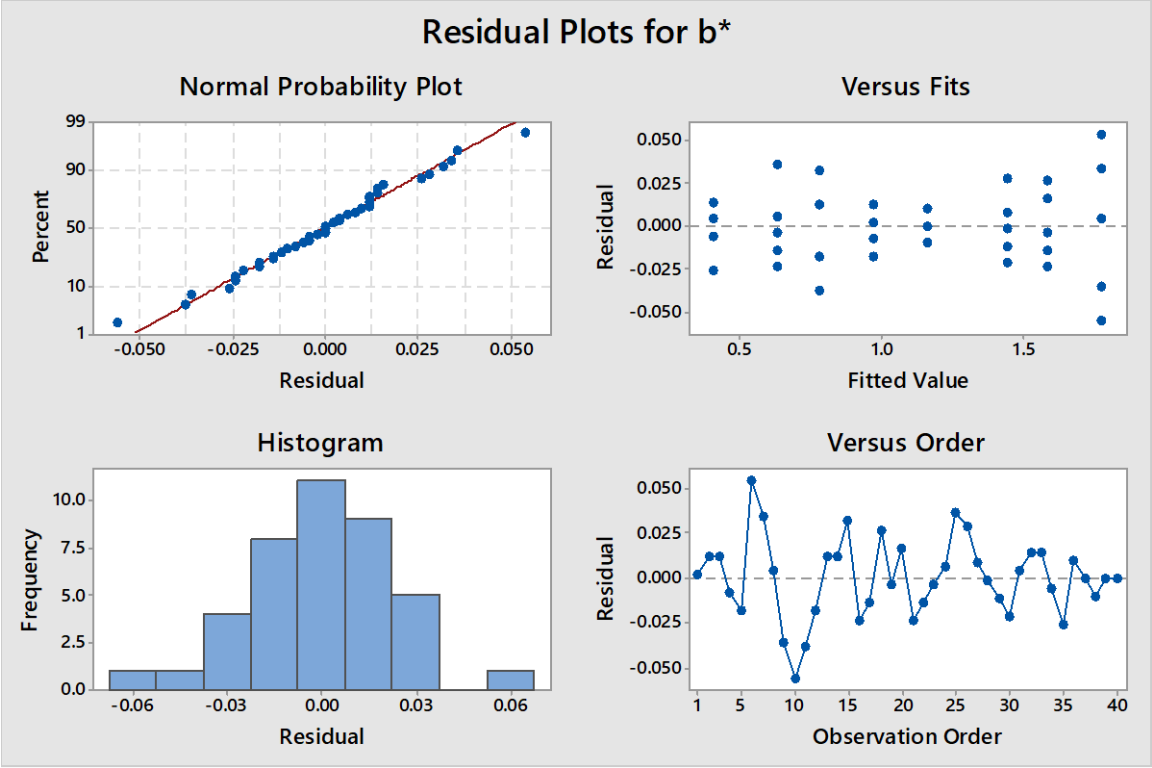

Figure G3. Residual plots for b* values of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).
Notes: n = 5.

One-way ANOVA: b* versus SOBF

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.


Factor Information

Factor  Levels  Values
Sample       8  C0, C3, C5, C7, UV0, UV3, UV5, UV7


Analysis of Variance

Source  DF   Adj SS   Adj MS  F-Value  P-Value
Sample   7  8.15679  1.16526  1970.83    0.000
Error   32  0.01892  0.00059
Total   39  8.17571


Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0243156  99.77%     99.72%      99.64%


Means

Sample  N     Mean    StDev        95% CI
C0      5  0.96800  0.01304  (0.94585, 0.99015)
C3      5   0.7780   0.0277  ( 0.7558,  0.8002)
C5      5   0.6340   0.0230  ( 0.6118,  0.6562)
C7      5  0.40600  0.01673  (0.38385, 0.42815)
UV0     5   1.7760   0.0462  ( 1.7538,  1.7982)
UV3     5  1.58400  0.02074  (1.56185, 1.60615)
UV5     5  1.44200  0.01924  (1.41985, 1.46415)
UV7     5  1.16000  0.00707  (1.13785, 1.18215)

Pooled StDev = 0.0243156
```

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Sample  N     Mean  Grouping
UV0     5   1.7760  A
UV3     5  1.58400    B
UV5     5  1.44200      C
UV7     5  1.16000        D
C0      5  0.96800          E
C3      5   0.7780            F
C5      5   0.6340              G
C7      5  0.40600                H

Means that do not share a letter are significantly different.
```

Note: C = control sample; UV = UV treated sample; 0,3,5,7 = storage period (days).

L* values (lightness) of skinless breast fillet

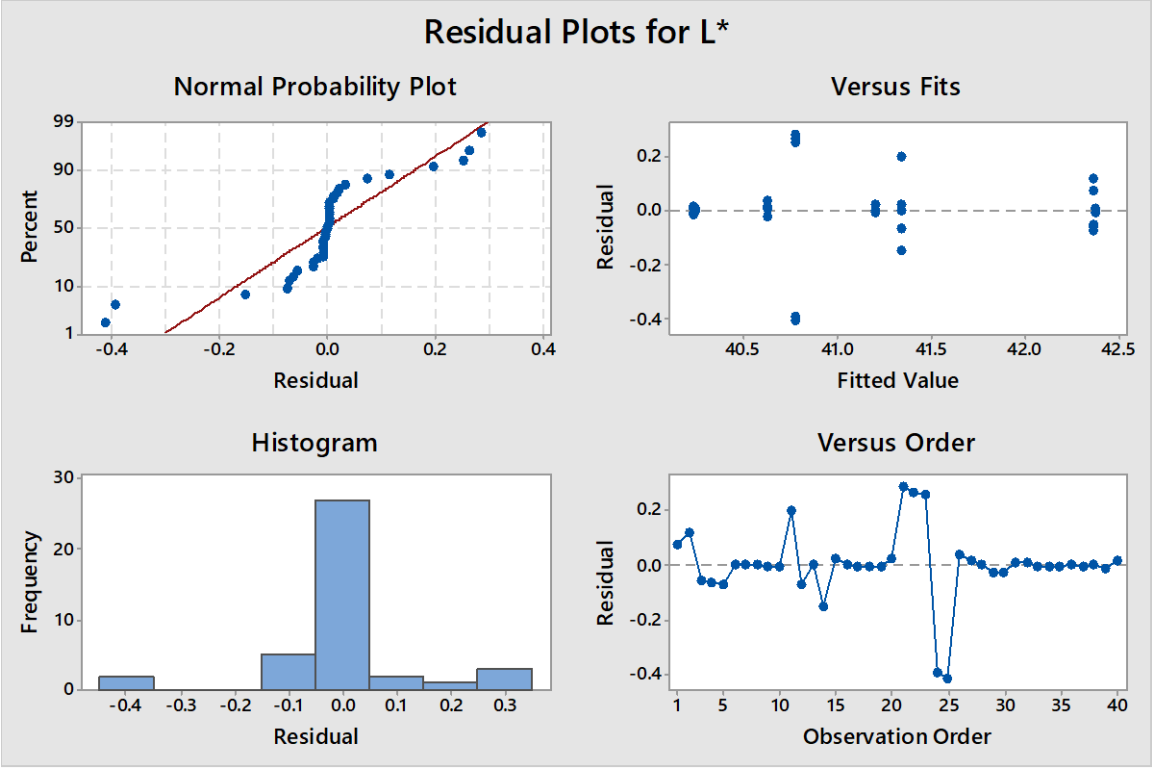

Figure G4. Residual plots for L* values of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).
Notes: n = 5.

One-way ANOVA: L* versus SLBF

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.


Factor Information

Factor  Levels  Values
Sample       8  C0, C3, C5, C7, UV0, UV3, UV5, UV7


Analysis of Variance

Source  DF   Adj SS   Adj MS  F-Value  P-Value
Sample   7  25.6700  3.66714   180.98    0.000
Error   32   0.6484  0.02026
Total   39  26.3184


Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0.142346  97.54%     97.00%      96.15%


Means

Sample  N     Mean   StDev        95% CI
C0      5  42.3740  0.0891  (42.2443, 42.5037)
C3      5  41.3500  0.1302  (41.2203, 41.4797)
C5      5   40.784   0.369  ( 40.654,  40.914)
C7      5  40.2440  0.0055  (40.1143, 40.3737)
UV0     5  42.3860  0.0055  (42.2563, 42.5157)
UV3     5  41.2080  0.0130  (41.0783, 41.3377)
UV5     5  40.6260  0.0261  (40.4963, 40.7557)
UV7     5  40.2360  0.0114  (40.1063, 40.3657)

Pooled StDev = 0.142346
```

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Sample  N     Mean  Grouping
UV0     5  42.3860  A
C0      5  42.3740  A
C3      5  41.3500    B
UV3     5  41.2080    B
C5      5   40.784      C
UV5     5  40.6260      C
C7      5  40.2440        D
UV7     5  40.2360        D

Means that do not share a letter are significantly different.
```

Note: C = control sample; UV = UV treated sample; 0,3,5,7 = storage period (days).

a* values (redness) of skinless breast fillet

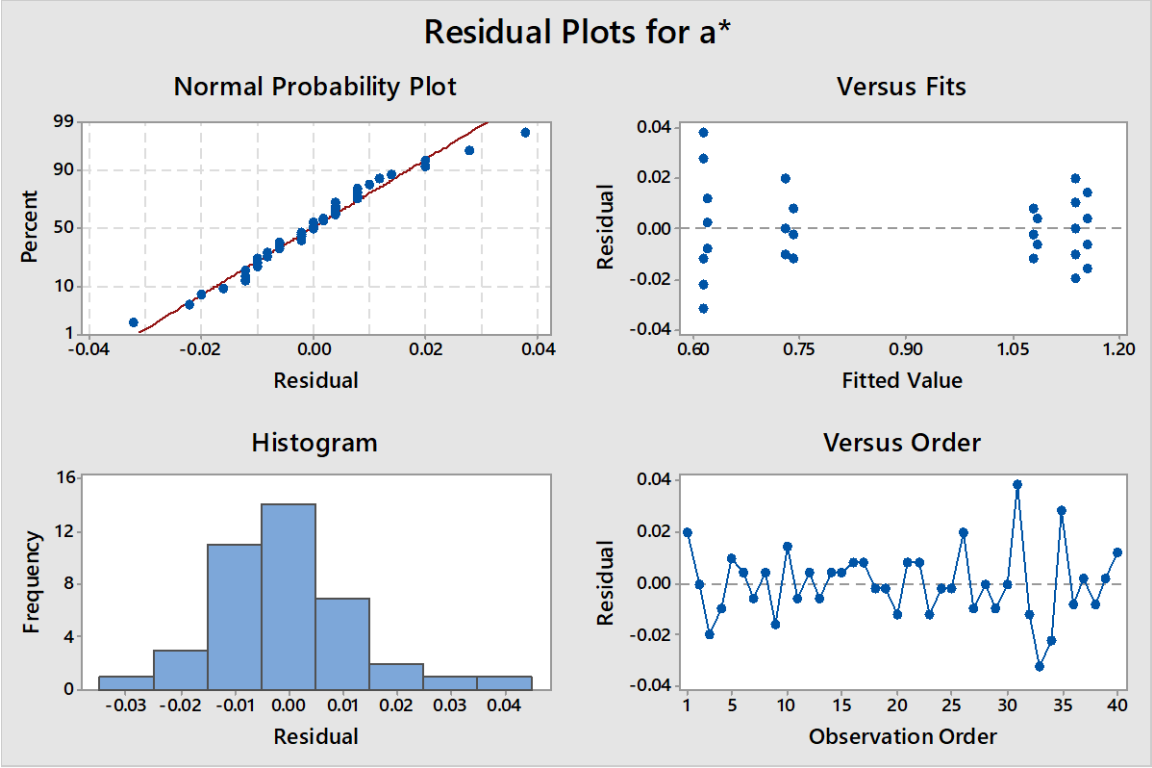

Figure G5. Residual plots for a* values of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).
Notes: n = 5.

