MICROWAVE-ASSISTED BLANCHING EFFECTS ON THE FRYING QUALITY OF SWEET POTATO: ANN MODELLING OF FRYING KINETICS

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DECLARATION

I, Ayooluwa Samuel AYOOLA a M.Eng. student in the Department of Agricultural and Biosystems Engineering, Landmark University, Omu-Aran, hereby declare that this thesis entitled "Microwave-Assisted Blanching Effects on The Frying Quality of Sweet Potato: ANN Modelling of Frying Kinetics" submitted by me is based on my original work. Any material(s) obtained from other sources or work done by any other persons or institutions have been duly acknowledged.

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CERTIFICATION

This is to certify that this thesis has been read and approved as meeting the requirements of the Department of Agricultural and Biosystems Engineering, Landmark University, Omu-Aran, Nigeria, for the award of M.Eng. in Agricultural Engineering.

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DEDICATION

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ABSTRACT

Deep frying of Sweet potato chips is often associated with high oil uptake which raises so many health concerns. Several pre-treatment methods have been found to decrease oil uptake. This study evaluated the effects of microwave-assisted blanching techniques on the frying kinetics and quality characteristics of sweet potato chips. Also, the frying kinetics were modelled with both mathematical models and artificial neural networks (ANN). Microwave blanching (MW), hot water + microwave blanching (HWMW) and osmotic dehydration + microwave blanching (OSMW) pre-treatments of potato chips were done while untreated samples were used as control (CT). The frying temperatures were at 130,150 and 170°C for 2, 4, 6, 8 and 10 minutes. The moisture ratio (MR) was fitted to 11 empirical models and the oil uptake was fitted to 5 empirical models. The model performance was also compared with ANN modelling. The results showed that ANN performed better in fitting the moisture ratio and oil uptake with $R^2 = 0.9$, RMSE= 1.034 and SSE= 0.131301864 while the Middili model had the best fit with $R^2 = 1$, RMSE= 0.002559 and SSE= 0.00001309 among the mathematical models used. HWMW pre-treated samples had the lowest moisture ratio of 0.376 (10 minutes of frying), while OSMW had the lowest oil uptake of 1.9% (8 minutes of frying) at temperatures of 170°C and 130°C respectively. At 150°C and 170°C, all pre-treated samples had higher k values than the untreated sample. Effective moisture diffusivity ranged from 1.212 $\times 10^{-6}$ to 9.999×10^{-7} m^2/s and highest activation energy of 117.14KJ/mol was found at OSMW. Oil uptake of the control sample ranged from 5.4% to 69.2% all through this study. This was significantly reduced as a result of the pre-treatment methods adopted. MW, HWMW and OSMW pre-treated sweet potato chips had oil uptake from 5.2% to 37.4%, 6.4% to 39.4% and 1.9% to 52.6% respectively. Statistical analysis showed that microwave-assisted blanching pre-treatments had significant effects ($p<0.05$) on the quality characteristics (colour, texture, ascorbic acid, microstructure, electrolyte leakage, shrinkage) of the fried sweet potatoes. Samples pre-treated with osmotic dehydration combined with microwave-assisted blanching had higher significant effects on quality characteristics compared to other pre-treated and untreated samples. OSMW (170°C) sample had the highest hardness value (13.841g/mm). The study also showed that the electrical conductivity of the fried samples at all frying conditions increased with increase in frying temperature, the OSMW (170°C) had the highest electrical conductivity of 200.67 µs/cm while CT

(170°C) had the lowest electrical conductivity 159 µs/cm. Microwave-assisted blanching pre-treatments had significant effects on the ascorbic acid value retention while CT had the least retention. Bulk density of fried samples also ranged from 0.44 to 0.53g/cm^3. Microstructure analysis revealed that the untreated samples had the highest oil retention in comparison with the pre-treated samples. Furthermore, the colour difference values of the samples also increased as the frying temperature increased. OSMW (170°C) sample had the highest colour difference of 49.49 while the control sample had the lowest colour difference of 33.46. Shrinkage values for the deep-fried sweet potatoes ranged from 5.7mm to 27.6mm. In all, the OSMW had better frying characteristics and is thus recommended for industrial purposes. Recommendations were made for further study on other potato varieties.

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CHAPTER 1

1. INTRODUCTION

1.1 Background to the study

1.1.1 Sweet Potato (*Ipomoea batatas*)

The sweet potato (*Ipomoea batatas L.*) is a member of the *Convolvulaceae* family. It is one of the most widely consumed tuber crops in the world (FAOSTAT, 2017). Sweet potatoes are high in starch, protein, dietary fibre, phenolic, vitamins and minerals, among other nutrients, but have a low fat content. Sweet potatoes also have physiological properties, such as blood glucose and cholesterol regulation, boosting immunity, guarding against cancer, oxidation and so on, which has resulted in it receiving a lot more attention and research in recent years (Wang *et al*., 2016).

Sweet potato is the most important food crop, after rice, wheat, cassava, maize and rice (Shekhar *et al*., 2015). Sweet potatoes are grown in China, Indonesia, Vietnam, India, the Philippines and Japan in Asia, Nigeria, Uganda, Tanzania, Rwanda, Burundi, Madagascar, Angola and Mozambique in Africa and Brazil and the United States in the Americas (FAO, 2012). In addition, sweet potato is critical for food security.

The roots, stems and leaves of the sweet potato are all edible, each with its own set of nutrients. Variable chemical compositions of sweet potatoes are further explained by pre- and post-storage circumstances, extraction and analytical techniques used and processing factors, in addition to genetic variation. (Anastácio *et al*., 2013).

Sweet potatoes are commonly baked, boiled, microwaved, steamed, or fried. The physical properties and chemical content of sweet potatoes would undoubtedly alter as a result of these cooking techniques (Wang and Kays, 2001; Padda and Picha, 2008; Takenaka, *et al.,* 2006).

In 2016, around 66% of the harvested potato crops (411 million ct.) were processed into chips and powders (National Agricultural Statistics Service, 2016). For the most part, this structure changes to a low water substance and high sugar or potentially fat substance after heat handling.

1.1.2 Frying of potato

The technique of frying potatoes in hot oil is extremely popular (Oke *et al.,* 2018; Zeb, 2019). However, tight quality control of fried potatoes, minimized oil absorption and limited amounts of carcinogens and acrylamide in fried potatoes are required due to health concerns (Furrer *et al*., 2018; Zeb, 2019).

Frying has long been employed to make meals with distinct organoleptic properties such as flavour, texture and colour in both domestic and commercial contexts. The frying process is complex because it involves many phases, beginning with the immersion of food in hot oil or fat that has been heated to temperatures over the boiling point of water (Pedreschi, 2012).

The critical challenge with frying food goods is that it changes their qualitative attributes including flavour and texture. Reduced cooking time and temperature, as well as the use of various pre-treatments, are some strategies for increasing fried potato quality.

1.1.3 Blanching process

Blanching is a method of preparing food that involves immersing it in hot water or steam for a short time. It prevents browning caused by enzymes by inactivating the enzymes that drive the browning response, as well as to drain soluble sugars from potatoes during frying (Garca-Segovia, 2016). Degradation of starch to soluble sugars lowers the quality of vegetables such as potatoes, particularly chipped potatoes. As a result, draining soluble sugars is important because soluble sugars tend to darken chips while frying due to the Maillard reaction and potatoes with a high soluble solids percentage may be rejected by processors. Arisseto *et al.* (2019) and Rimac-Brni *et al.* (2004) discovered that blanching is one of the pre-treatments that reduces oil uptake during the frying process.

Pre-blanching vacuum-fried foods has a lot of potential as a superior alternative to atmospheric frying because it minimizes the amount of oil absorbed significantly (Garca-Segovia *et al*., 2016). The temperature and time of the blanching process can have an impact on the pre-treatment's ability to reduce oil uptake.

1.2 Statement of the problem

Some fried samples are usually associated with high oil uptake. Oxidation of the absorbed oil during cooling or when shelved can result in some health concerns for humans like; hypertension, diabetes, cancers etc. There is also high level of post-harvest loss for sweet potatoes during its on-season, making its processing into other stable products a necessity. Furthermore, there is a huge demand of better quality product by consumers, making it important for the improvement of our processing technique. Application of artificial intelligence (AI) method in food processing is on the increase due to its flexibility over empirical models, it models several inputs and outputs together in a single structure. It is needed for the standardization of most food processing devices. AI has not been applied yet to frying technology.

1.3 Objectives

1.3.1 Main objective

The main aim of this study was to evaluate the effects of microwave-assisted blanching on the frying characteristics of sweet potato chips.

1.3.2 Specific objectives were to:

i. Determine the frying kinetics of blanched sweet potato chips;

ii. Model the frying kinetics of blanched sweet potato chips using empirical models and artificial neural network (ANN); and

iii. Determine the fried sweet potato chips' quality.

1.4 Justification of the project

1.4.1 Deep fat frying process

At a high temperature of roughly 180 °C, deep-frying is one of the most popular methods of food preparation. During the frying process, the oil and the material are constantly exposed to air oxygen and moisture in the food, resulting in a variety of reactions such as oxidation, hydrolysis, isomerization and polymerization.

Deep frying affects heat and mass transfer in foods, resulting in moisture loss and oil uptake in the final product (Freitas *et al*., 2009). Fried foods are dangerous to human health because of the rapid rate of oil absorption and oxidation that happens during frying. Researchers and food manufacturers have used a variety of pre-treatments before the frying process to reduce oil uptake in fried meals, including osmotic treatment, air drying, blanching and coating (Khazaei *et al*., 2016).

Fried dishes are popular all around the world because of their unique organoleptic properties (Liberty *et al.,* 2019). Fried meals, unfortunately, are high in fat and calories, which raises the risk of obesity, hypertension, cardiovascular disease, diabetes and cancer (Khawaja *et al.,* 2020; Provido et al., 2020). Frying produces high-calorie foods that also change nutrients due to oil absorption. In addition, frying has been connected to the creation of trans-fatty acids, which are harmful to your health (Djoussé *et al*., 2015). Deep frying is frequently done at high temperatures under atmospheric pressure, with a lot of oil absorbed (up to 50% of the fried meal's total weight) (Sothornvit, 2011).

The level of oil content in fried foods has been identified as a crucial element in the development of particular health problems. As a result, a rising number of research organizations are focusing on figuring out how oil absorption occurs and how to manage the amount of oil absorbed in foods fried (Li & Fan, 2015; Lumanlan *et al*., 2020; Touffet *et al*., 2020).

Although various strategies have been developed for oil content reduction in fried sweet potato chips, the method examined in this study, pre-treatment before frying, has yet to be so far investigated. As a result, the goal of this research is to see how blanching pre-treatments and osmotic dehydration as process treatments before frying affect the physicochemical properties of deep fried potato chips.

Finally, this research takes into account three of the 17 Sustainable Development Goals: SDG 2 (zero hunger), SDG 9 (industry, innovation and infrastructure) and SDG 12 (responsible consumption and production).

1.5 Scope of the project

This research work is to focus on the effect of microwave-assisted blanching pre-treatments on the frying quality of sweet potato (*Ipomoea Batatas*). The goal of this research is also to see how these pre-treatment methods affect the moisture loss and oil uptake kinetics during frying. This research project is expected to take a year to complete.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Sweet Potato (*Ipomoea batatas*)

Sweet potato (*Ipomoea batatas L*) is a *convolvulaceae* family dicotyledonous tuber crop that is one of the most significant staple crops. Sweet potato is an important root crop that contributes significantly to global food security, particularly in Sub-Saharan Africa (Low *et al*., 2009). According to Ingabire and Hilda (2011), sweet potato, which thrives in tropical and subtropical climates, provides nutritional benefits to both residents of urban and rural communities. In terms of global output, sweet potatoes are the sixth most significant crop. It ranks third in terms of production value and fifth in terms of caloric contribution to human nutrition (Shekhar *et al*., 2015). Abu *et al.* (2000) discovered that sweet potatoes have a high energy content (438 kJ/100 g edible component) and can provide more edible energy per acre per day than cereals such as wheat and rice. Variety, productivity, hardiness and ecological adaptability are just a few of the additional benefits (Laurie *et al*., 2012). Sweet potatoes are high in dietary fiber, potassium, copper, manganese, iron and vitamins A, C, B1, B2, B3, B6, E, biotin and pantothenic acid, as well as vitamins A, C, B1, B2, B3 (niacin), B6, E, biotin and pantothenic acid (carotenoids from orange-fleshed types). They also have a minimal fat and cholesterol content (Wang *et al*., 2016). Sugar, carbohydrate, vitamin C, beta-carotene, iron and other minerals are abundant in sweet potato roots (Laurie *et al*., 2012; Oloo *et al*., 2014). Sweet potatoes have a low glycaemic index despite their large carbohydrate content, owing to the slow digestion of the starch contained, making them good for diabetics and obese persons (Ellong *et al*., 2014; Fetuga *et al*., 2014; ILSI, 2008). Sweet potato crops in comparison to other roots and tubers like cassava and yam, have been found to have a high protein content (Oloo *et al*., 2014). Coloured pigments including -carotene, anthocyanin and phenolic compounds can be found in some sweet potato types. These colours are used to identify foods that are high in nutraceuticals (Oloo *et al*., 2014).

The leaves of sweet potatoes are high in vital amino acids like lysine and tryptophan, which are sometimes lacking in grains. As a result, sweet potatoes can simply be used to enhance the region's cereal-based meals (Mwanri *et al.,* 2011; Oloo *et al.,* 2014).

Finally, studies suggest that sweet potatoes can be used to manufacture a range of items, including beverages (wine, liquor, vinegar), sugar, biscuits, wheat, pasta and alcoholic beverages (Ellong *et al*., 2014).

2.2 Frying Mechanisms

2.2.1 General background on frying process

One of the oldest, simplest and most prevalent cooking methods is frying (Pedreschi *et al*., 2005). Food is immersed in edible oil at a temperature higher than the boiling point of water during the frying process (Hubbard and Farkas, 2000). Frying is a fast process of synchronous heat and mass transfer that can be used as a drying method, resulting in opposite-direction flows of water vapour (bubbles) and oil on the surface of the food product (Zhang *et al*., 2020). Due to the absorption of oil, frying produces high-calorie foods that also modify nutrients. Frying has also been linked to the production of harmful trans-fatty acids (Djoussé *et al*., 2015).