One-way ANOVA: a* versus SLBF

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.


Factor Information

Factor  Levels  Values
Sample       8  C0, C3, C5, C7, UV0, UV3, UV5, UV7


Analysis of Variance

Source  DF   Adj SS    Adj MS  F-Value  P-Value
Sample   7  2.03522  0.290745  1336.76    0.000
Error   32  0.00696  0.000218
Total   39  2.04218


Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0147479  99.66%     99.58%      99.47%


Means

Sample  N     Mean    StDev        95% CI
C0      5  1.14000  0.01581  (1.12657, 1.15343)
C3      5  1.08600  0.00548  (1.07257, 1.09943)
C5      5  0.74200  0.00837  (0.72857, 0.75543)
C7      5   0.6120   0.0311  ( 0.5986,  0.6254)
UV0     5  1.15600  0.01140  (1.14257, 1.16943)
UV3     5  1.08200  0.00837  (1.06857, 1.09543)
UV5     5  0.73000  0.01225  (0.71657, 0.74343)
UV7     5  0.61800  0.00837  (0.60457, 0.63143)

Pooled StDev = 0.0147479
```

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Sample  N     Mean  Grouping
UV0     5  1.15600  A
C0      5  1.14000  A
C3      5  1.08600    B
UV3     5  1.08200    B
C5      5  0.74200      C
UV5     5  0.73000      C
UV7     5  0.61800        D
C7      5   0.6120        D

Means that do not share a letter are significantly different.
```

Note: C = control sample; UV = UV treated sample; 0,3,5,7 = storage period (days).

b* values (yellowness) of skinless breast fillet

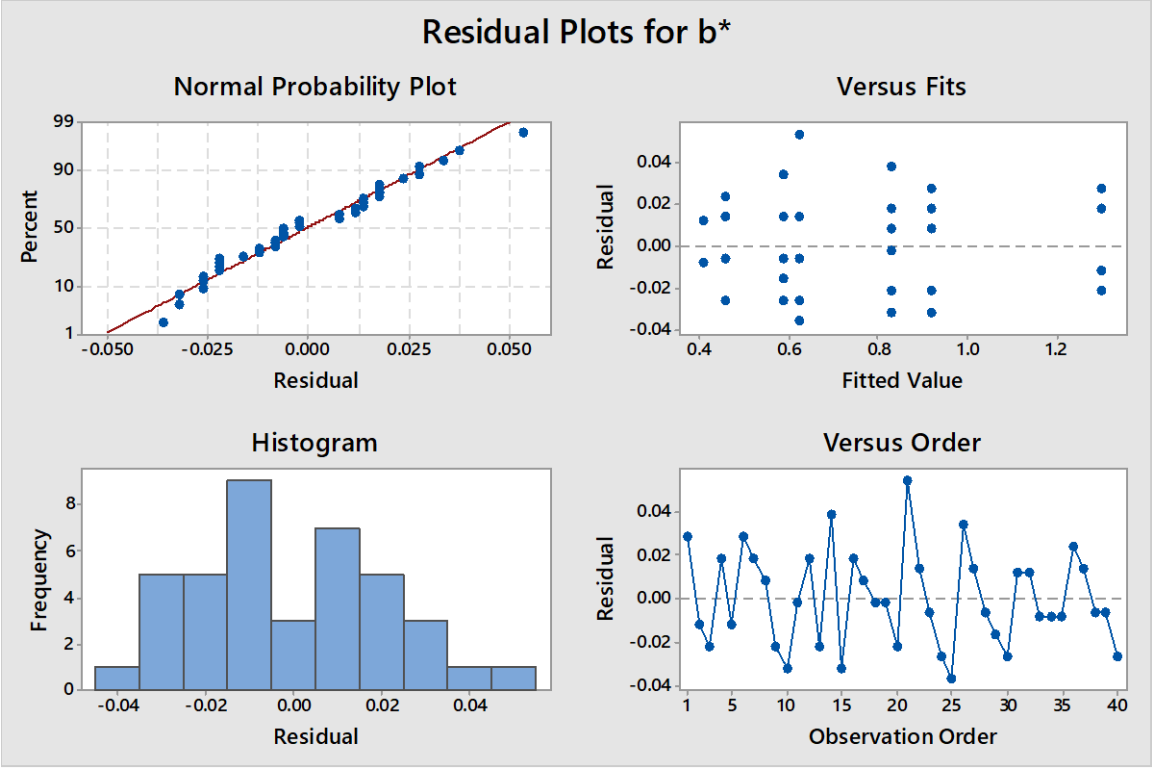

Figure G6. Residual plots for b* values of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).
Notes: n = 5.

One-way ANOVA: b* SLBF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Sample	8	C0, C3, C5, C7, UV0, UV3, UV5, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Sample	7	2.96623	0.423747	746.69	**0.000**
Error	32	0.01816	0.000567		
Total	39	2.98439			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0238223	99.39%	99.26%	99.05%

Means

Sample	N	Mean	StDev	95% CI
C0	5	1.30200	0.02168	(1.28030, 1.32370)
C3	5	0.8320	0.0286	(0.8103, 0.8537)
C5	5	0.6260	0.0358	(0.6043, 0.6477)
C7	5	0.40800	0.01095	(0.38630, 0.42970)
UV0	5	0.9220	0.0259	(0.9003, 0.9437)
UV3	5	0.83200	0.01483	(0.81030, 0.85370)
UV5	5	0.5860	0.0241	(0.5643, 0.6077)
UV7	5	0.45600	0.01949	(0.43430, 0.47770)

Pooled StDev = 0.0238223

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Sample	N	Mean	Grouping
C0	5	1.30200	A
UV0	5	0.9220	B
UV3	5	0.83200	C
C3	5	0.8320	C
C5	5	0.6260	D
UV5	5	0.5860	D
UV7	5	0.45600	E
C7	5	0.40800	E

Means that do not share a letter are significantly different.

Note: C = control sample; UV = UV treated sample; 0,3,5,7 = storage period (days).

Appendix H: Lipid oxidation data during shelf-life determination

Malonaldehyde Standard Curve

Table H1. Absorbance of different Malonaldehyde (MDA) concentration at 531 nm.

MDA Concentration (µM)	Abs 1	Abs 2	Average	SD
2	0.119	0.109	0.114	0.007
4	0.23	0.226	0.228	0.003
6	0.337	0.34	0.3385	0.002
8	0.453	0.445	0.449	0.006
10	0.563	0.566	0.5645	0.002

Notes: n = 2. MDA = Malonaldehyde.

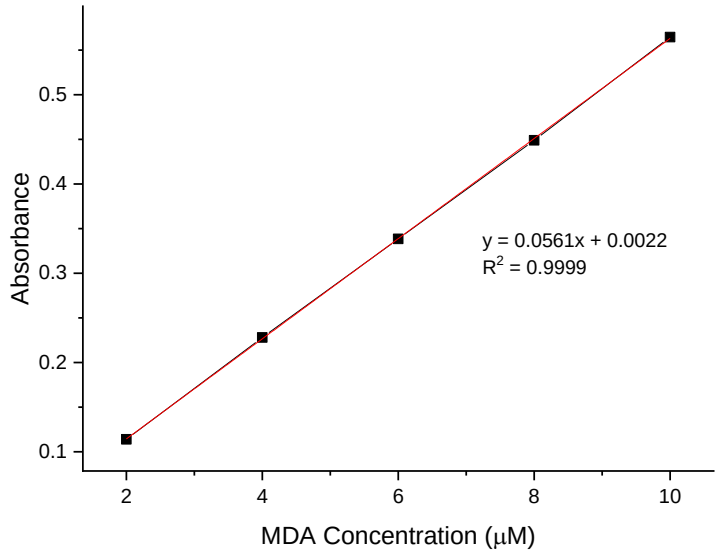

Figure H4. Malonaldehyde Standard Curve. Note: n = 2.

Table H2. TBARS value (mg MDA/kg) of fresh chicken samples.

Sample Type	Storage period	Sample	Control	UV-treated
Skin-on breast fillet	0	1	1.14	2.78
		2	2.26	3.90
		3	1.76	2.60
		Mean	1.72 ± 0.56	3.09 ± 0.70
	3	1	1.14	1.59
		2	0.94	3.71
		3	1.64	1.13
		Mean	1.24 ± 0.36	2.14 ± 1.38
	5	1	1.49	2.51
		2	1.33	2.15
		3	1.40	1.99
		Mean	1.40 ± 0.08	2.22 ± 0.27
	7	1	2.85	2.80
		2	2.08	3.06
		3	4.77	1.51
		Mean	3.23 ± 1.39	2.46 ± 0.83
Skinless breast fillet	0	1	1.86	2.14
		2	1.51	0.38
		3	2.95	1.50
		Mean	2.11 ± 0.75	1.34 ± 0.89
	3	1	0.71	0.44
		2	0.62	0.03
		3	0.42	0.19
		Mean	0.58 ± 0.14	0.22 ± 0.21
	5	1	1.09	2.33
		2	1.04	1.10
		3	0.97	1.41
		Mean	1.03 ± 0.06	1.61 ± 0.64
	7	1	2.35	1.26
		2	1.73	2.47
		3	2.33	1.47
		Mean	2.14 ± 0.35	1.73 ± 0.65

Notes: Mean values followed by standard deviation (±). n = 3.

Appendix I: Minitab output for lipid oxidation (TBARS value) during shelf-life determination

TBARS value for skin-on breast fillet

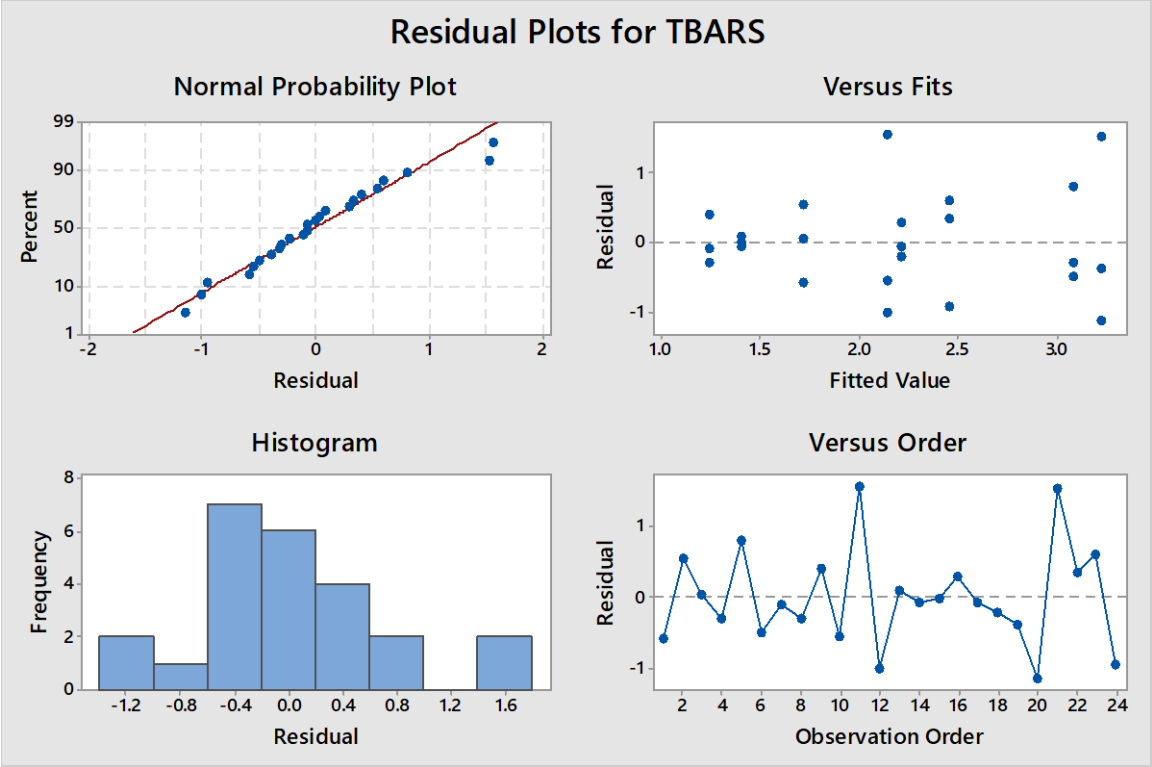

Figure I1. Residual plots for TBARS values of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).
Notes: n = 3

One-way ANOVA: TBARS versus SOBF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Sample	8	C0, C3, C5, C7, UV0, UV3, UV5, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Sample	7	11.15	1.5924	2.31	**0.079**
Error	16	11.04	0.6900		
Total	23	22.19			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.830685	50.24%	28.47%	0.00%

Means

Sample	N	Mean	StDev	95% CI
C0	3	1.720	0.561	(0.703, 2.737)
C3	3	1.240	0.361	(0.223, 2.257)
C5	3	1.4067	0.0802	(0.3900, 2.4234)
C7	3	3.233	1.385	(2.217, 4.250)
UV0	3	3.093	0.704	(2.077, 4.110)
UV3	3	2.143	1.376	(1.127, 3.160)
UV5	3	2.217	0.266	(1.200, 3.233)
UV7	3	2.457	0.830	(1.440, 3.473)

Pooled StDev = 0.830685

Note: C = control sample; UV = UV treated sample; 0,3,5,7 = storage period (days).

TBARS value for skinless breast fillet

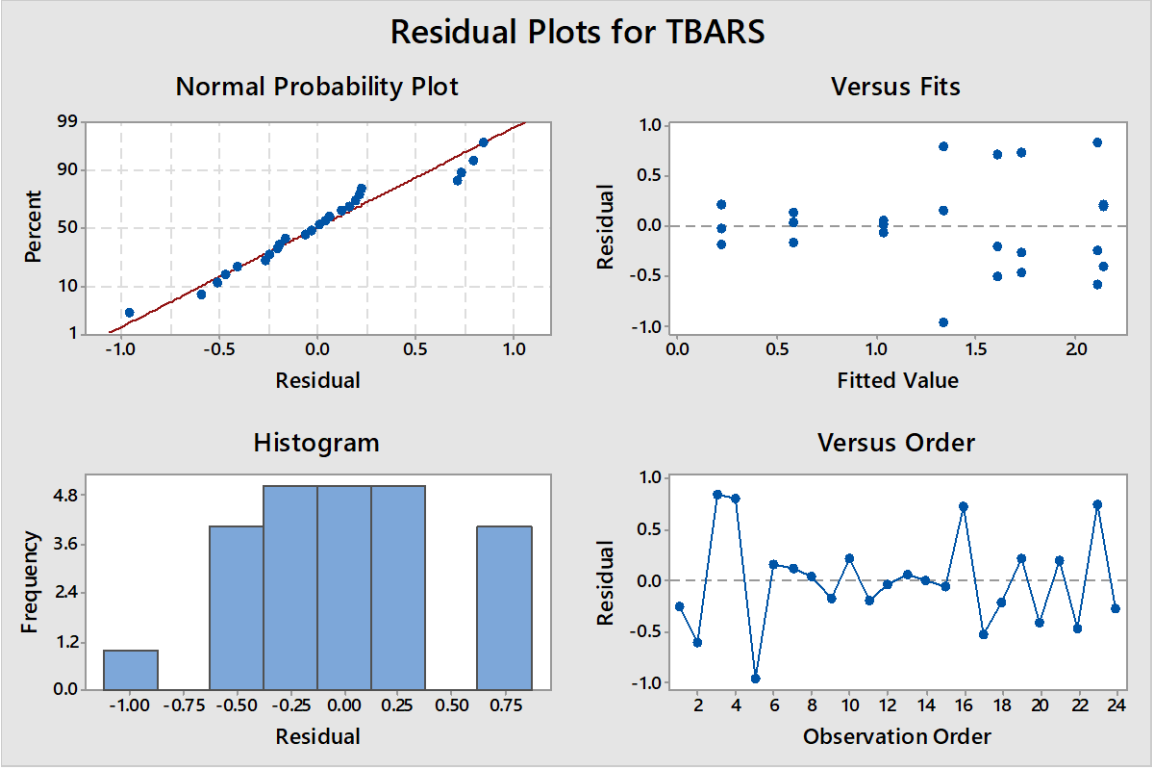

Figure I2. Residual plots for TBARS values of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).
Notes: n = 3

One-way ANOVA: TBARS versus SLBF

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.


Factor Information

Factor  Levels  Values
Sample       8  C0, C3, C5, C7, UV0, UV3, UV5, UV7

Analysis of Variance

Source  DF  Adj SS  Adj MS  F-Value  P-Value
Sample   7  10.118  1.4454     4.86    0.004
Error   16   4.755  0.2972
Total   23  14.873

Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0.545138  68.03%     54.04%      28.07%


Means

Sample  N    Mean   StDev        95% CI
C0      3   2.107   0.751  (  1.439,  2.774)
C3      3  0.5833  0.1484  (-0.0839, 1.2505)
C5      3  1.0333  0.0603  ( 0.3661, 1.7005)
C7      3   2.137   0.352  (  1.469,  2.804)
UV0     3   1.340   0.891  (  0.673,  2.007)
UV3     3   0.220   0.207  ( -0.447,  0.887)
UV5     3   1.613   0.640  (  0.946,  2.281)
UV7     3   1.733   0.647  (  1.066,  2.401)

Pooled StDev = 0.545138
```

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Sample  N    Mean  Grouping
C7      3   2.137  A
C0      3   2.107  A B
UV7     3   1.733  A B C
UV5     3   1.613  A B C
UV0     3   1.340  A B C
C5      3  1.0333  A B C
C3      3  0.5833    B C
UV3     3   0.220      C

Means that do not share a letter are significantly different.
```

Note: C = control sample; UV = UV treated sample; 0,3,5,7 = storage period (days).

Appendix J: Consumer Consent Form

PARTICIPANT CONSENT FORM

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction.

I understand that I have the right to withdraw from the study at any time and decline my answers.

I agree to voluntarily participate in this study under the conditions set out in the Information Sheet.

Signature: …… **Date**: ……

Full Name (Printed):

……

Appendix K: Sensory Evaluation Form

SENSORY ACCEPTANCE TEST

You will be given four coded samples. For each of the following characteristics, please taste the sample and indicate how much you like/dislike it by ticking **[√]** in the appropriate box. You may taste the sample more than once. Please rinse your mouth with water before and between samples.

Note: Each sample must be evaluated on a separate form

PRODUCT: Cooked Chicken Meat **SAMPLE CODE:**

Attribute	Dislike extremely	Dislike Very much	Dislike moderately	Dislike slightly	Neither Like nor dislike	Like slightly	Like Moderately	Like Very Much	Like Extremely
Appearance / colour									
Odour									
Flavour / Taste									
Texture									
Juiciness									
Overall Acceptability									

Appendix L: Consumer sensory results

Table L1. Consumer sensory values for fresh chicken samples (skinless and skin-on) stored at 4°C.

Panelist	Sample	Appearance	Odor	Flavor	Texture	Juiciness	Overall
1	874	6	9	6	4	4	5
2	874	6	7	5	6	5	5
3	874	6	7	4	4	4	4
4	874	3	6	6	3	4	3
5	874	4	7	6	4	5	4
6	874	7	7	7	6	6	7
7	874	6	5	6	5	5	5
8	874	6	5	6	5	5	6
9	874	8	7	7	6	6	6
10	874	6	7	4	4	4	4
11	874	6	5	6	5	5	5
12	874	8	7	7	6	6	6
13	874	8	7	7	6	6	6
14	874	3	6	6	3	4	3
15	874	7	8	8	6	6	7
16	874	7	8	8	6	6	7
17	874	6	5	6	5	5	5
18	874	3	6	6	3	4	3
19	874	4	5	6	4	4	4
20	874	6	6	6	5	5	5
21	874	6	6	6	5	5	5
22	874	6	9	6	4	4	5
23	874	5	7	6	6	6	5
24	874	6	6	5	5	5	5
25	874	5	5	6	7	6	6
26	874	4	6	7	7	5	5
27	874	5	5	6	6	5	5
28	874	5	3	6	5	5	5
29	874	6	6	6	5	5	5
30	874	5	5	5	5	6	4
	Mean	**5.63**	**6.27**	**6.07**	**5.03**	**5.03**	**5.00**
	SD	**1.38**	**1.31**	**0.91**	**1.10**	**0.76**	**1.08**

Table $L1_{contd}$. Consumer sensory values for fresh chicken samples (skinless and skin-on) stored at 4°C.