During the frying process, several events occur at the same time. Cooking, for example, generates starch gelatinization, protein denaturation, the Maillard reaction and caramelization, among other heat-induced chemical processes. Starch gelatinization happens when the starch granule's molecular structure is disrupted, causing expansion of particles and decreased solubility (Yusop *et al*., 2011).

The second is dehydration, which occurs when the oil temperature is maintained over 100°C, resulting in rapid water loss from fried items in the form of vapour. Additionally, the texture and structure of the foods alter during the frying process. Furthermore, fried foods include a lot of fat. Excessive intake of high-calorie meals has been linked to obesity, all of these things are risk factors for heart failure, including high blood pressure and diabetes. Additionally, due to the toxic material created during frying, excessive consumption of fried foods may pose a health risk (Hosseini *et al*., 2016).

Deep frying is frequently carried out at high temperatures under atmospheric pressure, absorbing a large amount of oil, which can account for up to 50% of the total weight of the fried meal (Sothornvit, 2011). With repeated frying, the risk of atherosclerosis rises due to the development of trans-fatty acids and the loss of essential fatty acids (Zhang *et al.,* 2020). The relationship between high blood pressure and oil degradation was explored by Soriguer *et al*. (2003). They discovered that when used cooking oil degraded, there was increase in the polar molecules concentration in the oil and that polar compounds in cooking oil were connected to hypertension. Fried foods have long been associated to a variety of human health issues, including lipid oxidation products and even premature death, making them a consumer concern. Researchers have focused their efforts on creating new technologies that would allow them to make better fried foods with less oil in order to deliver healthy and safe fried foods (Su *et al*., 2017; Tarmizi & Niranjan, 2010). Consumer demand for healthier fried dishes with less oil has resulted in a promising future for new alternative frying techniques. Even the food processing industry is developing new frying ways to produce fried foods that use less oil while maintaining the same quality as conventional immersion frying without diminishing flavour.

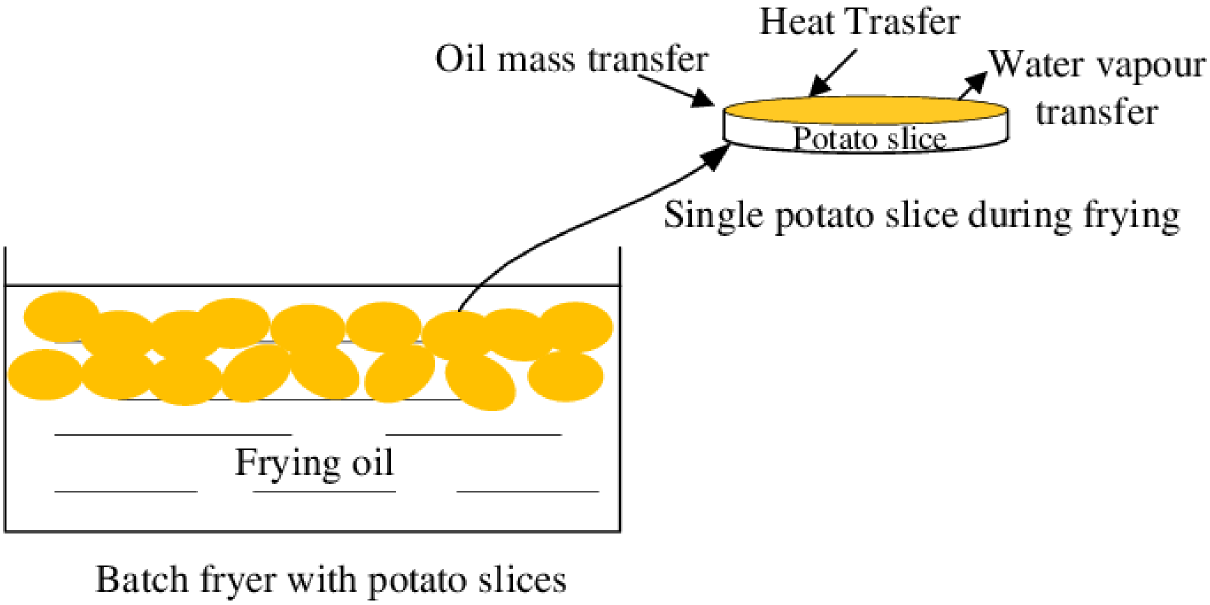


Figure 2.1. Heat and mass transfer chart during potato frying (Zhou *et al*., 2021).

Frying is a popular way to cook meat, fish and vegetables. Researchers have concentrated on creating new techniques to creating healthier fried foods with less oil content in order to give healthy and safe fried dishes (Su, *et al.,* 2017; Tarmizi & Niranjan, 2010).

2.2.1.1 Mechanism of oil absorption during frying

Water loss, oil absorption and the Maillard reaction's creation of acrylamide are the three major changes in food composition generated by frying (Zhang *et al*., 2020). The maillard reactions occur when sugar-free and protein-rich meals are fried, especially at high temperatures. Convection (in the oil mass) and conduction are used to transmit heat and mass (within the food). The convective heat transfer coefficient, defined as the ratio of convective heat transfer flux to thermodynamic driving force across the product surface–fluid interface, has been found to have a significant influence on fried meal surface temperature changes during frying (Alvis *et al.*, 2009). As a result, a thorough heat and mass movement analysis during frying is required for nutritional value monitoring (Bassama *et al*., 2015). Oil is used as a heating medium in traditional frying at temperatures of 160–180°C or higher (Banerjee and Sahu, 2017). The structure of fried meals changes dramatically when they are exposed to hot oil. The amount of oil in fried foods has been identified as a key factor in the development of certain health issues. There are two mass transfers in fried raw materials: one is water and soluble components going from the inner to the outer crust and the other is water on the surface evaporating and moving out as oil transfers in. The water content of fried raw materials has the biggest impact on oil uptake because the vapour leaves holes for the oil to penetrate (Marquez *et al.,* 2014). Understanding the mechanism of oil penetration during the frying process is critical in order to reduce oil content without compromising fried food quality.

Previously, oil absorption was thought to happen largely during the frying process, when the moisture in the meal's capillaries evaporated. The majority of fried food oil uptake occurs during the cooling phase, when the product is suctioned out of the oil, according to recent studies. Cooling causes water vapour in pores to condense and create pressure, allowing oil to absorb from the surface into the pores of fried products. Consider how French fries absorb oil, which may be divided into three categories (Koerten *et al.,* 2015).

i. During frying process, the chips absorb the oil inside the structure.

ii. After the removal of chips from the pan, the absorbed surface oil was immediately absorbed by the chips.

iii. The surface oil adhering to the frying surface throughout the cooling process.

Pre-treatment, frying condition modifications, hybrid fry method and post-frying treatment are all good studies on de-oiling approaches and mechanisms (Dehghannya & Abedpour, 2018). According to reports, the post-frying process minimized oil uptake and improved the texture of fried foods (Tarmizi & Niranjan, 2012). However, it has a number of drawbacks, including instrument contamination, increased oil oxidation and increased energy usage (Quan *et al*., 2016).

Pre-treatments such as blanching and/or osmotic dehydration have been used to reduce oil uptake during frying of fruits and vegetables (Krokida *et al*., 2001). Because of the substantial oil content observed on the surface of chips during the pressurisation step in a vacuum frying process, Moreira *et al*. (2009) demonstrated that a de-oiling operation must be used quickly after the product is fried to create chips with reduced oil content under vacuum. They discovered that the core held 14% of the total oil content (internal oil), with the remaining 86 percent being surface oil. The de-oiling process (centrifuging system) used in the study was capable of removing 80–90% of the total oil content in the chips.

Finally, incorporating an oil absorption mechanism will aid in the development of new frying techniques and approaches to overcome the limitations of traditional frying.

2.2.2 Review of microwave-assisted conventional food processing technologies before frying

Few pre-treatment procedures have been implemented prior to the frying of meals with the goal of reducing oil content and improving the organoleptic qualities of the fried dish, according to research findings (Oladejo *et al*., 2017).

For a variety of purposes, microwave heating and other modern food processing technologies have grown in favour as alternatives to traditional food processing techniques in the food industry. Microwave-assisted food processing techniques bring a new dimension by addressing the limits of established and future food processing procedures by utilizing the benefits of microwave energy (Ekezie *et al*., 2017).

Microwave frying technology has been shown to result in less oil uptake, crisper texture and improved colour in fried fruits and vegetables (Parikh & Takhar, 2016; Sensoy *et al*., 2013). The rapid evaporation of moisture in fried samples was aided by microwave cooking, resulting in a less compact crust and a denser interior structure with fewer pores (Parikh & Takhar, 2016). Less oil absorption after frying was caused by changes in the distribution and diameter of porous microscopic structures (Zhang *et al*., 2018). The efficiency with which microwave energy is absorbed and converted into heat is determined by the dielectric characteristics of materials in a microwave environment (Chandrasekaran *et al*., 2013). As a result, moisture evaporation and the creation of porous structures in MVF products were negatively impacted (Sansano *et al*., 2018). The dielectric characteristics of frying oil are low when compared to high-moisture content food items (the dielectric factor ranged from 1–3 and the dielectric loss factor ranged from 0–1), lowering microwave heating effectiveness (Su *et al*., 2020).

Microwave frying exposes samples to varied degrees of microwave radiation and oil heat (Zhang *et al*., 2020). As a result, the ability to absorb and convert microwave radiation to heat influences moisture evaporation and the creation of porous structures (Hu *et al*., 2021). The most significant influence on oil uptake is the surface shape and porous structures formed by moisture evaporation (van Koerten *et al*., 2015a; 2015b).

As a result, pre-treatments such as osmotic dehydration and coating pre-treatment are required to alter the dielectric characteristics and surface micromorphology of MVF potato chips in order to reduce oil uptake, accelerate moisture evaporation and improve overall quality.

2.2.3 Review of issues related to health hazard of application of microwave on human health

Food (cereals, legumes and tuber crops) are the primary source of energy and dietary protein for the majority of the world's population due to their broad availability and low cost (Ndidi *et al*., 2014). Despite these advantages, anti-nutrient factors (ANFs) found in many edible grains, such as phytic acid, tannins, trypsin inhibitor, saponins and oxalate, limit their consumption and utilization in the food processing industry. This is primarily due to the negative health impacts of these ANFs (Rahate *et al*., 2020). Anti-nutrients are substances that hinder nutrients from being released or absorbed, reducing their bio-accessibility and bioavailability in food (Rousseau *et al.,* 2020). ANFs help plants fight fungus, insects and predators chemically, which is beneficial; but, in animals and humans, ANFs reduce nutrient bioavailability, decreasing the nutritional value of foods (Sinha & Khare, 2017). To remove the ANFs found in food grains, various processing methods are used, including thermal (boiling autoclaving, hot air oven), enzymatic, soaking, germination, irradiation and fermentation. These methods improve the nutritional quality of edible food grains by lowering anti-nutritional components (Tanaskovi'c *et al.,* 2020; Mohapatra *et al.,* 2019; Shawrang *et al.,* 2011; Samtiya *et al.,* 2020). Each of these methods, however, has at least one disadvantage, such as long soaking times and loss of water-soluble nutrients, loss of heat-sensitive nutrients during thermal processing, difficulty controlling process parameters during enzymatic treatment and fermentation and waste generation during most of these processes. Alternative ways for lowering ANFs in food have been developed as a result of these constraints, including high-pressure processing (HPP), extrusion and microwave treatment (Zarei & Kafilzadeh, 2013; Shawrang *et al*., 2011; Linsberger-Martin *et al*., 2013). These technologies have a number of advantages over traditional methods, including being non-thermal (HPP), requiring less heating or cooking at high temperatures for a shorter time period (extrusion and microwave roasting), causing less nutritional harm and improving end product quality (Linsberger-Martin *et al*., 2013). Microwave pre-treatment is the most expensive of these alternatives (about USD1500-5500 per kilowatt), but it has lower operating and maintenance costs than traditional technologies, allowing for a quicker return on investment (Mujumdar & Zhonghua, 2008; Hasna, 2011; Vani *et al.,* 2012). Microwave treatment is a volumetric heating technology that reduces the amount of time it takes to cook by using the thermal energy released inside the meal. Additionally, rapid and consistent heating reduces compound degradation as well as the risk of by-product formation. The method is also low-fouling and energy efficient (it can transfer 80 percent of the energy into heat). It works well with heat-sensitive, highly viscous and multiphase fluids and it requires minimal equipment, clean operations and automated process control (Aguilar-Reynosa *et al.,* 2017; Guo *et al.,* 2017; Kautkar & Pandey, 2018), making it a cost-effective and user-friendly process (Aguilar-Reynosa *et al*., 2017; Kautkar & Pandey, 2018). Microwaves have been used for tempering, thawing, blanching, baking, roasting, drying, pasteurization, sterilization and bioactive chemical extraction, among other things (Chandrasekaran *et al*., 2017; Orsat *et al*., 2017). It helps to minimize anti-nutritional compounds in food, which increases protein digestibility, safety and quality in food grains in vitro, according to Guo *et al*. (2017).

Microwave application has been found to affect ANFs such as phytic acid (Kala & Mohan, 2012), tannins (Xu *et al*., 2016), trypsin inhibitors (Sharam *et al*., 2018), saponins (Kaur *et al.,* 2012) and oxalate in food products such as velvet bean, horse chestnut, kabuli chickpea, black soybean, buckwheat and others

2.3 Novel approaches on pre-treatments of frying products

Before frying, some pre-treatments are required, including blanching, osmotic pre-treatment, freezing and pre-drying. These pre-treatments have an impact on moisture removal kinetics, product yield, end-product moisture content, product fat content and fat distribution in the final product (Maity *et al.,* 2018).

i. Taiwo and Baik (2007) looked at how different pre-treatments affected the shrinkage and textural properties of fried sweet potatoes (blanching, freezing, air drying, osmotic dehydration and control). According to the research, the effects of the pre-treatments were found to be highly significant on the porosity of fried sweet potatoes, but less so on the bulk densities of the products. The pre-treated samples were thicker than the control samples after frying than the control samples.
Finally, the researchers discovered that pre-treatment increased the hardness, springiness, chewiness, cohesiveness and adhesiveness of fried samples in terms of hardness, springiness, chewiness and cohesiveness.

ii. Cheng *et al.,* (2021) investigated the effects of pulsed electric field (PEF) pre-treatment on the quantity of oil absorbed by potato chips. The effects of PEF on potato chip oil content, colour characteristics, texture, microstructure and acrylamide content were studied. According to the findings, the strength of the electric field had a substantial impact on the oil content and texture of potato chips. The pre-treated samples' hardness and crispness significantly enhanced as well. The results also indicated a smoother surface and lower oil content, which can be attributed to the cross-section area's increased porosity value. Finally, as a result of the pre-treatments, the processed samples had minimal acrylamide concentration.

iii. Ya Su *et al*. (2018) studied the efficacy of hybrid frying based on vacuum frying with ultrasound (USVF) and combined ultrasound and microwave frying (USMVF). The combination of ultrasound and microwave pre-treatment had a synergistic effect on the quality and energy efficiency of vacuum fried potato chips. Vacuum-fried potato chips had a lower oil uptake value, which was a benefit. The moisture loss kinetics and quality parameters greatly improved when the ultrasonic power was raised. In samples pre-treated with USMVF, moisture loss kinetics improved and SEM results revealed a more porous microstructure in USMVF samples.