Panelist	Sample	Appearance	Odor	Flavor	Texture	Juiciness	Overall
1	198	6	8	7	6	8	7
2	198	6	6	5	5	6	5
3	198	6	6	4	4	4	4
4	198	6	6	7	6	6	6
5	198	6	6	7	7	6	6
6	198	6	6	8	8	7	7
7	198	6	8	5	4	4	4
8	198	6	7	5	4	4	4
9	198	7	6	6	6	6	6
10	198	6	6	4	4	4	4
11	198	6	8	5	4	4	4
12	198	7	6	6	6	6	6
13	198	7	6	6	6	6	6
14	198	6	6	7	6	6	6
15	198	8	8	8	6	6	7
16	198	8	8	8	6	6	7
17	198	6	8	5	4	4	4
18	198	6	6	8	8	7	7
19	198	6	6	7	6	6	6
20	198	6	7	7	8	7	6
21	198	6	7	7	8	7	6
22	198	6	8	7	6	8	7
23	198	5	6	7	5	6	6
24	198	7	5	8	5	7	6
25	198	6	8	8	4	4	5
26	198	6	7	7	6	5	4
27	198	5	8	6	6	5	5
28	198	5	7	6	6	6	4
29	198	6	7	6	5	5	4
30	198	7	8	6	6	6	5
	Mean	**6.20**	**6.83**	**6.43**	**5.70**	**5.73**	**5.47**
	SD	**0.71**	**0.95**	**1.19**	**1.26**	**1.20**	**1.14**

Table $L1_{contd}$. Consumer sensory values for fresh chicken samples (skinless and skin-on) stored at 4°C.

Panelist	Sample	Appearance	Odor	Flavor	Texture	Juiciness	Overall
1	602	7	8	7	5	8	7
2	602	6	6	5	5	6	6
3	602	6	6	5	5	5	5
4	602	3	5	6	4	4	4
5	602	7	5	6	4	4	4
6	602	7	5	5	7	7	7
7	602	9	8	9	9	8	9
8	602	4	6	6	5	6	6
9	602	5	8	7	6	6	7
10	602	5	6	5	5	5	5
11	602	7	8	9	9	8	9
12	602	9	8	7	6	6	7
13	602	8	8	7	6	6	7
14	602	6	5	6	4	4	4
15	602	3	8	7	7	7	7
16	602	5	8	7	7	7	7
17	602	8	8	9	9	8	9
18	602	9	7	7	6	6	7
19	602	9	5	5	7	7	7
20	602	6	8	4	3	2	3
21	602	7	8	4	3	2	4
22	602	6	8	7	5	8	7
23	602	5	5	6	5	6	6
24	602	6	4	5	6	5	5
25	602	8	6	4	5	6	4
26	602	6	5	6	7	5	6
27	602	5	4	5	6	7	6
28	602	4	3	6	5	5	6
29	602	5	5	6	6	6	5
30	602	6	5	6	5	5	7
	Mean	**6.23**	**6.30**	**6.13**	**5.73**	**5.83**	**6.10**
	SD	**1.70**	**1.58**	**1.36**	**1.55**	**1.60**	**1.56**

Table $L1_{contd}$. Consumer sensory values for fresh chicken samples (skinless and skin-on) stored at 4°C.

Panelist	Sample	Appearance	Odor	Flavor	Texture	Juiciness	Overall
1	279	6	7	4	7	7	6
2	279	5	6	5	5	5	5
3	279	1	6	5	5	5	5
4	279	4	5	6	3	4	4
5	279	3	5	3	5	2	2
6	279	5	5	4	6	6	5
7	279	6	7	7	7	8	7
8	279	6	7	7	7	8	7
9	279	4	6	8	8	8	8
10	279	4	6	5	5	5	5
11	279	7	7	7	7	8	7
12	279	6	6	8	8	8	8
13	279	7	6	8	8	8	8
14	279	7	5	6	3	4	4
15	279	6	6	7	6	7	6
16	279	7	6	7	6	7	6
17	279	8	7	7	7	8	7
18	279	8	5	4	6	6	5
19	279	9	5	6	3	4	4
20	279	6	9	8	8	8	8
21	279	7	9	8	8	8	8
22	279	6	7	4	7	7	6
23	279	6	6	6	5	5	6
24	279	6	8	7	6	6	7
25	279	6	5	6	6	5	7
26	279	8	7	5	4	4	6
27	279	7	6	7	6	5	7
28	279	8	8	7	6	6	6
29	279	7	6	5	6	6	6
30	279	8	7	6	6	5	6
	Mean	**6.13**	**6.37**	**6.10**	**6.00**	**6.10**	**6.07**
	SD	**1.70**	**1.13**	**1.42**	**1.46**	**1.65**	**1.44**

Table $L1_{contd}$. Consumer sensory values for fresh chicken samples (skinless and skin-on) stored at 4°C.

Panelist	Sample	Appearance	Odor	Flavor	Texture	Juiciness	Overall
1	930	5	5	4	1	1	2
2	930	6	8	8	6	7	7
3	930	8	8	8	8	8	8
4	930	3	7	4	2	1	3
5	930	5	4	4	4	5	4
6	930	4	5	6	3	3	4
7	930	8	9	8	7	3	7
8	930	3	4	6	6	3	5
9	930	7	7	6	4	4	6
10	930	7	7	6	4	4	6
11	930	5	4	5	4	4	4
12	930	8	5	6	2	2	5
13	930	7	7	6	6	5	6
14	930	6	6	6	5	5	6
15	930	3	5	4	4	3	3
16	930	5	7	7	6	5	5
17	930	4	5	5	5	5	4
18	930	2	3	2	3	3	3
19	930	5	5	5	1	1	3
20	930	5	7	5	4	3	4
21	930	7	5	4	3	7	5
22	930	6	5	6	4	5	6
23	930	8	5	8	7	6	7
24	930	4	5	4	4	4	4
25	930	6	6	6	6	6	6
26	930	6	7	5	6	6	5
27	930	5	5	6	5	4	5
28	930	5	6	6	6	6	6
29	930	6	5	5	4	5	5
30	930	5	5	5	6	6	5
	Mean	**5.47**	**5.73**	**5.53**	**4.53**	**4.33**	**4.97**
	SD	**1.61**	**1.39**	**1.41**	**1.76**	**1.81**	**1.43**

Table $L1_{contd}$. Consumer sensory values for fresh chicken samples (skinless and skin-on) stored at 4°C.

Panelist	Sample	Appearance	Odor	Flavor	Texture	Juiciness	Overall
1	839	8	7	2	9	9	6
2	839	6	8	8	7	8	8
3	839	4	6	2	2	2	2
4	839	4	6	6	4	2	4
5	839	7	6	4	3	5	6
6	839	5	7	7	7	5	6
7	839	4	1	5	6	3	5
8	839	7	5	6	4	4	5
9	839	6	5	5	4	4	6
10	839	6	5	5	4	4	6
11	839	7	6	6	7	7	7
12	839	6	5	5	2	2	5
13	839	5	7	5	4	2	5
14	839	5	5	7	6	6	6
15	839	4	6	7	6	5	6
16	839	5	6	6	5	7	6
17	839	8	8	7	7	7	8
18	839	5	5	5	2	2	4
19	839	2	2	2	2	2	2
20	839	6	7	5	7	7	6
21	839	7	4	5	7	6	6
22	839	5	6	4	2	5	4
23	839	4	5	4	4	6	4
24	839	3	5	4	3	3	3
25	839	7	7	8	7	6	7
26	839	6	6	7	6	6	6
27	839	5	5	6	5	5	5
28	839	6	6	8	4	6	5
29	839	6	7	8	4	4	6
30	839	7	7	7	3	4	5
	Mean	**5.53**	**5.70**	**5.53**	**4.77**	**4.80**	**5.33**
	SD	**1.43**	**1.51**	**1.74**	**1.96**	**1.97**	**1.45**

Table $L1_{contd}$. Consumer sensory values for fresh chicken samples (skinless and skin-on) stored at 4°C.

Panelist	Sample	Appearance	Odor	Flavor	Texture	Juiciness	Overall
1	120	7	5	6	4	4	4
2	120	6	8	8	7	6	7
3	120	6	7	7	7	6	6
4	120	4	5	6	3	1	3
5	120	4	7	7	6	5	7
6	120	8	6	7	7	6	7
7	120	8	8	8	9	9	9
8	120	5	6	6	4	3	5
9	120	7	5	6	6	6	6
10	120	6	5	6	6	6	6
11	120	8	6	7	7	7	7
12	120	7	7	7	4	2	7
13	120	7	7	6	6	3	5
14	120	4	7	6	5	6	6
15	120	7	8	7	4	2	5
16	120	7	2	6	6	6	4
17	120	8	8	7	7	5	7
18	120	7	9	3	5	5	5
19	120	8	9	3	5	5	5
20	120	4	7	6	6	6	6
21	120	4	6	6	4	6	6
22	120	7	6	4	5	2	4
23	120	6	5	6	8	8	7
24	120	5	6	5	6	5	6
25	120	5	7	7	7	7	7
26	120	6	6	5	5	7	6
27	120	4	6	5	4	5	5
28	120	5	5	5	5	6	6
29	120	6	3	5	6	5	4
30	120	6	4	6	6	4	5
	Mean	**6.07**	**6.20**	**5.97**	**5.67**	**5.13**	**5.77**
	SD	**1.39**	**1.61**	**1.22**	**1.37**	**1.85**	**1.28**

Table $L1_{contd}$. Consumer sensory values for fresh chicken samples (skinless and skin-on) stored at 4°C.

Panelist	Sample	Appearance	Odor	Flavor	Texture	Juiciness	Overall
1	058	4	5	5	3	3	2
2	058	6	7	6	4	4	6
3	058	6	5	1	1	1	2
4	058	4	5	6	4	2	4
5	058	4	6	3	3	5	3
6	058	6	5	5	3	3	4
7	058	8	7	9	9	9	8
8	058	8	4	4	6	3	6
9	058	6	5	6	6	4	5
10	058	6	5	6	6	6	6
11	058	8	6	7	7	6	6
12	058	6	6	5	2	5	6
13	058	6	7	4	4	3	4
14	058	4	6	5	4	4	5
15	058	6	5	3	4	4	4
16	058	6	7	7	7	7	7
17	058	8	8	7	6	4	7
18	058	6	8	5	5	6	6
19	058	4	9	5	8	6	5
20	058	8	7	6	7	7	7
21	058	8	6	7	7	7	7
22	058	4	6	6	6	4	6
23	058	7	6	7	6	5	6
24	058	6	5	9	5	5	6
25	058	7	6	9	8	6	6
26	058	7	7	8	8	6	8
27	058	6	6	7	7	8	7
28	058	5	7	7	7	7	7
29	058	6	8	8	8	6	7
30	058	6	6	7	8	8	8
	Mean	**6.07**	**6.20**	**6.00**	**5.63**	**5.13**	**5.70**
	SD	**1.34**	**1.16**	**1.86**	**2.04**	**1.89**	**1.62**

Notes: 874 = Untreated SOBF day 1; 198 = UV-C treated SOBF day 1; 602 = Untreated SLBF day 1; 279 = UV-C treated SLBF day 1; 930 = Untreated SOBF day 7; 839 = UV-C treated SOBF day 7; 120 = Untreated SLBF day 7; 058 = UV-C treated SLBF day 7. n = 60.