Finally, vacuum frying technology using a combination of ultrasonic and microwave has been shown to be a substantially more effective method in terms of energy efficiency and product quality.

iv. According to Sothornvit *et al*., (2011), after 1.5% guar gum and 1.5 % xanthan gum solutions coating treatment, the fat content of banana chips produced by vacuum frying was reduced by 25.22 % and 17.22 %, respectively.

v. Using atmospheric frying, guar gum and glycerol coating reduced the oil content of potato chips by 51.8 %, according to Yu *et al*., (2016). Zhang *et al*., (2016) discovered that the initial moisture content had a substantial impact on the rate of oil uptake but had little effect on the end oil content or oil fraction, suggesting that moisture content alteration by pre-treatment may have little impact on final product oil uptake.

2.3.1 Effects of pre-drying and freezing prior to frying

Pre-drying reduces the amount of free water in fried foods and the longer the pre-drying time, the lower the end product's initial water content (Rahimi and Ngadi, 2014). Pedreschi and Moyano (2005) discovered that pre-frying drying reduced oil absorption and improved the crispness of fried potato slices. According to Alimi *et al*. (2013a) pre-drying before frying could be employed before coating in fried yam chips. After pre-drying, the moisture content and L* values of fried yam slices were found to be lower. The influence of batter formulations and pre-drying time on the surface, osmotic and ultimate oil content of fried food coatings was explored by Rahimi & Ngadi (2014), who discovered that batter without pre-drying had a larger oil content than batter that had been pre-dried. Song *et al.* (2007) examined the effect of vacuum-microwave pre-drying on vacuum-fried potato chips. The results showed that vacuum-microwave pre-drying of vacuum-fried potato chips reduced oil and moisture content while also modifying the colour and texture (increased L* value and crisp crust).

Freezing is another way to reduce the initial water content while maintaining the qualities of fried items (Fan *et al.,* 2005). In fried meals, it contributes in the production of a porous sponge-like structure (Ren *et al.,* 2018). The potential of freezing food items before frying them to limit oil absorption and improve the product's sensory qualities was also investigated (Maity *et al.,* 2012). Maity *et al.* (2012) investigated the texture kinetics of snacks using frozen, frozen-thawed and unfrozen products, the results showed that freezing increased activation energies during frying and that the sensory acceptability of fried snacks treated with freezing prior to frying was comparable to that of those not pre-frozen. The effect of pre-freezing on vacuum-fried jackfruit chips was investigated by Maity *et al.* (2018). During vacuum frying, the a-value increased while the b-value decreased. The crispiest texture and the lowest instrumental breaking force were found in pre-frozen jackfruit chips. The porous structure of pre-frozen fried jackfruit chips demonstrated a high porosity and low surface shrinkage, resulting in little oil penetration and good consumer approval. Albertos *et al*. (2016) looked into the effects of pre-treatments like freezing and high-pressure processing. Carrot chips that were frozen before being fried had a porous structure and structural changes. The researchers discovered that freezing carrot snacks before frying improved crispness, reduced oil absorption and improved organoleptic and antioxidant activity.

2.3.2 Effects of blanching pre-treatments before frying

Blanching is the process of submerging items in boiling water or steam for a short period of time. It's used to prevent enzyme-induced browning (Garca Segovia *et al*., 2016). It can also absorb soluble sugars from potatoes when fried (Xin *et al*., 2015). (Xin *et al*., 2015). Blanching fried items before frying can alter their colour, texture and a* value, resulting in a crisper crust and less shrinking on the surface. Oil absorption is inhibited by gelatinization of the surface starch (Xin *et al*., 2015). Before deep frying, blanching (either steam blanching or hot water blanching) is performed to inhibit enzymatic activity (Ren *et al.,* 2017). The permeability of the crust has been discovered to be an important element in determining oil uptake. In practice, most pre-frying processes have focused on surface structural changes and the production of a crispy crust with little oil penetration (Rahimi *et al.,* 2017; Rahimi & Ngadi, 2014).

According to Pedreschi & Moyano (2005), when blanched pre-dried potato chips were fried, the oil content was lowered and the texture was improved. Ren *et al.* (2018)

investigated the impact of several pre-treatments (blanching, osmotic dehydration, coating and freezing) on the qualitative characteristics of vacuum-fried shiitake mushroom slices, both separately and in combination. The fastest drying rate was achieved by combining blanching with osmotic dehydration and freezing. To achieve the lowest oil content and optimum sensory attributes in vacuum fried shiitake mushroom chips, blanching, osmotic dehydration and coating preparation were utilized. Pre-blanching enhances the colour of vacuum-fried meals, according to Garca-Segovia et al. (2016), resulting in a higher L* value and decreased oil content. Sulphited and blanched potato slices combined with hot-air dried pre-treatments had a substantial influence on colour (L*, a*, b* and ΔE), as well as overall quality of potato chips, according to Troncoso *et al.* (2009). Blanched and dried potato slices had better a* and ΔE values but lower L* values, whereas sulphited fried potato slices had a significant improvement in colour features but lower a* and ΔE values. The two pre-treatments had no discernible differences in overall quality.

2.3.3 Effects of microwave-assisted blanching pre-treatments before frying

Microwave cooking has become an essential component of meal preparation. In a fast alternating electromagnetic field, microwaves can interact directly with polar water molecules and charged ions, generating frictional heat and causing charged ions to flow throughout the meal, reducing the time it takes to heat it (Chavan and Chavan, 2010). Microwave heating has a number of advantages over traditional heating processes, including energy conservation, time savings, improved uniformity and the possibility to create goods with unique micro mechanics (Adedeji *et al*., 2009).

According to Dorantes-Alvarez *et al*. (2011), the energy density of microwave blanching varies between 0.15 KJ/g in strawberries and 2.55 KJ/g in potatoes

The amount of oil in fried foods can be reduced by microwaving samples before frying and increase their quality (Amiryousefi *et al.,* 2016). Erdodu *et al*. (2007) researched and discovered that employing microwave heating to reduce cooking time and temperature reduced acrylamide levels in potato chips. The most substantial reduction in oil uptake was seen in chicken nuggets precooked at 6.7 W/g microwave power and fried at 170°C, according to Adedeji *et al*. (2009). The effect of microwave pre-treatment at various time intervals on the mass transfer of moisture and oil in chicken nuggets during frying was investigated by Ngadi *et al.* (2009). According to the findings, heating chicken nuggets in the microwave for longer reduced average water loss and oil absorption (Ngadi *et al*., 2009).

Microwave pre-cooking differs from blanching in that the products are fried quickly without sacrificing the reducing sugars and asparagine that give fried dishes their crispy crusts and texture, whereas blanching may result in the loss of soluble sugars (Erdo *et al*., 2007).

2.3.4 Effects of osmotic dehydration pre-treatments prior to frying

To prevent oil uptake, a variety of environmentally friendly pre-treatment technologies, such as osmotic dehydration (Piyalungka *et al*., 2019), pre-drying (Jia *et al*., 2018) and coating with hydrocolloids, are now being used (Arslan *et al*., 2018). (Arslan *et al*., 2018). Ananey-Obiri and colleagues (Ananey-Obiri *et al*., 2018). By increasing the solid content of raw materials, acting as a lipid barrier, reducing the surface area exposed to oil and modifying the microstructure of materials, these pre-treatments were able to limit oil uptake (Ananey-Obiri *et al*., 2018).

There has been little research on the use of osmotic dehydration before frying. Osmotic dehydration improves the quality of finished fried foods by reducing discolouration (Zhang *et al.,* 2020). The impact of osmotic solutions on French fry quality were explored by Krokida *et al*. (2001). According to their findings, samples that had been pre-treated in osmotic solutions had significantly lower oil and moisture content than samples that had not been pre-treated. Despite the fact that this conclusion was reached without taking solid immersion into consideration when calculating oil absorption on a dry basis, Moreno and Bouchon (2008) discovered that osmotic dehydration has no influence on oil absorption. According to Kim *et al*. (2013) pre-treatments of blanching and osmotic dehydration (3 percent NaCl solution, 25°C, 5 min) reduced oil uptake while improving texture, colour, flavour and overall quality of deep-fried potato chips.

Finally, we may use it in combination with other pre-processing methods like high hydrostatic pressure, high-intensity electrical fields, vacuum, microwave and ultrasonic processing to increase osmotic dehydration diffusion rates (Karizaki *et al*., 2013; Mujumdar *et al*., 2010).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Materials

Fresh sweet potatoes were bought at a market in Ogbomosho, Oyo State, Nigeria. Soybean oil, which was used as frying oil, was bought at a local market in Omu-aran, Kwara State. N-hexane laboratory reagent (Sigma-Aldrich) was purchased, sucrose solution was gotten from the industrial chemistry laboratory of Landmark University. The sweet potatoes were shaped into a circle using a circular cutting mould with a diameter of 45±2 mm.

3.2 Sample Preparation

The potatoes were washed, peeled and sliced into 7 mm thick slices with a 45±2 mm diameter. a digital Vernier calliper was used to ensure the thickness of the potato slices was within range. The sweet potatoes slices were blanched using the following pre-treatments:

3.2.1 Control

The sweet potato slices (7 mm) were cut from fresh sweet potato tubers and then rinsed in distilled water and dried with a kitchen towel before frying to remove any starch particles sticking to the surface.

3.2.2 Microwave blanching

The microwave blanching method by Oladejo *et al.,* (2017) was adopted for this work. Freshly cut sweet potato slices (7 mm) were blanched in a calibrated LG (MS2044DMB/ 00) kitchen microwave oven at microwave power of 700 W for 60s. A sample was blanched per 60s.

3.2.3 Hot water blanching

According to the procedure used by (Pedreschi *et al*., 2005), the sweet potato slices were blanched using a water bath, 1:25(kg/ml) at 85°C for 3.5min. The samples were placed in a 250ml size bottle, filled with 25ml of deionized water. The samples were gently dried with a paper towel before being introduced into the fryer.

3.2.4 Osmotic dehydration

The method by Gallegos-Marin *et al.*, (2016) was used for the osmotic dehydration pre-treatment of the sweet potato samples. Osmotic solution of 29% of sucrose in 100ml of deionized water was prepared for the osmotic dehydration pre-treatment of the sweet potato slices. Slices of sweet potato 7mm thickness were cut using a manual slicer, the thickness was determined and maintained using a digital Vernier calliper. The samples were submerged in osmotic solution in a ratio sample 1:25, they were gently shaken in a mechanical shaker for 30mins.

3.3 The frying process

Samples of sweet potato slices were fried in an electric deep fryer, one at a time. Each sample was fried at a certain temperature with respect to time as the variation applies.

The temperature variation was for 130, 150 and 170°C while the time variations were 2, 4, 6, 8 and 10 minutes, respectively. The samples were taken out of the fryer after each frying time and the oil was allowed to drain on a kitchen towel for 2 minutes.

Each of the temperature was set for each of the frying time. The weight before frying and after frying were recorded using a digital analytical weighing balance. This process was repeated for all the samples.

3.4 Frying kinetics

3.4.1 Moisture loss

The moisture ratio of the potato slices after the deep frying process was determined by recording the values for weight of sample before and after frying. Pedreschi and Moyano (2005) utilized a model to represent moisture loss during frying that took into account that the physical properties of the potato slices change with the moisture level during the operation, making the effective moisture diffusion coefficient a function of time (Alvarez *et al.*, 1986). Eq. (1) was successfully applied to simulate moisture loss during axial frying of sweet potato chips (Pedreschi and Moyano, 2005):

$$M_R = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\left\{\frac{1}{(2n+1)^2} \times \left[\exp\left(-\frac{(2n+1)^2\pi^2}{4(1+b)}\left[\left(1+\frac{D_0 t}{l^2}\right)^{1+b}\right]\right)\right]\right\} \qquad 1$$

where l is the half thickness of the slice; M_t is moisture content at time t (db); M_0 is initial moisture content (db); M_e is the equilibrium moisture content (db); t is the frying time (min), D_0 is the effective moisture diffusion coefficient at t= 0 and b is a dimensionless parameter. It is reasonable to assume that the moisture content is negligible when the equilibrium is reached in the frying process, so $M_e = 0$ in Eq. (1).

Therefore, the equation for MR can be rewritten as,

$$\mathrm{MR} = \frac{M_t}{M_0} \quad 2$$

3.4.2 Oil uptake

After frying at 130, 150 and 170°C for 2, 4, 6, 8 and 10 minutes, respectively, the oil absorbed by the sweet potato chips was measured using the approach given by Hsu *et al*. (2016).

The fried sweet potato slices were oven dried at 105°C for 12 hours. After the drying process, determination of the oil content was done using the Soxhlet extraction method. The samples were ground into a powder, which was then assembled in a Soxhlet apparatus for 4 hours at 50°C using an organic solvent (n-hexane) and the oil content was estimated using the formula below.

Oil Uptake (OU) = $W_1 - W_2$ (kg) 3

where: W_1 is the initial weight before frying

W_2 is the final weight after oil extraction.

Plate 3.1: Oil extraction using Soxhlet's apparatus.

3.4.3 Effective diffusivity

Using the equation below, Fick's second law of diffusion was used to get the effective water diffusion coefficient (Movahhed, 2019).

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(\frac{-(2n+1)^2 \pi^2 D_{eff} t}{4L^2}\right) \quad 4$$

eq. (1) can be changed to eq. (2) if the moisture content at equilibrium is insignificant (Me = 0) (Pedreschi and Moyano, 2005).

$$MR = \frac{M_t}{M_0} = \frac{8}{\pi^2} \exp\left(\frac{\pi^2 D_{eff} t}{4L^2}\right) = \frac{8}{\pi} \exp(-kt) \quad 5$$

where: MR is the moisture ratio (dimensionless), M_t is the moisture content at time t (db. %), M_0 is the initial moisture content (d.b %), M_e is the equilibrium moisture content (d.b %), D_{eff} is the effective moisture diffusion coefficient (m^2/s), t is frying time (s), n is a positive integer, L is half of the sample's thickness (m), k is the rate constant (min^{-1}).