Appendix M: Minitab output for consumer sensory scores

Appearance of skin-on breast fillet

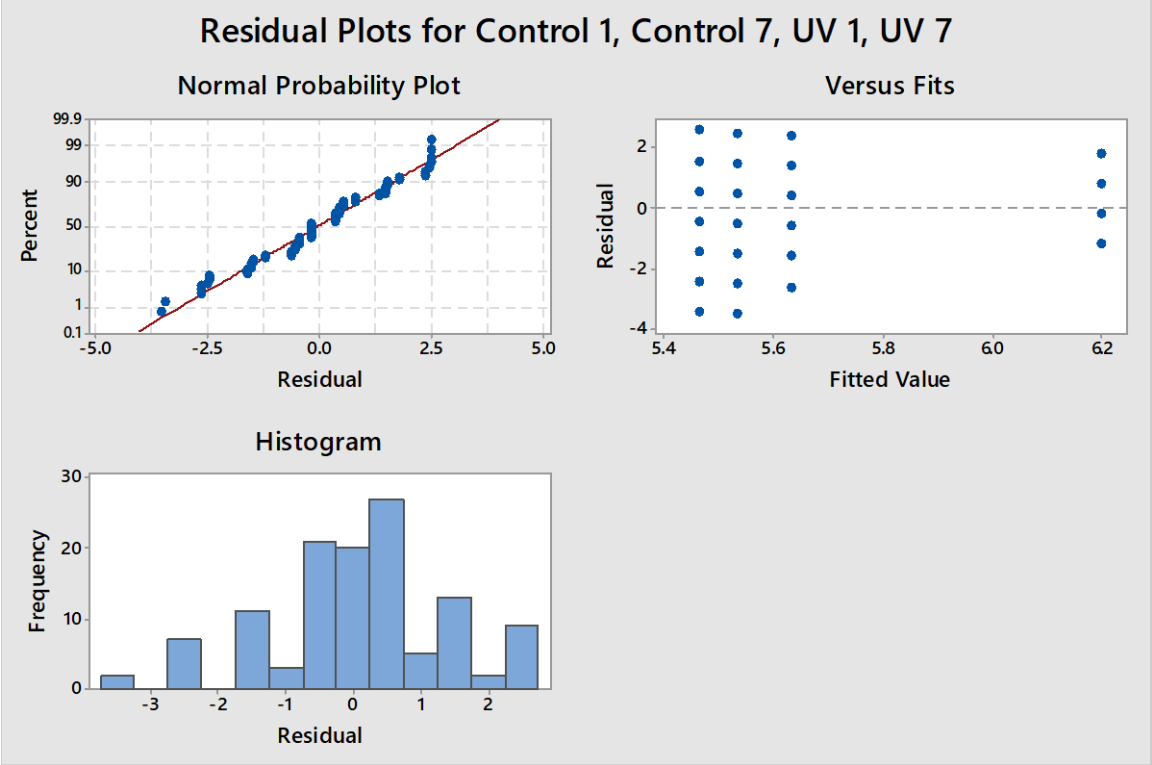

Figure M1. Residual plots for appearance sensory scores of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	Control 1, Control 7, UV 1, UV 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	10.09	3.364	1.91	**0.132**
Error	116	204.70	1.765		
Total	119	214.79			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.32840	4.70%	2.23%	0.00%

Means

Factor	N	Mean	StDev	95% CI
Control 1	30	5.633	1.377	(5.153, 6.114)
Control 7	30	5.467	1.613	(4.986, 5.947)
UV 1	30	6.200	0.714	(5.720, 6.680)
UV 7	30	5.533	1.432	(5.053, 6.014)

Pooled StDev = 1.32840

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Odor of skin-on breast fillet

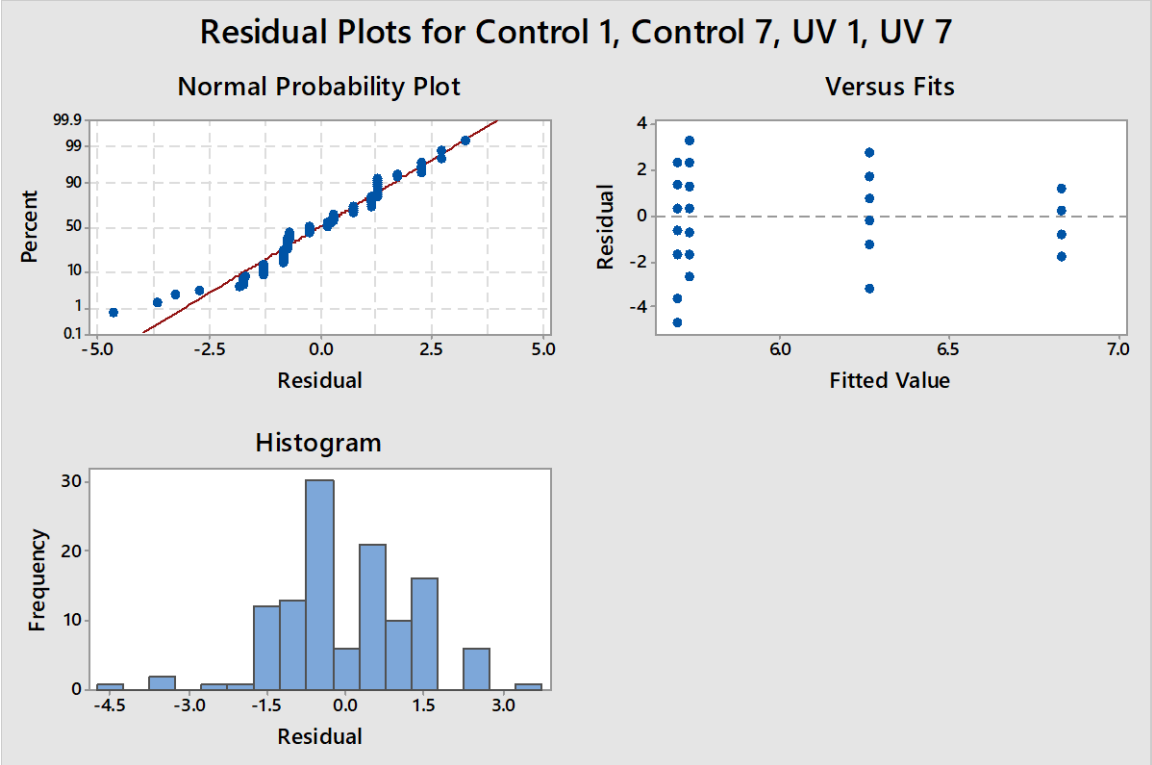

Figure M2. Residual plots for odor sensory scores of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	Control 1, Control 7, UV 1, UV 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	25.67	8.556	5.01	**0.003**
Error	116	198.20	1.709		
Total	119	223.87			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.30714	11.47%	9.18%	5.25%

Means

Factor	N	Mean	StDev	95% CI
Control 1	30	6.267	1.311	(5.794, 6.739)
Control 7	30	5.733	1.388	(5.261, 6.206)
UV 1	30	6.833	0.950	(6.361, 7.306)
UV 7	30	5.700	1.512	(5.227, 6.173)

Pooled StDev = 1.30714

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
UV 1	30	6.833	A
Control 1	30	6.267	A B
Control 7	30	5.733	B
UV 7	30	5.700	B

Means that do not share a letter are significantly different.

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Flavor of skin-on breast fillet

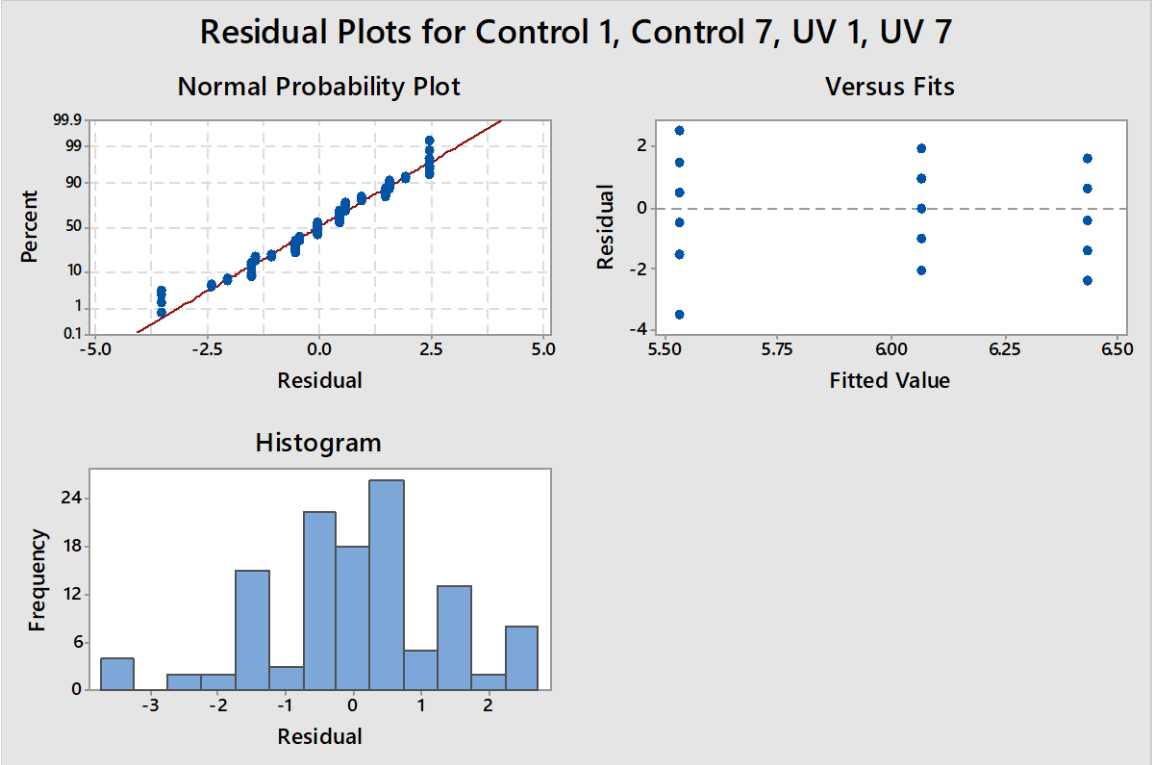

Figure M3. Residual plots for flavor sensory scores of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	Control 1, Control 7, UV 1, UV 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	17.43	5.808	3.21	**0.026**
Error	116	210.17	1.812		
Total	119	227.59			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.34602	7.66%	5.27%	1.18%

Means

Factor	N	Mean	StDev	95% CI
Control 1	30	6.067	0.907	(5.580, 6.553)
Control 7	30	5.533	1.408	(5.047, 6.020)
UV 1	30	6.433	1.194	(5.947, 6.920)
UV 7	30	5.533	1.737	(5.047, 6.020)

Pooled StDev = 1.34602

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
UV 1	30	6.433	A
Control 1	30	6.067	A
UV 7	30	5.533	A
Control 7	30	5.533	A

Means that do not share a letter are significantly different.