The effective moisture diffusivity can be obtained from equation (4) below.

$$k = \frac{\pi^2 D_{eff}}{4L} \quad 6$$

where: k is the rate constant (min^{-1}), D_{eff} is the effective moisture diffusion coefficient (m^2/s), L is half of the sample's thickness (m).

3.4.4 Activation energy

An Arrhenius equation can be used to represent the temperature dependence of effective diffusivity (Saravacos and Maroulis, 2001).

$$D_{eff} = D_0 \exp(-\frac{E_a}{RT}) \quad 7$$

where: D_{eff} is effective moisture diffusion coefficient (m^2/s), D_0 is the pre-exponential factor or pre-factor of Arrhenius equation (m^2/s), E_a is the activation energy (J/mol), R is universal gas constant (8.314472 J/mol.K) and T is the absolute temperature (°K).

3.5 Modelling of the kinetics

3.5.1 Modelling of the moisture ratio

The moisture ratio values were modelled using 11 experimental models as shown in the Table 3.1. The non-linear regression method was used to fit data into these models.

Table 3.1 Mathematical models for moisture loss kinetic

S/N	Model name	Equation
1	Lewis	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Modified page	$MR = \exp(-(kt)^n)$
4	Henderson and Pabis	$MR = a\exp((-kt))$
5	Logarithmic	$MR = a\exp(-(kt)) + c))$
6	Two term	$MR = a\exp(-k_0t) + b\exp(-k_1t)$
7	Two-term exponential	MR = a exp(-kt) + (1-a) exp (-kat)
8	Wang and Singh	$MR = 1 + at + bt^2$
9	Diffusion approach	$MR = a\exp(-kt) + (1 - a)\exp(-kbt)$
10	Midilli	$MR = a\exp(-kt^n) + bt$
11	Verma	$MR = a\exp(-k_1t) + (1 - a)\exp(k_2t)$

3.5.2 Modelling of the oil uptake

The experimental data for the oil uptake were modelled using 5 experimental models as shown in Table 3.2.

Table 3.2. Mathematical models for oil uptake kinetics.

Models	Equations	Reference
Second order polynomial	$O = at^2 + bt + c$	Pedreschi and Moyano (2005).
Exponential	$O = a\exp(-bt) + c$	Pedreschi and Moyano (2005).
Linear	$O = \frac{1+t}{at+b}$	Pedreschi and Moyano (2005).
Linear	$O = \frac{abt}{1+bt}$	Pedreschi and Moyano (2005).
Exponential	$O = \frac{1-\exp(-at)}{(1-bt)}$	(Krokida, Oreopoulou, Maroulis, & Marinos-Kouris, 2001)

3.6 ANN Modelling

Models, or their basic or numerical representations, are required for an unpredictable framework to perform optimally, which explains the increasing modeling practice in modern research (Mrinal, 2008).

A model structure of a biological network is an artificial neural network (ANN) (Bas and Boyhaci, 2007). A basic processing element of an ANN is an artificial neuron. It takes in data from a variety of sources, combines it, applies a non-linear operation on the result and then outputs the final result (Ohale *et al*., 2017).

Sixty (60) experimental data sets were employed in the ANN analysis. The training set accounted for 70% of the total data sets (42) while the testing (9) and validation data sets (9) were each given 15% to evaluate the network's performance.

The neural network tool box in the MATLAB program (2017) was used to conduct the analysis. The multilayer feed forward back propagation learning algorithm was employed as an ANN connection type. Learngdm was in charge of the adaptive learning function.

3.6.1 ANN structure

The input variables for the network structure were frying time (min), blanching treatments and frying temperature (°C), while the output variables were moisture ratio and oil uptake. As a result, data sets for input/output variables are loaded into the MATLAB graphical user interface's neural network tool box. The network was trained using the network trainlm function. The Levenberg-Marquardt strategy was used to train the network training function and this method was used to update the weight and bias values. With a momentum weight and a bias learning function, it's a gradient descent algorithm. After multiple trials, the network is trained utilizing two hidden layers and ten numbers of hidden neurons. As seen in Eq. 1, the logsig function is employed to transform a neuron's input signal to its output signal (1). The structure of the neural network is shown in Figure 3.1 and its transfer function is shown in Figure 3.2.

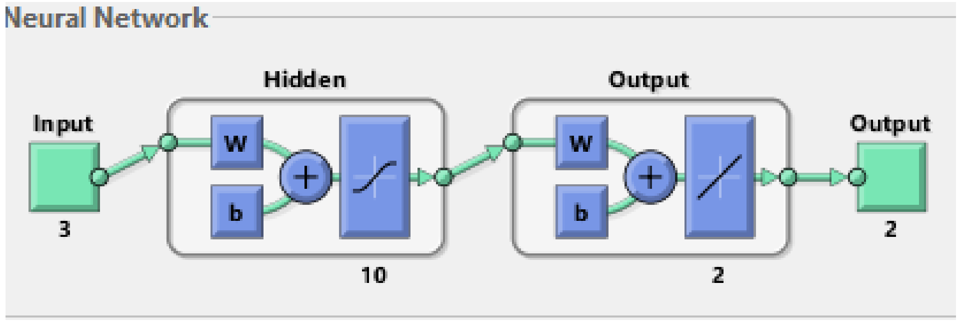


Fig. 3.1. ANN topology (3 inputs, 10 hidden neurons, 2 output)

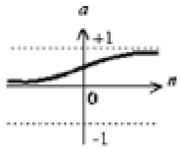


Fig. 3.2: Graphical illustration of logsig function.

a = logsig (n) 8

3.7 Modelling performance evaluation

Three metrics were used to assess fit quality: coefficient of determination (R^2), root mean square error (RMSE) and sum of square error (SSE) (SSE). The model with the highest R^2 value, lowest RMSE and lowest SSE values was the best.

$$R^2 = \frac{1-[\text{sum}_{(i=1 \text{ to } n)}\{w_i(y_i-f_i)^2\}]}{[\text{sum}_{(i=1 \text{ to } n)}\{w_i(y_i-y_{av})^2\}]}=1-\frac{SSE}{SST} \quad 9$$

where: f_i is the predicted value from the fit,

y_{av} is the mean of the observed data

y_i is the observed data value.

w_i is the weighting applied to each data point, usually w_i=1.

SSE is the sum of squares due to error and SST is the total sum of squares.

$$SSE= [\text{sum}_{(i=1 \text{ to } n)}\{w_i(y_i - f_i)^2\}] \quad 10$$

$$RMSE= S = (MSE)^{0.5} \quad 11$$

Where MSE is the mean square error or the residual mean square

$$\text{Where } MSE = {SSE}/{V} \quad 12$$

3.8 Quality characteristics

3.8.1 Colour

The product's colour after frying at different time and temperature is a factor that explains the quality index and acceptability of the fried potato chips. Therefore, the colour was analysed using a chromaticity instrument (Chroma meter CR-410). The L*, a* and b* measurements were recorded when the samples were exposed to a standard light. The values of Hunter L (lightness), a (redness) and b (yellowness) were determined. L*is a crucial metric when it comes to frying food goods (Mariscal & Bouchon, 2008). The higher the value of L*, the brighter appearance and also the more satisfied consumers are with the fried sweet potato chips. The colour difference was further calculated using the method adopted by (Su, 2015). The measurement was performed in triplicate.

3.8.2 Texture

The texture analysis method adopted was the one developed by Fan, Zhang, & Mujumdar, (2005). Texture analysis of potato chips was done using Stable Micro Systems (TA.XT plus) texture analyser which was coupled with guillotine blade with a Slotted blade insert (upon which the samples are placed for analysis). Tests were carried out with the following settings:

1. Test mode: compression
2. Pre-test speed: 1.50mm/sec
3. Test speed: 2.00mm/sec
4. Post-test speed: 10.00mm/sec
5. Distance: 6.00mm
6. Trigger force: 25.00g

3.8.3 Ascorbic acid

Titration with 2, 6-dichlorophenol indophenol was used to assess the ascorbic acid content of fresh and fried sweet potato samples (Qing *et al.,* 2006). Oxalic acid at a concentration of 5% was used to extract ascorbic acid.

A spectrophotometric approach was used to evaluate the extract, which was read at 515nm using a uv/vis spectrophotometer (Lingguong 752, Shanghai, China). The data was analyzed on a dry weight basis, with micrograms per 100g of solid being used as a unit of measurement.

3.8.4 Shrinkage

Before and after frying, the sample dimensions (thickness and diameter) were measured with a steel calliper. Measurements were taken at three different locations on each sample. Shrinkage was calculated using the percentage change in thickness and diameter (Barat *et al*., 2001; Kawas & Moreira, 2001a).

The diameter of degree of shrinkage (S_i) was calculated using the formula below. The measurement was performed in triplicate to get desired results.

$$\mathrm{S_i} = \left(\frac{\mathrm{d_0} - \mathrm{d_{(t)}}}{\mathrm{d_0}}\right)100 \qquad 13$$

$where$ $\mathrm{S_i}$ is the diameter of degree of shrinkage (mm)

d_0 is the initial diameter of the sample (mm)

$d_{(t)}$ is the diameter (mm) of sample after frying at time (t).

3.8.5 Bulk density

A material's bulk density is defined as the weight of a volume unit of powder and is commonly stated in g/cm^3, kg/m^3, or g/100 ml. Sweet potato slices were mashed in a mortar and 1g of ground sample was placed in a 250ml measuring cylinder. The cylinder was repeatedly tapped until the volume was stabilized. Bulk density values were obtained by dividing the weight of flour (g) by the volume of flour (cm^3) (Onwuka, 2005). The bulk density was calculated using the formula below (Dehghannya *et al*., 2016a).

$$\rho = \frac{m}{v} \qquad 14$$

where: ρ= bulk density (g/cm^3)

m = mass of the sample (g)

v = volume of the measuring cylinder (cm^3)

3.9 Cell Integrity

3.9.1 Electrolyte leakage

Measurements of electrolyte leakage are used to assess the integrity and permeability of horticultural commodity cell membranes, as well as to quantify ion efflux from cells in a solution (Murray *et al*., 1989).

The electrolyte leakage of the fried samples was measured using the method by Bi *et al*. (2011), which was modified slightly. Grounded sweet potato chips of approximately 2g were poured into a 50ml centrifuge tube containing 20ml distilled water. These samples were centrifuged at 300r/min for 4 hours at room temperature in a Gallenkamp centrifuge. A supernatant was obtained by centrifugation. The electrical conductivity of the solution was measured using a conductivity meter (Omega TDH-5031). The amount of electrolyte leakage was measured in triplicate.

3.9.2 Microstructure

Following the approach outlined by Quan *et al*., (2016), the microstructure of sweet potato chips after frying was determined. The surface morphology of potato strips after frying at specific temperatures (130, 150 and 170°C) was examined using a scanning electron microscope (SEM-2380, Hitachi, Japan). At a magnification of ×100 μm, the changes in cell morphology of sweet potato chips were studied.

3.10 Experimental design

The experiments employed a three-replicate factorial design with a 4 X 3 X 5 factorial design. Control, MW, HWMW and OSMW pre-treatment techniques were used with frying temperatures 130, 150 and 170°C and frying time 2,4,6,8,and 10 minutes. Moisture loss and oil uptake served as dependent variables.

3.11 Statistical analysis

The quality characteristics tests were done in triplicates and the data was analysed using a two-way analysis of variance (ANOVA). The difference between mean values was enumerated using Tukey's multiple range test and the data were indicated as means and standard deviation (SD). The statistical differences were determined using SPSS 22.0 software (SPSS Inc., Chicago, IL, USA), with the level of significance set at $p<0.05$. MATLAB (2016a) software was used for mathematical modelling, the curve fitting tool was used to evaluate the experimental data to get R^2, RMSE and SSE values and ANN was used for the computer modelling of the frying kinetics data.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Frying kinetics

4.1.1 Moisture loss kinetic

Sweet potato chip moisture loss curves (moisture content vs. frying time) during deep frying that have been pre-treated with control, microwave, hot water combined with microwave and osmotic dehydration combined with microwave blanching are shown in figures 4.1, 4.2 and 4.3. The graphs depict the relationship and interaction between moisture ratio and frying time at various temperatures (130, 150 and 170°C) and frying times (2, 4, 6,8,10 minutes).

The curves represent normal drying behaviour for food commodities, according to Garayo and Moreira (2002), Shyu and Hwang (2001) and Gamble *et al*. (1987). A normal drying procedure consists of three phases. The first is the warm-up period, when the meal absorbs heat from its surroundings until it reaches evaporation temperature. The constant-rate period is defined as a constant rate of evaporation per unit of surface area surrounded by a heating medium during the second phase. The falling-rate period is the third stage, which lasts until the moisture content in the air reaches equilibrium. The moisture level of each frying arrangement rapidly decreased at the start (within 2 minutes) (the microwave blanched samples reducing faster than samples with other pre-treatment procedures) and the moisture loss rate thereafter decreased as the moisture content decreased over time. At the beginning of the frying procedure, the moisture content in each frying condition decreased significantly with frying time and the moisture ratio rate then decreased with time. The occurrence of faster rate of water evaporation from the sample at higher frying temperature can be related to the rapid decline in moisture content value of the sweet potato chips (Diamante *et al*., 2011a). According to Ran *et al*. (2019), pre-treatment in salt solutions improved the dielectric properties of carrots, resulting in a significant increase in the moisture loss rate during microwave-assisted frying.

Islam *et al*. (2019) found that as the frying time was increased, the moisture content of fried edamame fell and the dehydration rate reduced. Deep fat frying of potato particles over the first 150 seconds resulted in significant moisture loss, according to Huang & Fu (2014). Similar findings were reported by Karizaki *et al*. (2013), who found a significant decrease in the moisture content of fried potato samples. Qiu *et al*. (2018) observed that when frying time increased, the moisture content of fried sweet potato chips decreased. Furthermore, as seen in Figures 4.1, 4.2, 4.3, fried samples with the microwave (MW) pre-treatment process greatly increased moisture loss. It shows that at all frying temperatures, MW pre-treated samples lost more moisture than other fried samples pre-treated with other pre-treatment methods (hot water + microwave, osmotic dehydration + microwave and the control). As shown in Fig. 4.1, there was significant increase in moisture loss rate ($p < 0.05$) with the microwave blanched samples in frying at each time point and became faster as the frying time increased. Figures 4.2 and 4.3 shows that moisture content dropped faster in fried OSMW (osmotic dehydration combined with microwave blanching) samples compared to other pre-treated samples.

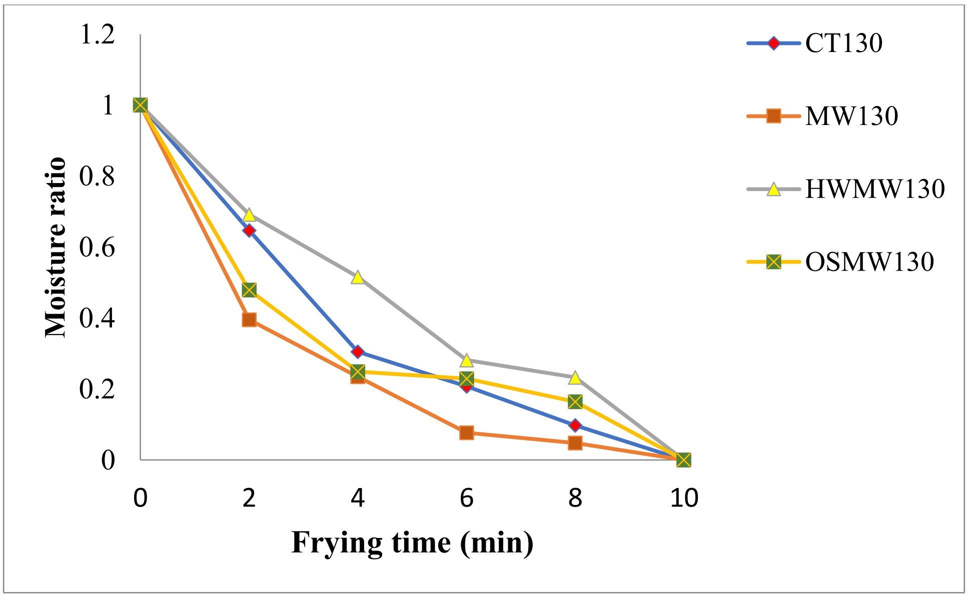


Figure 4.1. Effects of frying time and pre-treatments on the moisture loss rate of sweet potatoes fried at 130°C.

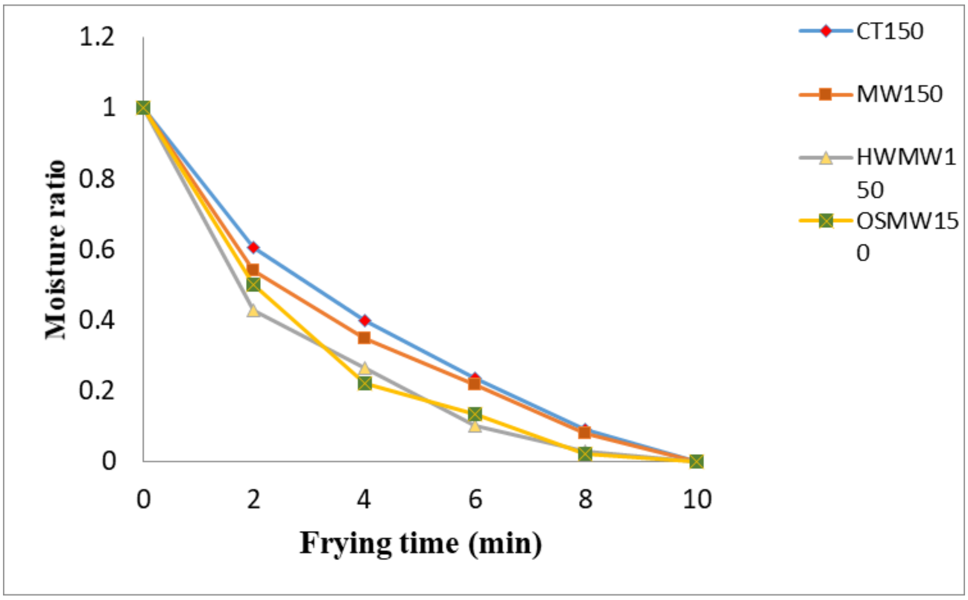


Figure 4.2. Effects of frying time and pre-treatments on the moisture loss rate of sweet potatoes fried at 150°C.

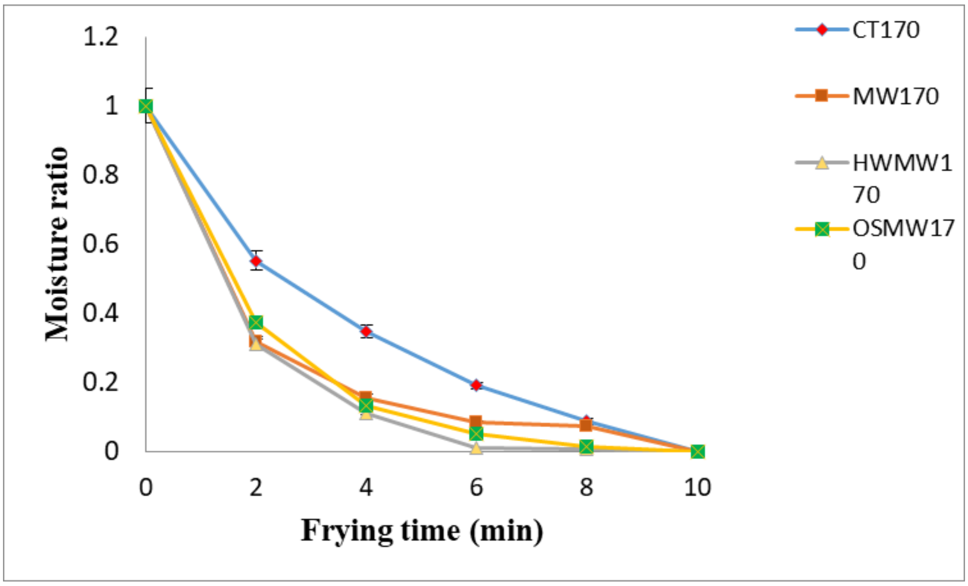


Figure 4.3. Effects of frying time and pre-treatments on the moisture loss rate of sweet potatoes fried at 170°C.

The R^2 value for the rate of moisture transfer ranged from 0.9861-1, as shown in table 4.1, indicating a very excellent fit. For all pre-treatment conditions, the rate constant (k) values for moisture loss increased (MW, HWMW and OSMW). These k- values were higher than the rate constant values of the control samples at all frying temperatures.

Table 4.1: Mathematical models result for moisture loss kinetic

Treatment	Temperature	Model	R^2	RMSE	SSE
Control	130°C	Middili	0.9944	0.04467	0.003991
Control	150°C	Logarithmic	0.9997	0.01047	0.0002191
Control	170°C	Logarithmic	0.9999	0.005363	0.00005752
MW	130°C	Logarithmic	0.9979	0.02708	0.001467
MW	150°C	Logarithmic	0.9996	0.01172	0.0002748
MW	170°C	Middili	0.9984	0.0235	0.001105
HWMW	130°C	Middili	0.9895	0.05815	0.006764
HWMW	150°C	Logarithmic	0.9981	0.02624	0.001377
HWMW	170°C	Logarithmic	0.9994	0.01567	0.0004914
OSMW	130°C	Middili	0.9861	0.06565	0.008621
OSMW	150°C	Middili	0.9983	0.02479	0.001229
OSMW	170°C	Middili	1	0.002559	0.00001309

Table 4.2 shows the effective moisture diffusivity values of mass transfer during the frying of sweet potato samples. For the mass transfer, the effective moisture diffusivity values varied from 1.212×10^{-6} to 9.999×10^{-7} m^2/s. These results are comparable to those reported by Oladejo *et al*. (2017) in their study of the effects of ultrasound pre-treatments on the kinetics of moisture loss and oil uptake during deep fat frying of sweet potatoes (*Ipomoea batatas*), who found values of 2.29×10^{-9} to 9.32×10^{-9} m^2/s.

The effective moisture diffusivity values increased significantly for most of the pre-treatments, however at OSMW 170°C, the effective diffusivity decreased compared to samples with other pre-treatments fried at the same temperature. This is most likely due to a crust forming on the sweet potato's surface, which prevented moisture transmission.

The activation energy values for the rate of moisture transfer of fried sweet potato samples for control, MW, HWMW and OSMW are presented in Table 4.2. The R^2 values ranged from 0.9861 to 1, indicating a well-fitting model. The activation energy is the amount of energy necessary to convert a reactant into a product at the simplest level (Hindra & Baik, 2006; Huang & Fu, 2014; Oyedeji *et al*., 2016). As a result, in this study, the activation energy is defined as the minimum amount of energy required to start moisture loss during frying. The value of the activation energy of osmotic dehydration combined with microwave blanching samples was the highest, whereas the activation energy of the control sample was the lowest. This indicates that the untreated fried sweet potato was the least responsive to temperature variations.

The pre-treated fried potato (blanched, blanched and dried) had a higher activation energy than the control, according to Troncoso and Pedreschi (2009). The use of osmotic solution pre-treatments in this investigation may have contributed to the same outcomes.

The appendix section contains the results of the mathematical modeling of the moisture ratio, which were then fitted into 11 experimental models. The model with the highest R^2, lowest RMSE and lowest SSE was chosen as the best fit. The Midilli and Logarithmic models outperformed the other nine models, however the Midilli model was chosen as the best overall model with R^2 of 1, RMSE of 0.002559 and SSE of 0.00001309.

Table 4.2. Effective diffusivity and activation energy values of untreated and pre-treated sweet potato samples.

Pre-treatment method	$D_{eff}(m^2/s)$	$E_a(KJ/mol)$	$K(min^{-1})$	R^2
CT1	1.212×10^{-6}		0.2089	0.9944
CT2	1.187×10^{-6}		0.1367	0.9997
CT3	1.245×10^{-6}		0.2202	0.9999
CT		0.96		
MW1	1.658×10^{-6}		0.4801	0.9979
MW2	1.243×10^{-6}		0.09471	0.9996
MW3	1.511×10^{-6}		0.748	0.9984
MW		3.15		
HWMW1	8.078×10^{-7}		0.1479	0.9895
HWMW2	1.765×10^{-6}		0.402	0.9981
HWMW3	2.932×10^{-6}		0.5868	0.9993
HWMW		47.96		
OSMW1	9.999×10^{-7}		0.008621	0.9861
OSMW2	1.837×10^{-6}		0.001229	0.9983
OSMW3	2.257×10^{-6}		0.4932	1
OSMW		117.14		

D_{eff} =Effective diffusivity, E_a =Activation energy, k =moisture loss rate constant and the confidence level is set at 95%.

4.1.2 Oil uptake kinetic

The amount of oil that is absorbed is one of the most important aspects of fried foods. Food composition, surface roughness, frying conditions and oil types are only a few of the elements that affect oil uptake during frying (Zhang *et al.,* 2018). Oil can account for up to 50% of the overall weight of some things (Bouchon, 2009). In this investigation, the control sample's oil content ranged from 5.4 % to 69.2 %. As a result of the pre-treatment techniques used, the oil uptake was greatly reduced. Fried sweet potato chips with oil content ranging from 5.2 % to 37.4 %, 6.4 % to 39.4 % and 1.9 % to 52.6 % were produced by MW, HWMW and OSMW, respectively.

Figures 4.4, 4.5 and 4.6 show the effects of temperature change, time variation and combinations of microwave blanching, hot water blanching and osmotic dehydration on the oil uptake of fried sweet potato chips. Temperature and time of frying were also critical factors in oil absorption (Fig 4.4, 4.5 and 4.6). As the frying time and temperature increased, the oil absorption became increasingly significant. The oil uptake increased significantly ($p < 0.05$) when the moisture evaporated at the start of the frying, but subsequently remained essentially constant after reaching equilibrium during each frying operation. As the frying time increased, the tissue and holes in the food matrix expanded further. The creation of capillary holes and a crust on the surface structure allowed significant oil uptake into the material during the early stages of frying the sweet potatoes (Dehghannya & Abedpour, 2018). As a result, there was more oil adherence on the pores (Sobukola *et al*., 2013). Similar findings were also reported by Garayo and Moreira (2002) for potato chips and vacuum fried gilthead sea beam (*Sparus aurata*) fillets (Andres-Bello *et al*., 2010).

In comparison to other pre-treatments, microwave-assisted osmotic dehydration blanched samples showed decreased oil content. This decrease could be due to soluble solids permeating the food matrix (Garcia *et al*., 2016). On the fried sweet potato chip surfaces, the osmotic solution generated a crust with fewer pores and structural damage. As a result, the amount of oil absorbed throughout the cooling and pressurization processes was lowered (Sobukola *et al*., 2013). The pressure and areas for oil penetration were reduced after frying, resulting in less oil uptake (Jia *et al*., 2018; Zhang *et al*., 2018).

When compared to the control sample, Bunger *et al*. (2003) discovered a 22.2% reduction in oil uptake of potatoes pre-treated (soaked) in NaCl solution. At 175°C frying temperature, Lalam *et al*. (2013) found that methylcellulose (MC) coated chicken nuggets had 26.4g/100g and 14.3g/100g less oil uptake in the crust and core, respectively, than control samples. According to Donath *et al*. (2003) a pre-dried chickpea flour-based snack item fried at 175°C had a 54 % lower oil content than the control sample. Karizaki *et al*. (2013) discovered that pre-treated fried samples with osmotic dehydration and ultrasound assisted osmotic dehydration contained less oil than untreated samples. Yu *et al*. (2016) discovered that covering deep-fried potato chips with guar gum and glycerol significantly reduced oil absorption.

Following the frying process, oil removal from fried dishes is a key challenge. Deep frying necessitates a de-oiling process to remove oil that has clung to the surface of the products as well as oil that has absorbed into the pores during the frying process. Deep fryers are frequently used in conjunction with centrifuge processes to limit oil uptake in fried items following deep frying (Moreira *et al*., 2009). According to Shyu *et al*. (2005) centrifugation after deep frying reduced oil uptake in fried carrot chips by 12.3% w.b.