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Texture of skin-on breast fillet

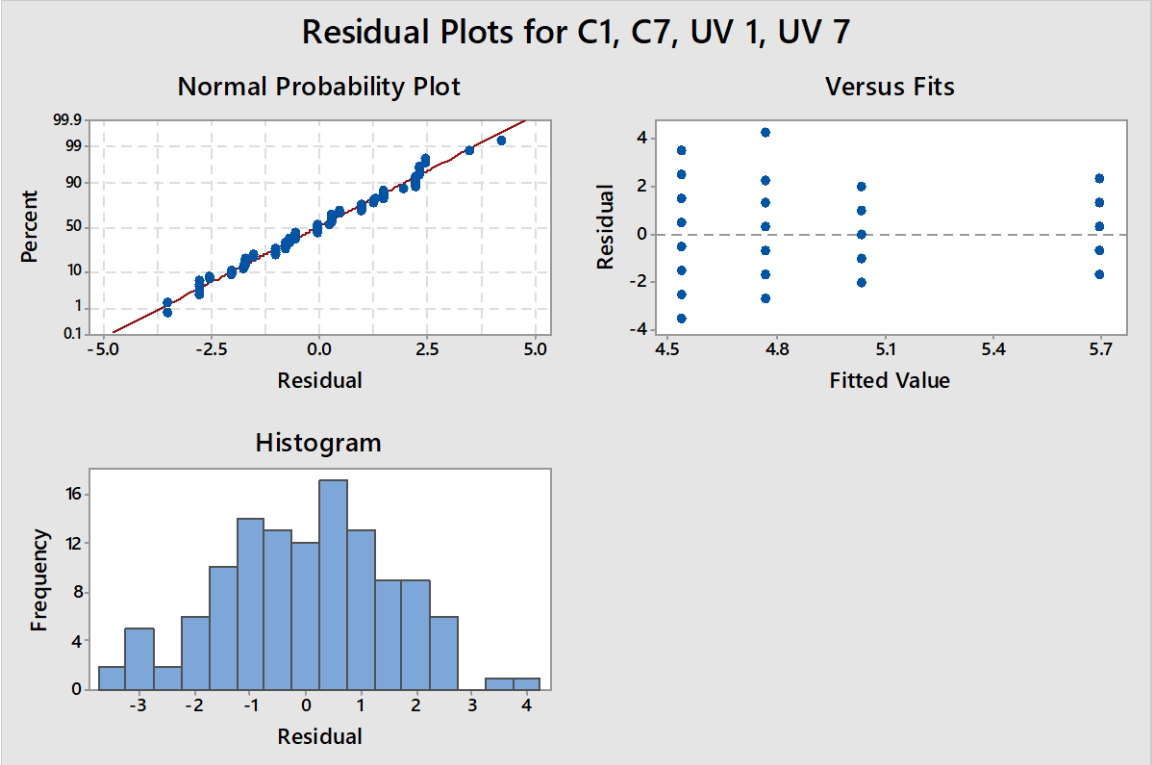

Figure M4. Residual plots for texture sensory scores of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV 1, UV 7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	22.89	7.631	3.14	**0.028**
Error	116	282.10	2.432		
Total	119	304.99			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.55945	7.51%	5.11%	1.02%

Means

Factor	N	Mean	StDev	95% CI
C1	30	5.033	1.098	(4.469, 5.597)
C7	30	4.533	1.756	(3.969, 5.097)
UV 1	30	5.700	1.264	(5.136, 6.264)
UV 7	30	4.767	1.960	(4.203, 5.331)

Pooled StDev = 1.55945

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
UV 1	30	5.700	A
C1	30	5.033	A B
UV 7	30	4.767	A B
C7	30	4.533	B

Means that do not share a letter are significantly different.

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Juiciness of skin-on breast fillet

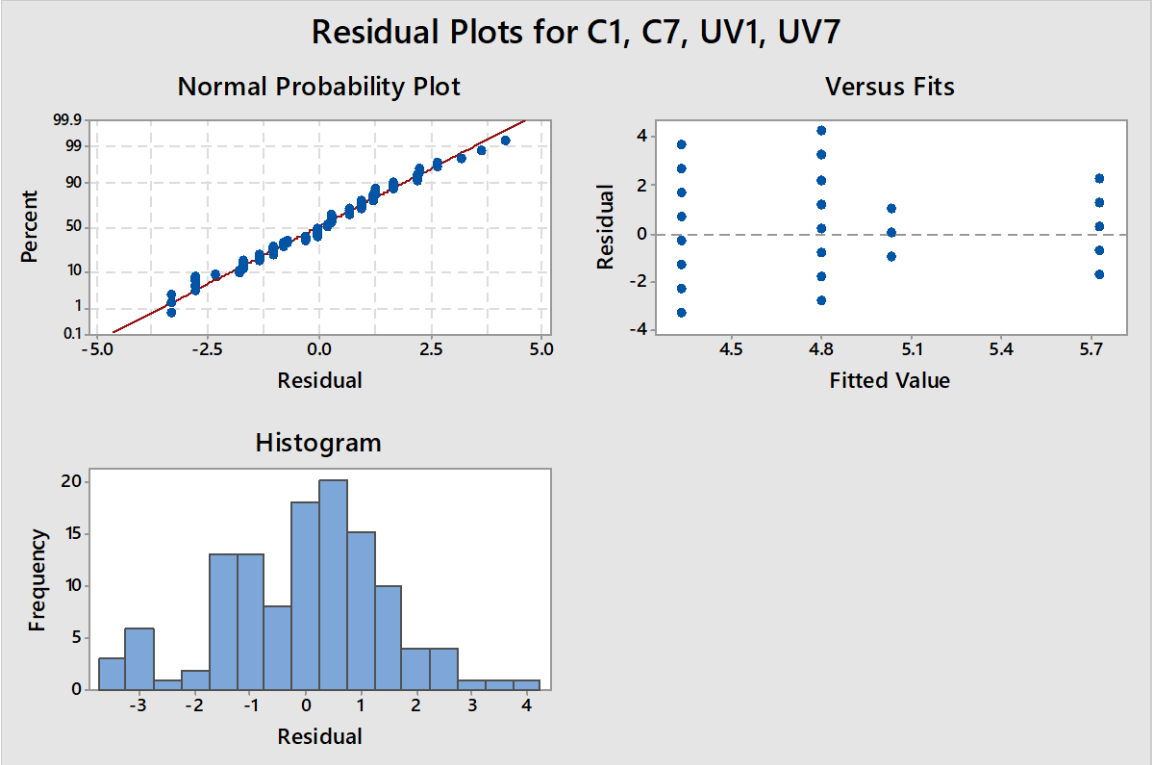

Figure M5. Residual plots for juiciness sensory scores of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV1, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	30.63	10.208	4.45	**0.005**
Error	116	266.30	2.296		
Total	119	296.93			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.51515	10.31%	7.99%	4.02%

Means

Factor	N	Mean	StDev	95% CI
C1	30	5.033	0.765	(4.485, 5.581)
C7	30	4.333	1.807	(3.785, 4.881)
UV1	30	5.733	1.202	(5.185, 6.281)
UV7	30	4.800	1.972	(4.252, 5.348)

Pooled StDev = 1.51515

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
UV1	30	5.733	A
C1	30	5.033	A B
UV7	30	4.800	A B
C7	30	4.333	B

Means that do not share a letter are significantly different.

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Overall of skin-on breast fillet

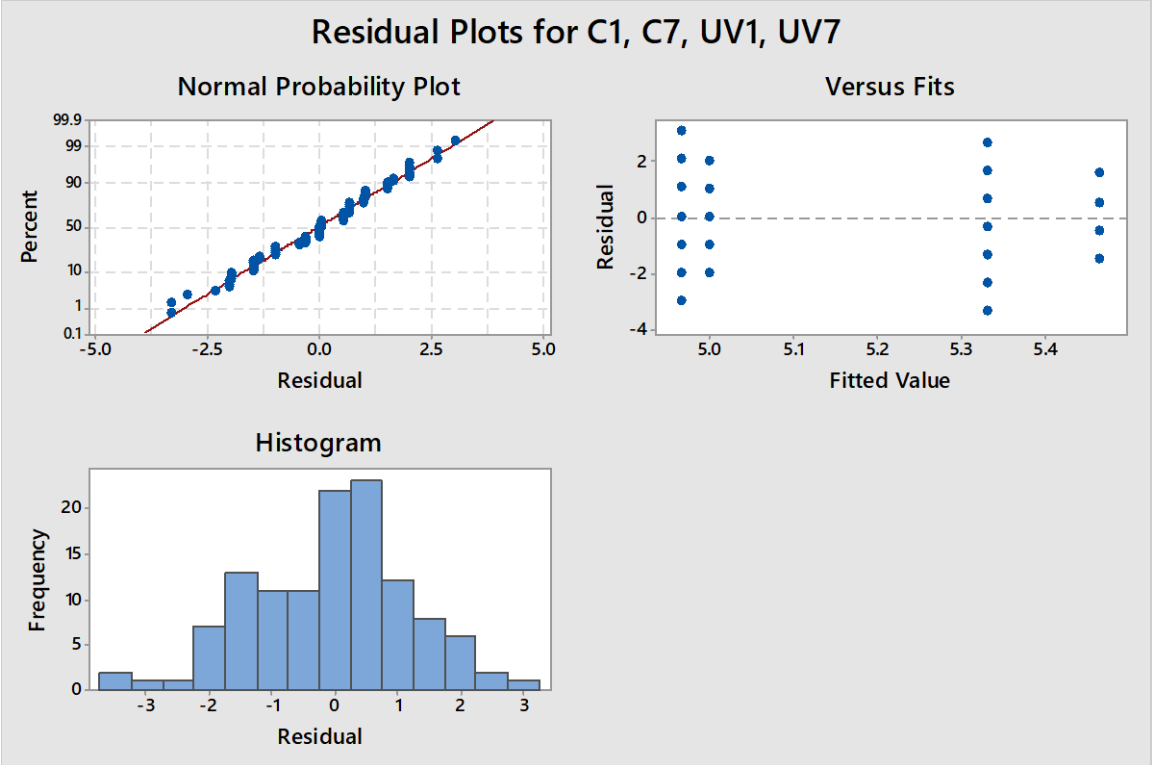

Figure M6. Residual plots for overall sensory scores of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV1, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	5.492	1.831	1.11	**0.348**
Error	116	191.100	1.647		
Total	119	196.592			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.28352	2.79%	0.28%	0.00%