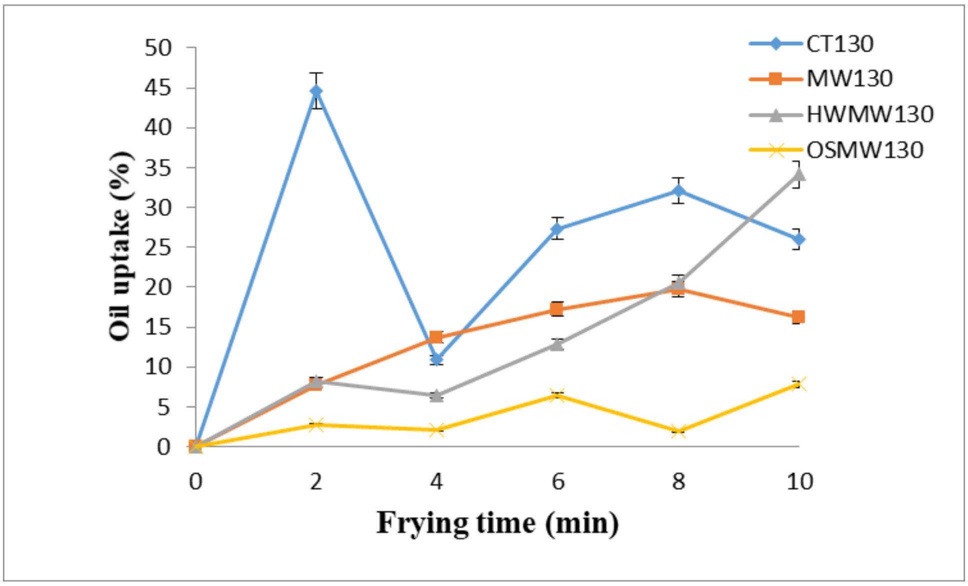


Figure 4.4. Effects of frying time and pre-treatment on the oil uptake of fried sweet potatoes at 130°C.

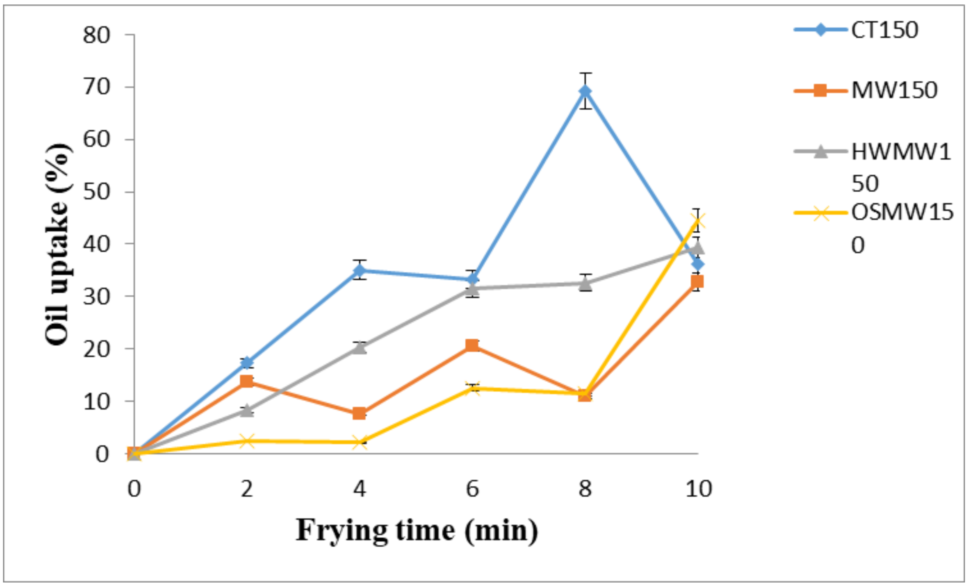


Figure 4.5. Effects of frying time and pre-treatment on the oil uptake of fried sweet potatoes at 150°C.

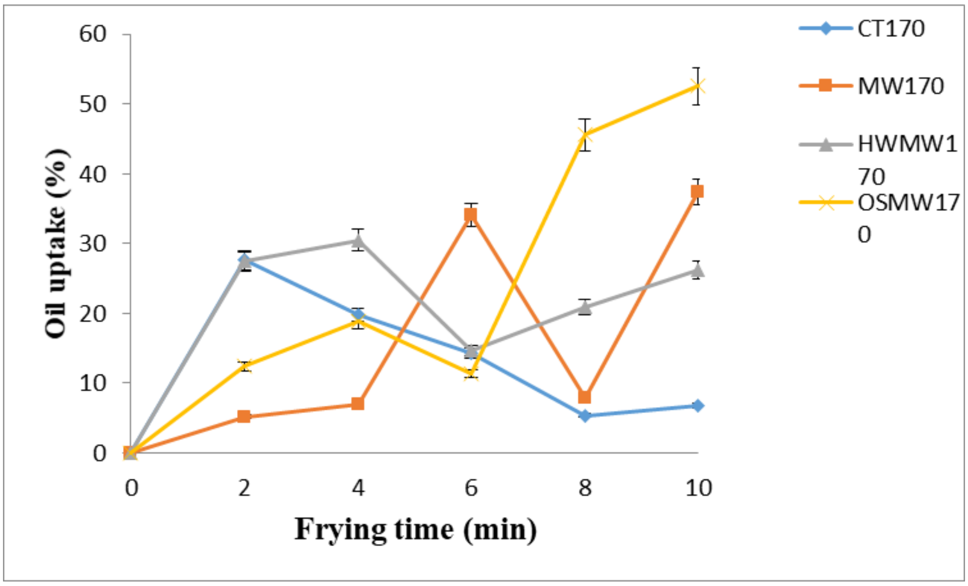


Figure 4.6. Effects of frying time and pre-treatment on the oil uptake of fried sweet potatoes at 170°C.

The fitting result for the oil uptake results into five mathematical models is shown in table 4.3. Selection of the best fit model was based on the criteria of the highest R^2, lowest RMSE and SSE values. The 4th and 5th model had similar R^2 values but the 5th model eventually had the overall best fit with a R^2 value of 0.9727, RMSE value of 0.3059 and SSE value of 0.3742.

Table 4.3: Mathematical models result for oil uptake kinetic.

Treatment	Temperature	Model	R^2	RMSE	SSE
Control	130°C	Exponential	0.9433	0.4841	0.9373
Control	150°C	Exponential	0.9572	0.497	0.9879
Control	170°C	Exponential	0.9727	0.3059	0.3742
MW	130°C	Exponential	0.8828	0.4126	0.6809
MW	150°C	Exponential	0.9614	0.2344	0.2198
MW	170°C	Exponential	0.9499	0.2583	0.2669
HWMW	130°C	Second order	0.8104	0.6641	1.323
HWMW	150°C	Linear	0.9245	0.4544	0.8258
HWMW	170°C	Linear	0.9044	0.3236	0.4189
OSMW	130°C	Exponential	0.8583	0.1988	0.1581
OSMW	150°C	Second order	0.9496	0.1724	0.08914
OSMW	170°C	Second order	0.94	0.2176	0.1421

4.2 Quality attributes

4.2.1 Colour

Moisture loss, oil migration, starch gelatinization, protein denaturation and the Maillard reaction, as well as frying temperature and time, all affect the colour of fried food (Krokida *et al*., 2001).

The frying temperature and frying duration had a substantial impact on the colour values ($P < 0.05$) L*, a* and b* of the fried sweet potato chips. The L* value is a key criterion for determining fried food quality and a higher L* was expected. After 10 minutes of frying at 130, 150 and 170°C, the total colour difference (ΔE) values of fried sweet potatoes increased as shown in Fig. 4.7. The colour difference values ranged from 33.46-47.45(control), 39.68-47.27 (microwave blanching), 38.75-47.55 (Hot water + microwave blanching) and 39.69-49.39 (osmotic dehydration + microwave blanching). The colour difference was highest for osmotic combined with microwave blanching pre-treated samples with a value of 49.39 and lowest at the control sample at a temperature of 130°C with a ΔE of 33.46. The immersion of sweet potato samples in sucrose solution resulted in a reduction in the lightness of the sweet potatoes, which is a symptom of browning, according to (Calder *et al*., 2011). As the frying temperature/time increases, the magnitude of the total colour difference values increases and the extent of the increase grows faster at higher frying temperatures. The difference in total colour difference values was shown to be exponential in the figure 4.7.

ΔE increased rapidly with time at the start of the operation, reaching greater values at higher temperatures. The maximum overall colour values were affected by the treatment, temperature and time combination.

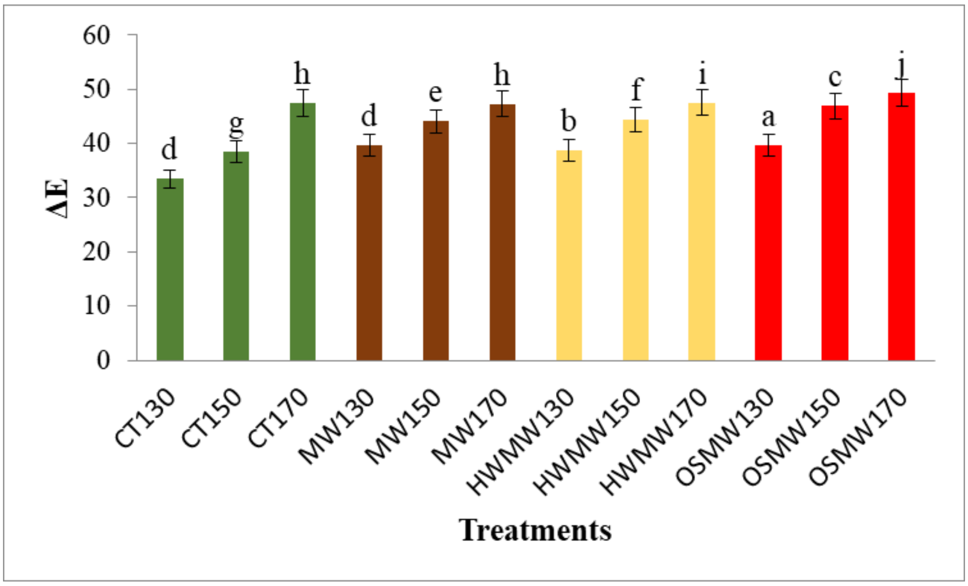


Figure 4.7: Effects of frying temperature and pre-treatment on the colour difference of fried sweet potatoes.

4.2.2 Texture (Hardness)

With increasing frying temperature and frying time, the hardness of fried sweet potato chips increased significantly ($p < 0.05$). The production of crust was accelerated at the samples' outer zones and moisture loss was quick as a result of the higher oil temperature, resulting in increased end product hardness (Esan *et al*., 2015). The microwave blanched samples, on the other hand, exhibited the lowest hardness value (1.62g/mm) after the control samples at 170°C.

The effects of pre-treatments, frying time and temperature on the hardness of microwave-assisted vacuum-fried sweet potato chips are shown in Figure 4.8. Sucrose osmotic dehydration in combination with microwave blanching pre-treatment improved the hardness of the fried sweet potato chips ($p<0.05$), indicating that sucrose osmotic dehydration in combination with microwave blanching pre-treatment resulted in a harder textural feature of the samples. Microwave absorption was increased and water loss from samples during frying was accelerated, resulting in a denser porous structure and a harder crust in the fried sweet potato chips (Adedeji & Ngadi, 2018). Reduced porosity or a denser porous structure would lower the brittleness of the surface layer in the fried crust, resulting in an increase in the stiffness of the fry (van Koerten *et al*., 2015a). Similar findings were made in previous studies by Piyalungka *et al*. (2019), who found that pre-treating vacuum fried pumpkin chips in a 20 percent (w/w) maltodextrin solution enhanced the hardness of the chips.

The figure also shows that the HWMW blanched samples at the three different temperatures had the lowest hardness value compared to the MW and OSMW samples even though the untreated samples had the lowest hardness values. The softening of texture caused by damaged structural components of cell walls, such as cellulose and pectin, caused by blanching techniques could account for this effect (Loredo *et al*., 2014). Membranes of cells degradation lowers the cell's turgor pressure and lowers the cell's hardness (Gonzalez *et al*., 2010b).

Sweet potato starch granules gelatinized gradually as the temperature increased, resulting in a soft texture (Fig. 4.8) at lower temperatures 130°C and 150°C, the texture of samples fried at these temperatures was influenced by starch gelatinization of the sweet potatoes. The sample's tissue becomes softer as the degree of starch gelatinization increases (Alvarez *et al*., 2001). As a result, gelatinization and alterations in cell walls and membranes were attributed for the softening of texture in HWMW blanched samples.

Furthermore, despite similar levels of enzyme inactivation, Osmotic dehydration combined with microwave blanching (OSMW) at a final temperature of 170°C resulted in improved texture compared to CT, MW, HWMW blanched samples at the same temperatures. Higher temperatures and osmotic dehydration pre-treatment may have contributed to increased microwave absorption and hence faster water loss from samples during frying, resulting in a denser porous structure and tougher crust in the fried sweet potato chips (Adedeji & Ngadi, 2018).

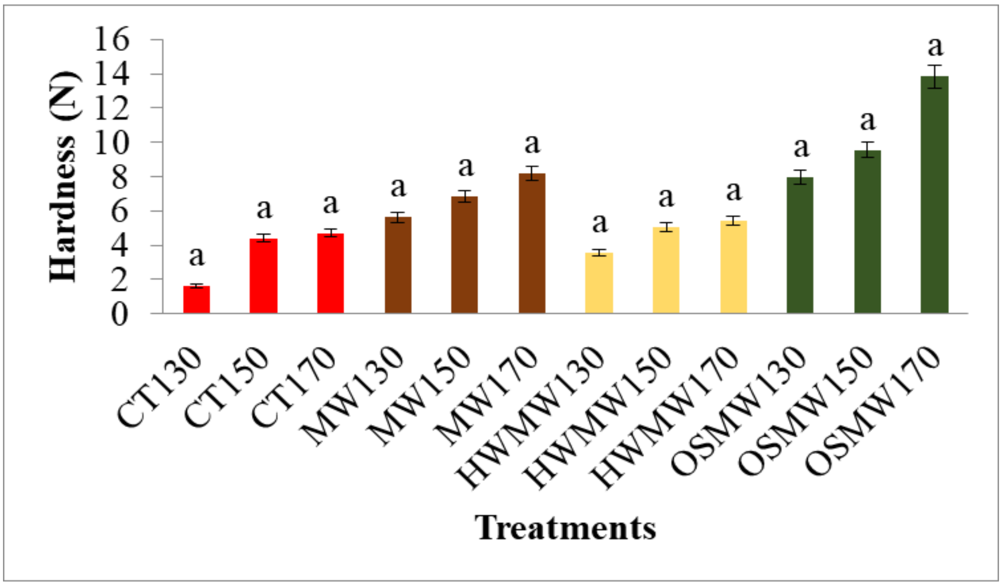


Figure 4.8: Effects of frying temperature and pre-treatments on the texture (hardness) of fried sweet potatoes.