Means

Factor	N	Mean	StDev	95% CI
C1	30	5.000	1.083	(4.536, 5.464)
C7	30	4.967	1.426	(4.503, 5.431)
UV1	30	5.467	1.137	(5.003, 5.931)
UV7	30	5.333	1.446	(4.869, 5.797)

Pooled StDev = 1.28352

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Appearance of skinless breast fillet

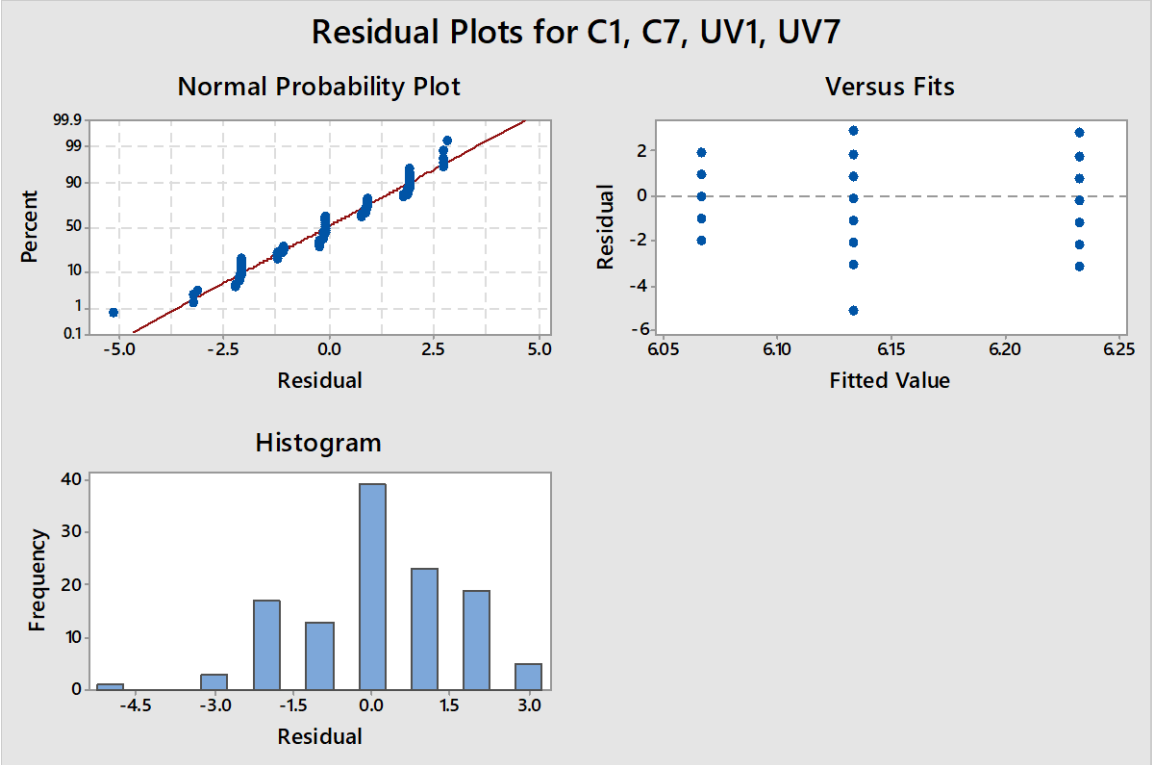

Figure M7. Residual plots for appearance sensory scores of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV1, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	0.558	0.1861	0.08	**0.971**
Error	116	274.567	2.3670		
Total	119	275.125			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.53849	0.20%	0.00%	0.00%

Means

Factor	N	Mean	StDev	95% CI
C1	30	6.233	1.695	(5.677, 6.790)
C7	30	6.067	1.388	(5.510, 6.623)
UV1	30	6.133	1.697	(5.577, 6.690)
UV7	30	6.067	1.337	(5.510, 6.623)

Pooled StDev = 1.53849

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Odor of skinless breast fillet

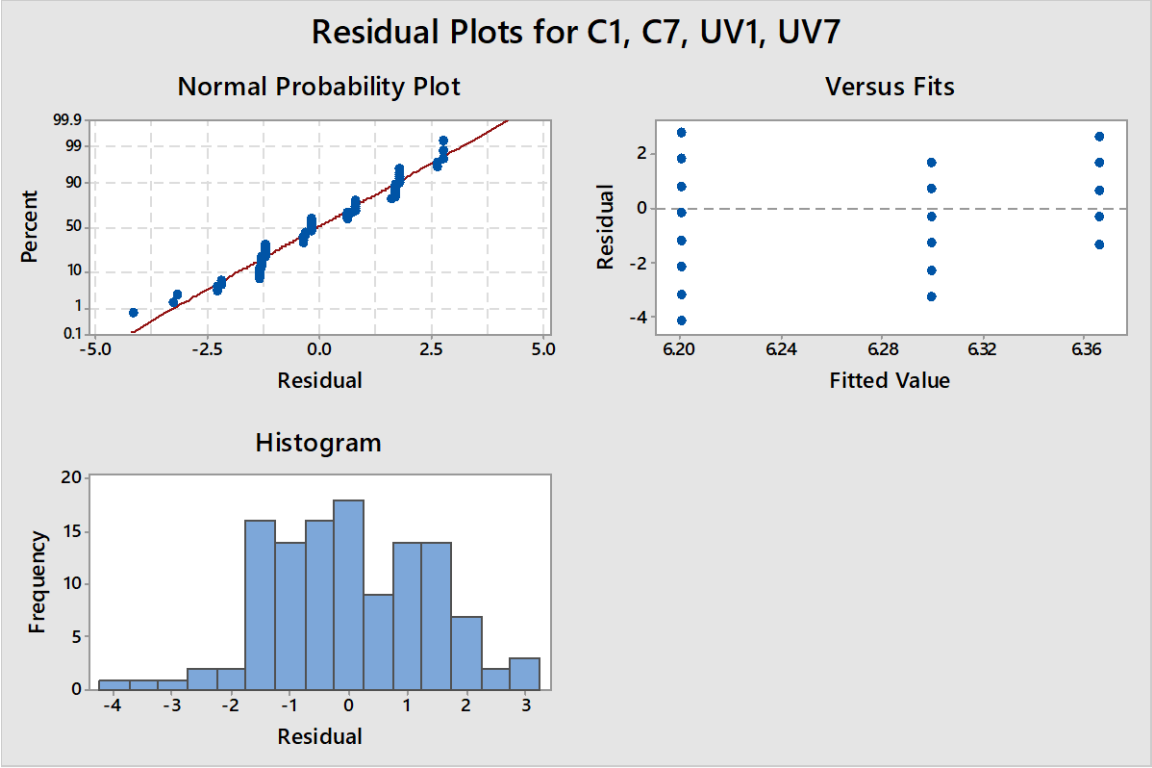

Figure M8. Residual plots for odor sensory scores of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV1, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	0.600	0.2000	0.10	**0.958**
Error	116	222.867	1.9213		
Total	119	223.467			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.38610	0.27%	0.00%	0.00%

Means

Factor	N	Mean	StDev	95% CI
C1	30	6.300	1.579	(5.799, 6.801)
C7	30	6.200	1.606	(5.699, 6.701)
UV1	30	6.367	1.129	(5.865, 6.868)
UV7	30	6.200	1.157	(5.699, 6.701)

Pooled StDev = 1.38610

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Flavor of skinless breast fillet

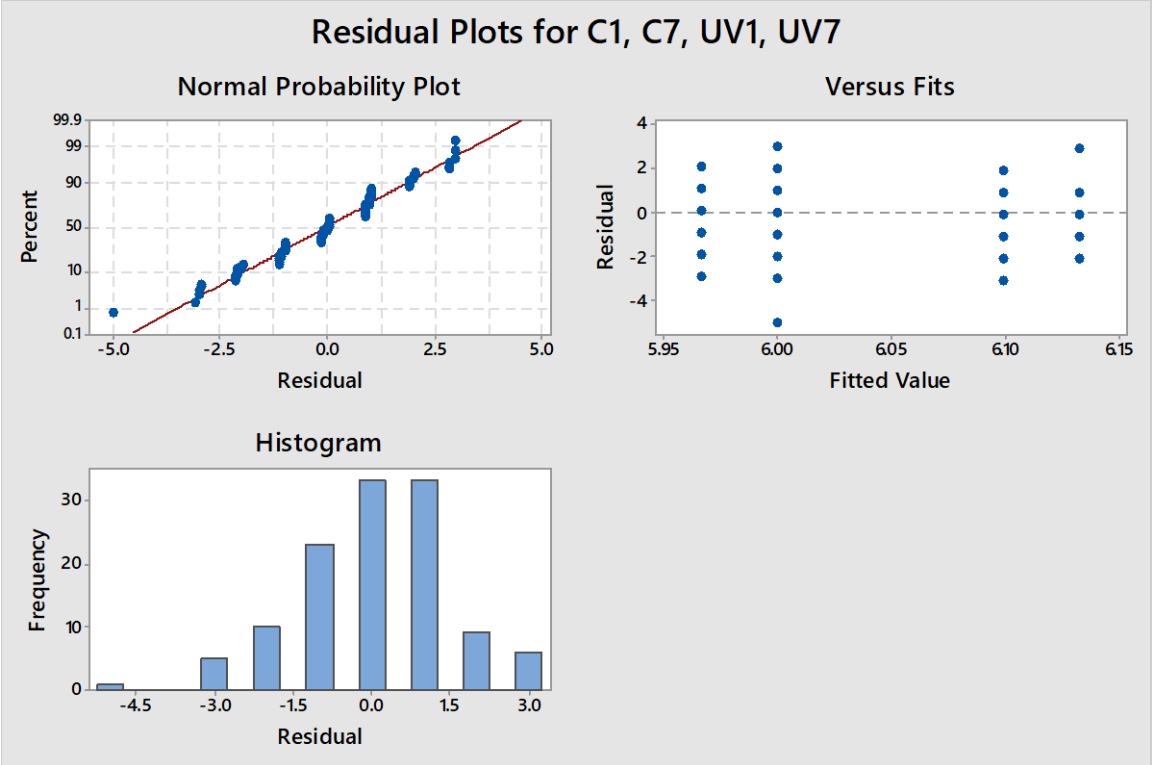

Figure M9. Residual plots for flavor sensory scores of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV1, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	0.567	0.1889	0.09	**0.968**
Error	116	255.133	2.1994		
Total	119	255.700			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.48305	0.22%	0.00%	0.00%

Means

Factor	N	Mean	StDev	95% CI
C1	30	6.133	1.358	(5.597, 6.670)
C7	30	5.967	1.217	(5.430, 6.503)
UV1	30	6.100	1.423	(5.564, 6.636)
UV7	30	6.000	1.857	(5.464, 6.536)

Pooled StDev = 1.48305

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Texture of skinless breast fillet

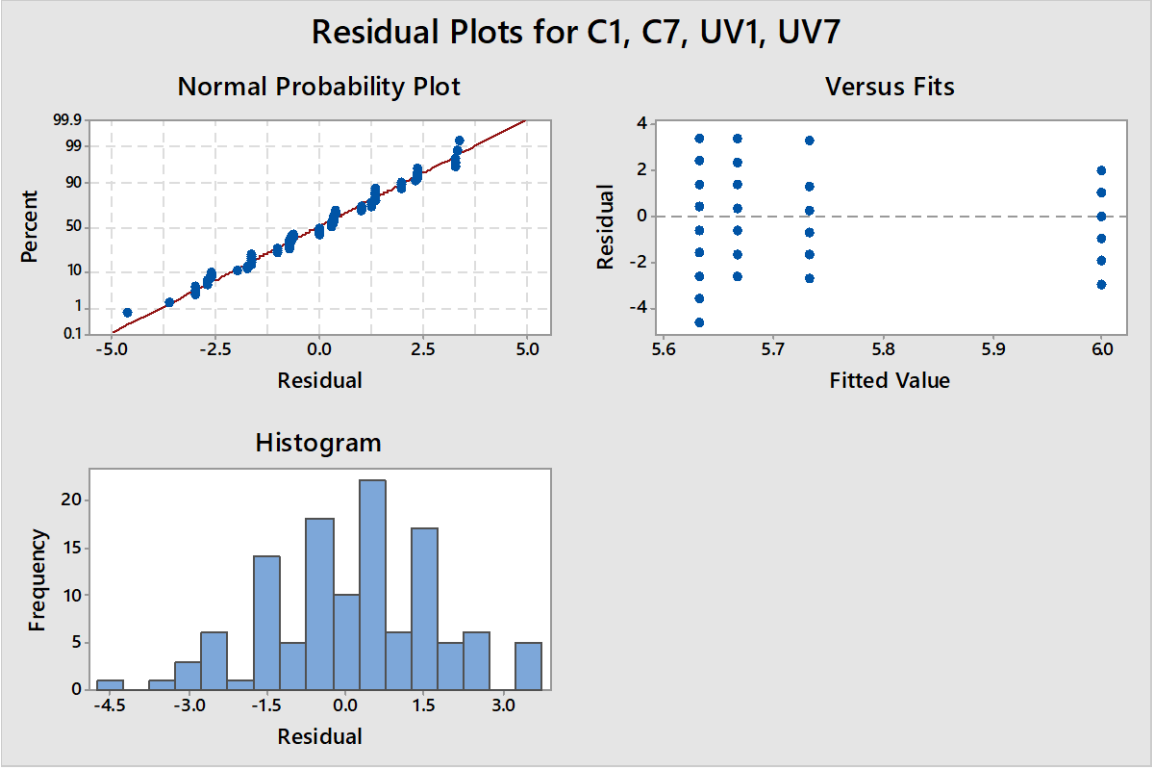

Figure M10. Residual plots for texture sensory scores of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV1, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	2.492	0.8306	0.31	**0.816**
Error	116	307.500	2.6509		
Total	119	309.992			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.62815	0.80%	0.00%	0.00%

Means

Factor	N	Mean	StDev	95% CI
C1	30	5.733	1.552	(5.145, 6.322)
C7	30	5.667	1.373	(5.078, 6.255)
UV1	30	6.000	1.462	(5.411, 6.589)
UV7	30	5.633	2.042	(5.045, 6.222)

Pooled StDev = 1.62815

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Juiciness of skinless breast fillet

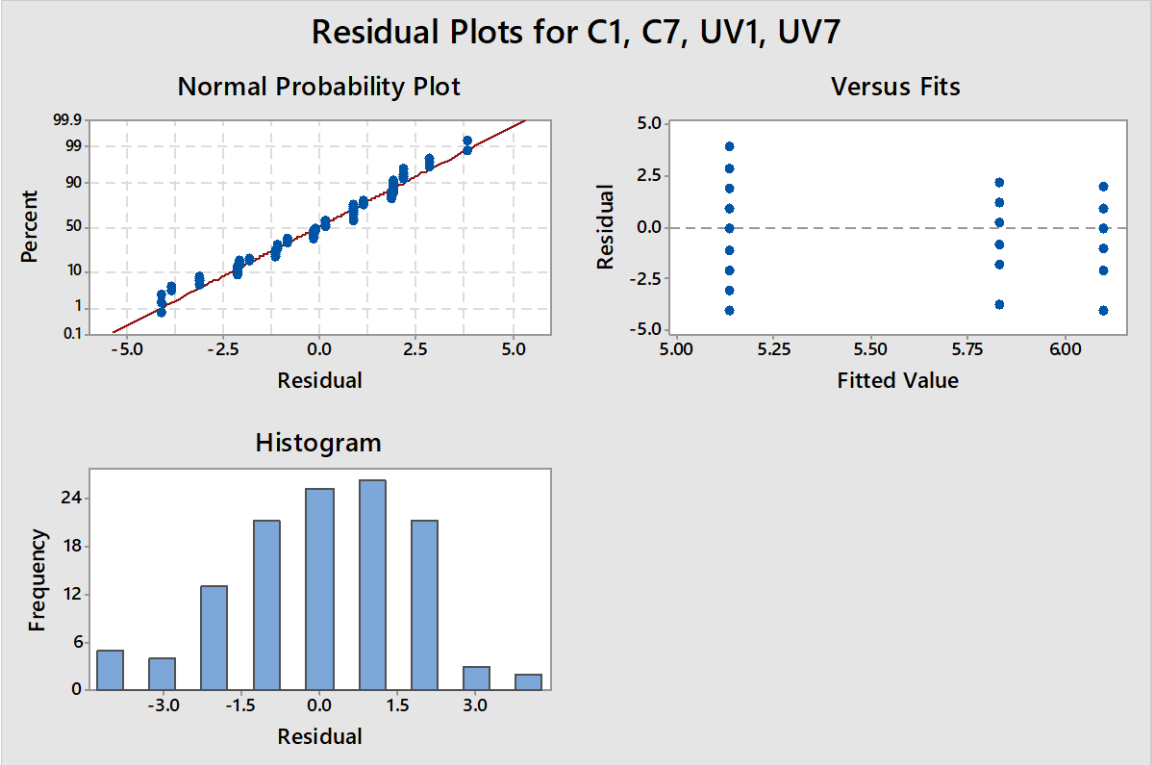

Figure M11. Residual plots for juiciness sensory scores of skinless breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV1, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	21.90	7.300	2.38	**0.073**
Error	116	355.80	3.067		
Total	119	377.70			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.75135	5.80%	3.36%	0.00%

Means

Factor	N	Mean	StDev	95% CI
C1	30	5.833	1.599	(5.200, 6.467)
C7	30	5.133	1.852	(4.500, 5.767)
UV1	30	6.100	1.647	(5.467, 6.733)
UV7	30	5.133	1.889	(4.500, 5.767)

Pooled StDev = 1.75135

Note: Control = Untreated control sample; UV = UV treated sample; 1 and 7 = storage time point (days)

Overall of skinless breast fillet

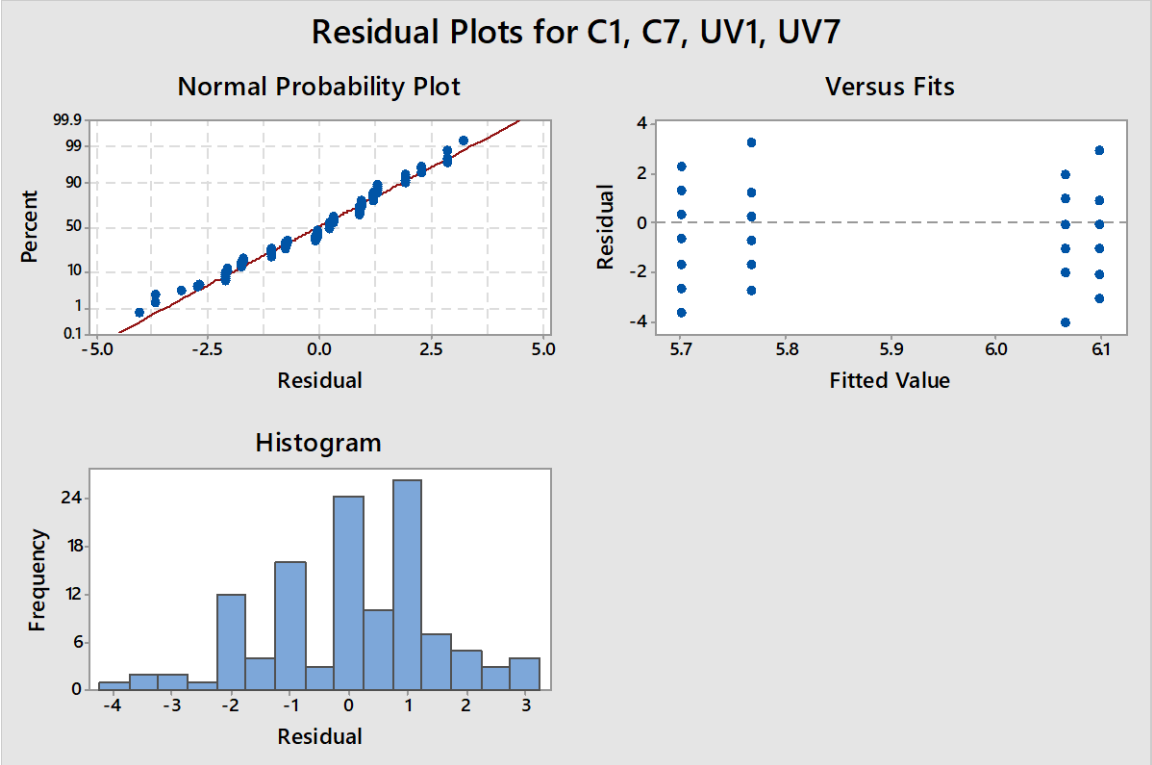

Figure M12. Residual plots for overall sensory scores of skin-on breast fillet generated by Minitab 17 (Minitab Inc., USA, 2009).

One-way ANOVA: Control (day 1 and day 7) and UV-C treated (day 1 and day 7)

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	C1, C7, UV1, UV7

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	**P-Value**
Factor	3	3.758	1.253	0.57	**0.635**
Error	116	254.233	2.192		
Total	119	257.992			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.48043	1.46%	0.00%	0.00%

Means

Factor	N	Mean	StDev	95% CI
C1	30	6.100	1.561	(5.565, 6.635)
C7	30	5.767	1.278	(5.231, 6.302)
UV1	30	6.067	1.437	(5.531, 6.602)
UV7	30	5.700	1.622	(5.165, 6.235)

Pooled StDev = 1.48043

Note: C = Untreated control sample; UV = UV-C treated sample; 1 and 7 = storage time point (days)