4.2.3 Ascorbic acid

Figure 4.9 shows that at all frying conditions, the ascorbic acid value was retained and affected significantly ($p<0.05$) for all treatments, the lowest ascorbic acid value was 0.235mg (MW170) and highest ascorbic value was 0.46mg (0SMW170). The ascorbic acid content of osmotic dehydration combined with microwave blanching (OSMW) pre-treated samples was higher than that of other pre-treated samples. This result could be attributed to the loss of water and solid gain during the immersion of samples in osmotic solution (Karnjanapratum *et al*., 2017). As a result, it can be concluded that OSMW blanching could result in significant improvement of the ascorbic acid retention of fried sweet potatoes.

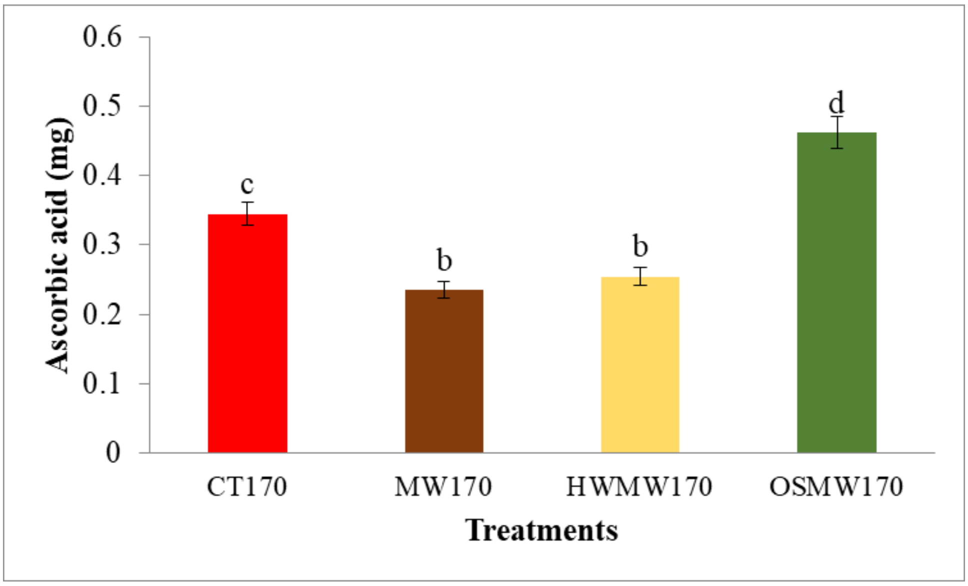


Figure 4.9: Effects of frying temperature and pre-treatments on the ascorbic acid values of fried sweet potatoes.

4.2.4 Bulk Density

Bulk density is one of the major functional properties of foods. Functional properties are the fundamental physicochemical features of foods that reflect the intricate interactions of food components' structures, molecular conformation, compositions and physicochemical properties with the environment and the conditions in which they are measured and linked (Kaur and Singh, 2006; Siddiq *et al*., 2009). Functional features are required to help predict and evaluate how new proteins, fats, carbohydrates (starch and sugars) and fibres will behave in specific food systems, as well as to show if they may be utilised to supplement or replace current protein sources, (Kaur and Singh, 2006; Siddiq *et al*., 2009) carbohydrates (starch and sugars), fat and fibre.

Fig 4.10 shows the effect of pre-treatments on the functional property (bulk density) of the fried sweet potatoes. The bulk density values ranged from 0.44-0.53g/cm^3. The OSMW (170°C) sample exhibited the maximum bulk density, whereas the HWMW (150°C) sample exhibited the lowest. Because particle size is inversely related to bulk density, a product's bulk density is determined by particle size (Onimawo and Akubor, 2012). Bulk density is also a key factor in determining how easy it is to package and transport particle or powdered foods. Joel *et al*., (2014) reported similar results with a bulk density of 0.60g/ml-0.85g/ml. The results in this study is also in agreement with the results of Donaldben *et al*., (2020), where the bulk density increased significantly and ranged from 0.67-0.79 g/cm^3. Akubor and Ukwuru (2003), also reported similar results of increased bulk density of soybean and cassava flours with bulk density values range of 0.50-0.67 g/cm^3. Higher bulk density is better because it allows for easier dispersion and a thinner paste, however powdered meals with low bulk density are a favourable physical property for deciding key transport and storage variables.

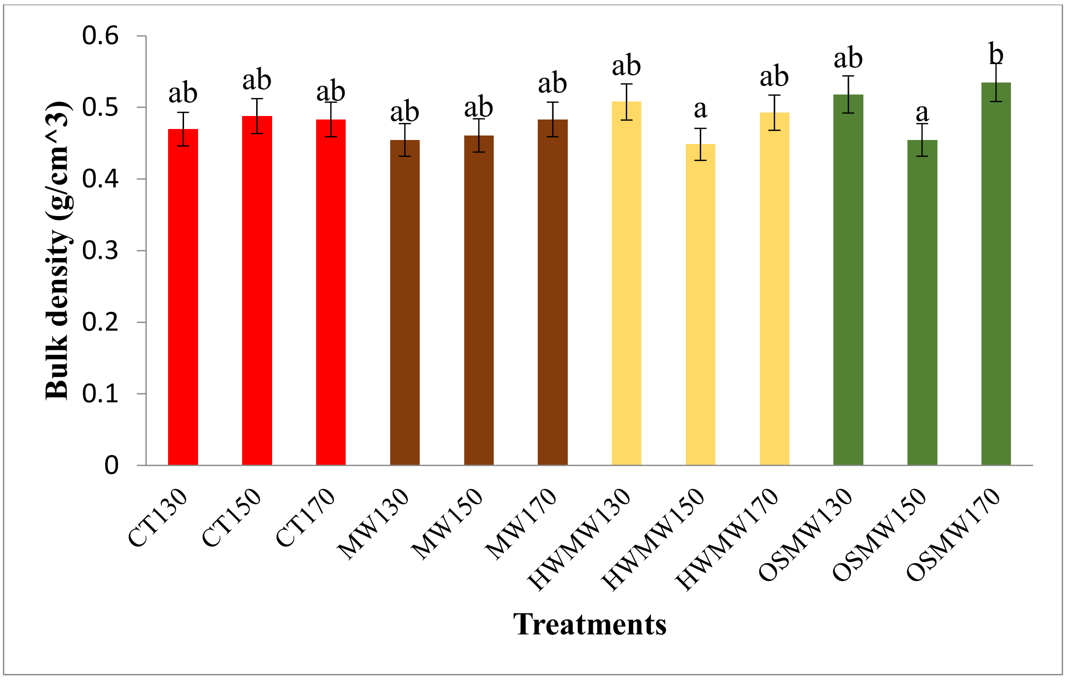


Figure 4.10: Effects of frying temperature and pre-treatments on the bulk density of fried sweet potatoes.

4.2.5 Electrolyte leakage

The effects of pre-treatment on the electrical conductivity of fried sweet potatoes at 130, 150 and 170°C are shown in Fig. 4.11. Electrical conductivity of fried sweet potatoes increased with increasing frying temperature (P0.05) under all pre-treatment conditions. When the final temperature was 170°C, the relative electrical conductivity increased rapidly in all four pre-treatments, but the OSMW sample had the highest electrical conductivity (200.67µs/cm), which was likely due to increased cell-membrane permeability with increased temperature, which facilitated intracellular ion diffusion into the mannitol (isotonic solution) (Gonzalez &Barrett, 2010a). The sample that had not been treated (130°C) had the lowest electrical conductivity (159 µs/cm).

Furthermore, the pectin components in the central lamella deteriorated as the temperature increased, resulting in enhanced electrical conductivity (Roberts & Proctor, 1955).

Fuentes *et al*. (2014) reported a similar finding, with electrolyte loss from potato discs reaching 95% after heat treatment at 70°C. According to Ersus and Barrett (2010), onion tissues had 92 % ion leakage after 100 pulse treatments at 333 V/cm. Zhang *et al*. (2020) found that relative electrical conductivity increased considerably with increased temperature ($P < 0.05$) in their research on the Effect of radio-frequency-assisted blanching on the polyphenol oxidase, microstructure, physical properties and starch content of potato. During heating from 20 to 95°C, Chaiwanichsiri *et al*. (2001) investigated the electrical conductivity of 50 g/kg suspensions of starch from various origins. The free ions inside the granules, primarily potassium, magnesium, calcium and sodium (Noda *et al.,* 2005), began to enlarge when the starch granules began to swell (at around 62°C in the case of the potato starch suspension), resulting in an increase in electrical conductivity. The electrical conductivity increased as the temperature increased until the granules collapsed (about 72°C in the case of potato starch suspension). At that point, all of the ions inside were completely released into the suspension. A comparable mechanism could occur in potato tissue during cooking, which would explain the large increase in EL between 60 and 70 °C. Furthermore, the solubilisation of peptic chemicals at high temperatures (Alvarez *et al*., 2001), which causes cell wall breakdown, also causes ion transport to the apoplast, adding to the rise in EL values.

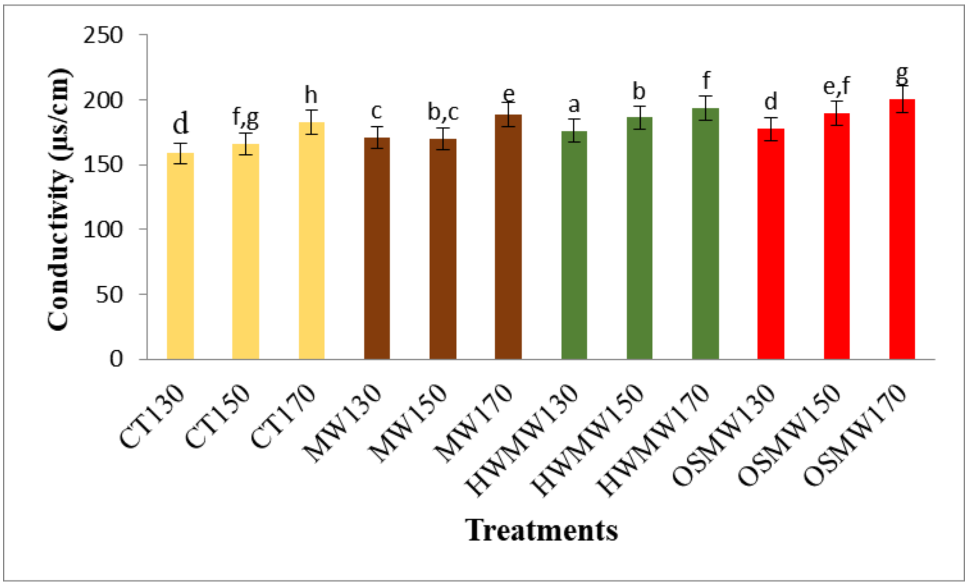
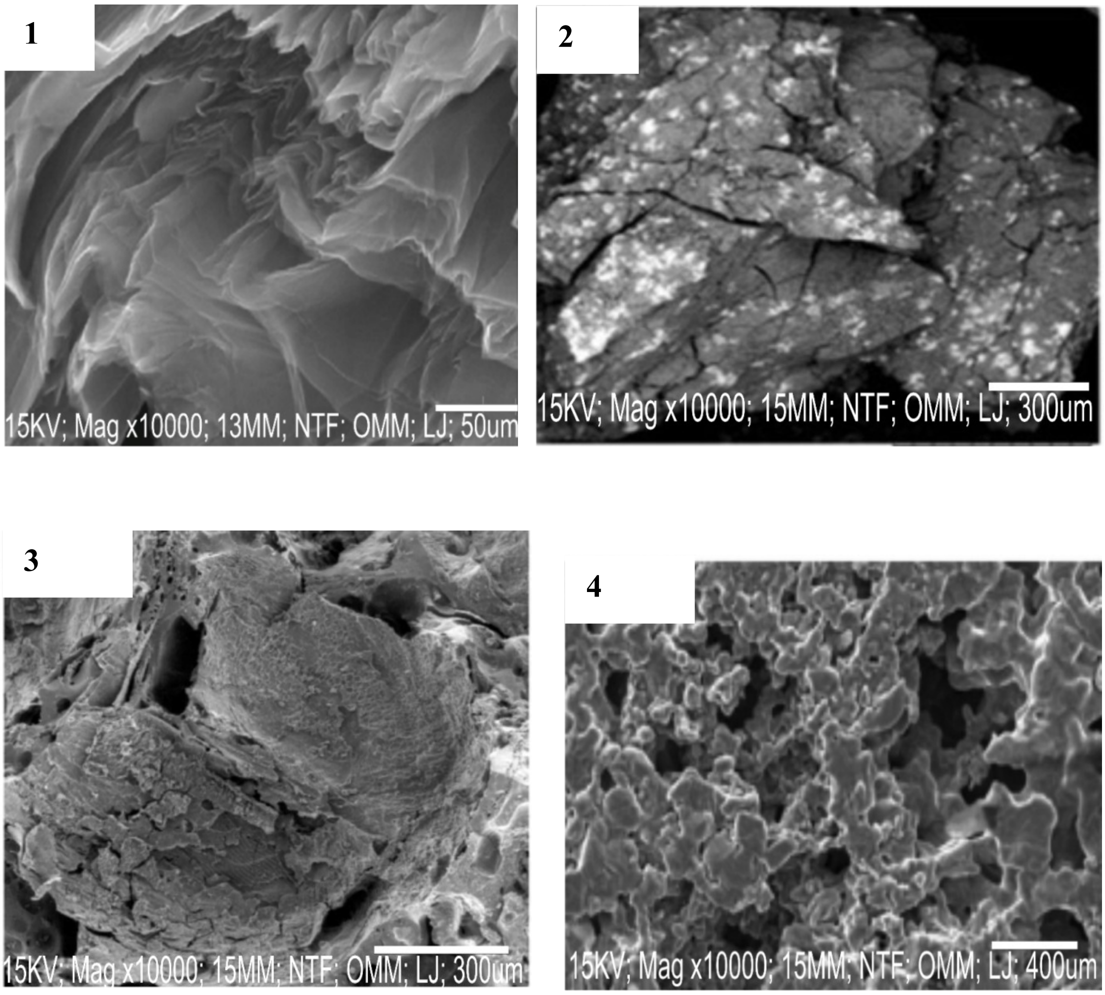


Figure 4.11: Effects of frying temperature and pre-treatments on the electrical conductivity of fried sweet potatoes.

4.2.6 Microstructure

The characterization of microstructural changes generated by microwave-assisted blanching and other pre-treatments application could aid in explaining the observed impacts on mass transfer and qualitative attributes.

Structures of untreated and pre-treated fried sweet potatoes fried at 170°C for 10 minutes are shown in plates 4.1, 4.2, 4.3 and 4.4. The structure of untreated (CT170) fried sweet potato is shown in Figure 4.1. In the figure, the oil absorbed by the untreated sample is clearly evident. The untreated samples absorbed much more oil than the treated samples, as well. The structure of an OSMW pre-treated fried sweet potato sample is shown in Figure 4.4. According to Oladejo *et al*. (2017), microstructure analysis revealed that untreated samples absorbed more oil than pre-treated samples and that samples pre-treated in microwave-assisted osmotic dehydration absorbed the least amount of oil compared to other pre-treated samples. When comparing the structure of CT, MW and HWMW samples to the structure of CT, MW and HWMW samples, oil uptake is reduced. This also supported what was reported in section 4.1.2, namely that at a frying temperature of 170°C, the fried samples pre-treated in OSMW had the lowest oil content compared to the other samples. The structure of fried sweet potato prepared using OSMW blanching is shown in Figure 4.4. The ruptured structure was filled with oil as a result of osmotic dehydration, which fractures the central lamella and dissolves the cell wall (pectin) (Prinzivalli *et al*., 2006). Shamaei *et al*. (2012) discovered that the concentration of osmotic solution affected the microstructure of fruit, which was supported by this investigation. According to Lisiska and Golubowska (2005), thermal procedures such as blanching and frying generated the largest changes in potato tissue. They also found that drying potato slabs before frying caused significantly higher tissue damage.



Plates 4.1-4.4: Scanning electron microscope images of different pre-treated fried sweet potato chips at 170^{o}C. Image was selected of each treatment as follows: Ct170-untreated fried chip (1), MW170-microwave treated fried chip (2), HWM170- Hot water + microwave treated fried chip (3) and OSMW170- osmotic + microwave treated fried chip (4) respectively.

4.2.7 Shrinkage

Figure 4.12 shows the influence of several pre-treatments on the degree of volume shrinkage of sweet potato chips during deep frying at temperatures of 130, 150 and 170°C as a function of frying time. During the early phases of frying, volume shrinkage was mostly caused by the loss of water.

The amount of water lost and the amount of oil absorbed by the sweet potato chips are proportional to the degree of shrinkage. The sweet potato chips sample with MW blanching at 130°C had the lowest shrinkage value of 5.7mm during the frying process, while the sample with HWMW 170°C had the highest shrinkage value of 27.6mm, which was significantly higher than the other pre-treated samples (and the control) due to less oil uptake and more water loss in this sample compared to the others. In the study "Reducing oil content of fried potato crisps greatly utilizing a 'sweet' pre-treatment approach," Tran *et al.,* (2007) reported similar findings. The pre-dried and dipping potato crisps shrank substantially more during the frying process than the pre-dried non-dipping (and control) samples, owing to lower oil uptake and higher water loss in these samples (potato crisps) in contrast to the other samples (potato crisps).

The figure also illustrates that the degree of shrinkage of the samples was determined by the frying temperature, with the degree of shrinkage increasing inexorably as the frying temperature was increased.

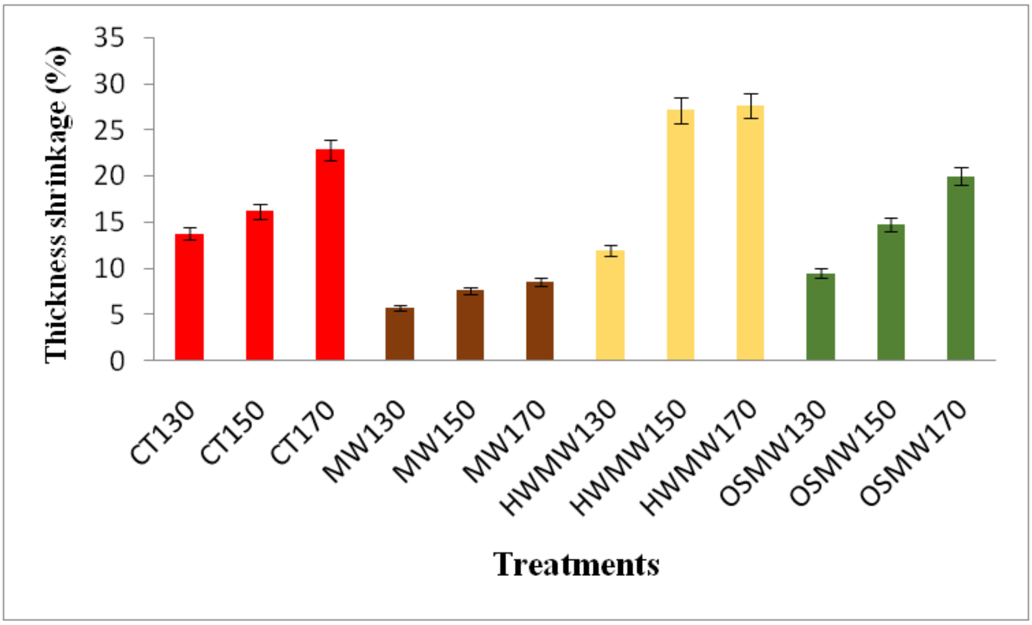


Figure 4.12: Effects of frying temperature and pre-treatments on the shrinkage of fried sweet potatoes.

4.3 ANN Modelling

4.3.1 Training and analysing the network

The Neural Fitting method was used to select data, design a network and train it. The mean square error (MSE) and regression analysis coefficient (R^2) in the MATLAB software were used to assess its performance. The back-propagation (BP) algorithm was used to train the multi-layer perceptron (MLP). The Levenberg-Marquardt approach was used to achieve error minimization in MLP networks. Supervised training was performed on the input and output variables.

The best number of neurons in the hidden layer, training samples, validating samples and testing samples were chosen using the trial-and-error method to produce a better prediction of the output response. For the ANN modeling, a total of 60 samples were used: 42 for training, 9 for testing and 9 for validation. Errors were relayed back through the neurons throughout the training process, causing the weights of the neurons to be changed. This training procedure was repeated until the desired result was achieved. The network was trained for 9 iterations after trial and error was used to determine the appropriate number of neurons for the hidden layer. The trained network's MSE is 1.24954e-1, with an R^2 of 0.97643 as the regression coefficient. Thus, once the network's performance has reached its optimal fit, it is trained for another 9 epochs before stopping the training process, preventing the network from being overfit. In the performance parameter neural network, the best fit point is checked at 0.1867. As illustrated in Fig. 4.13, the best fit point occurs at epoch number three. The experimental design matrix, as well as the artificial neural network prediction and error difference, are shown in Table 4.4. Figure 4.14 shows the parity plots for the training, testing and entire data sets. The correlation between predicted responses (outputs) and experimental data was measured by the regression coefficient.

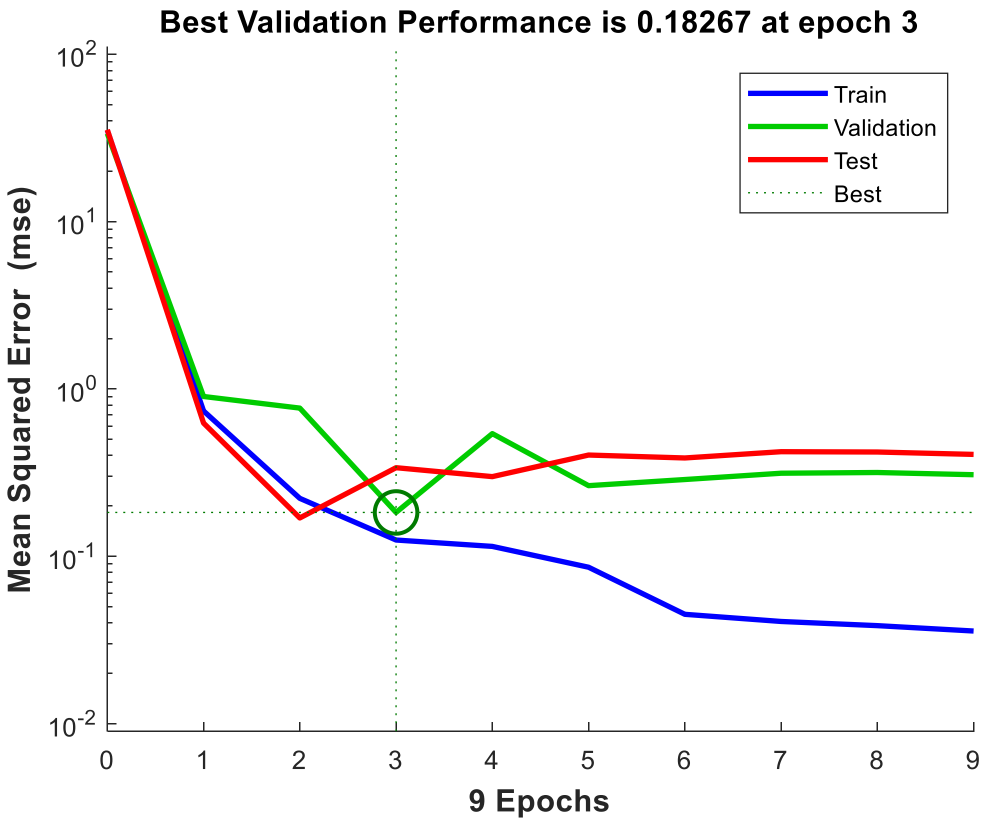


Figure 4.13. Mean square error relative to number of epochs.

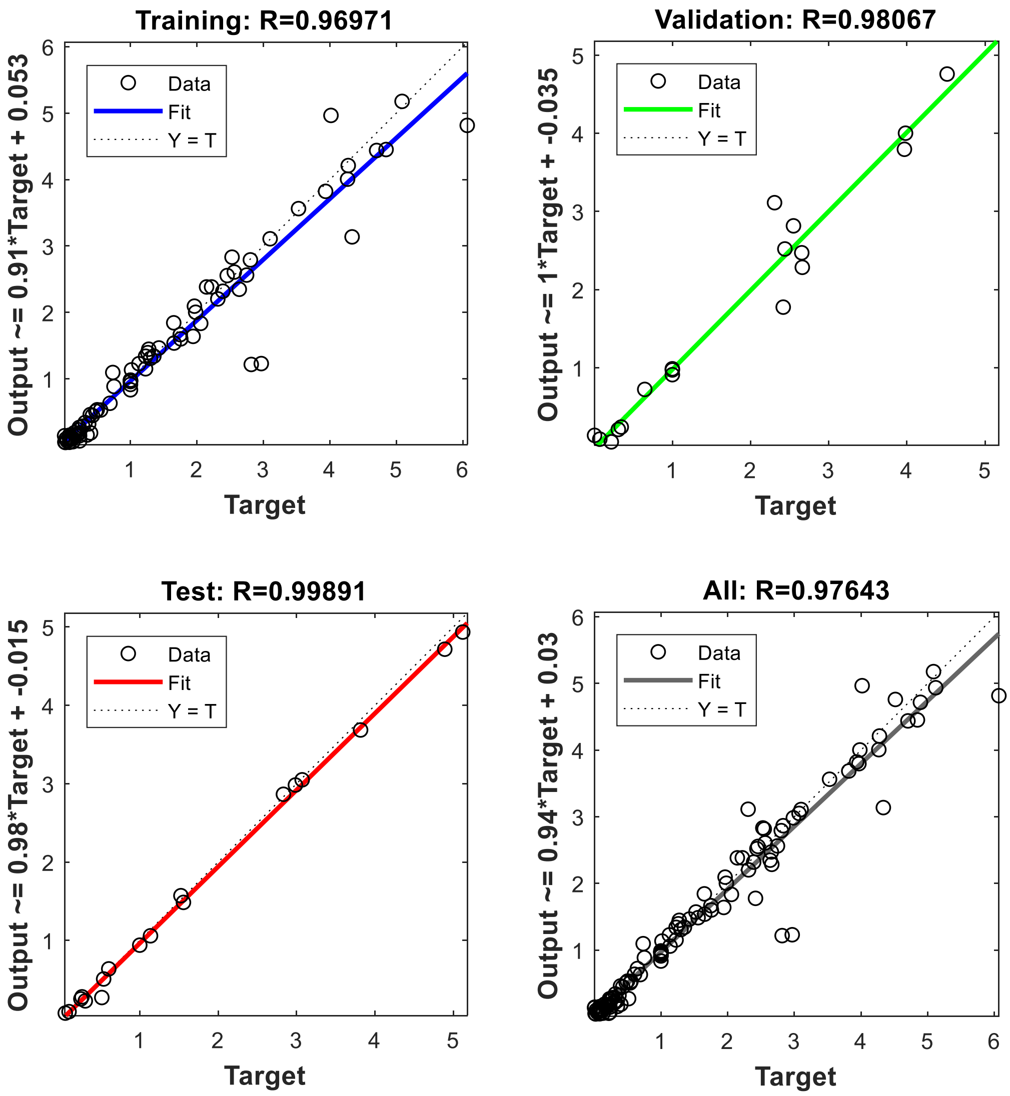


Fig. 4.14. Correlation plots of predicted Vis-a Vis experimental values for the ANN model data sets.

4.3.2 Appraisal of model predictability in artificial neural network

It was important to execute supervised training in order to evaluate the ANN output error between the actual and anticipated output in order to estimate the model fit for prediction in artificial neural networks (Adesina *et al*., 2021). The predictive measures employed for the model evaluation were coefficient of determination (R^2), root mean square error (RMSE) and sum of square error (SSE) (Ghaffari *et al*., 2006). The optimal neural network model is one with the fewest mistakes (RMSE, SSE) and the highest R^2 proximity to unity (Nath and Chattopadhyay, 2007; Sin *et al*., 2006; Taiwo *et al*., 2018). The basic chart for the training, testing and validation data sets is shown in Figure 4.15.

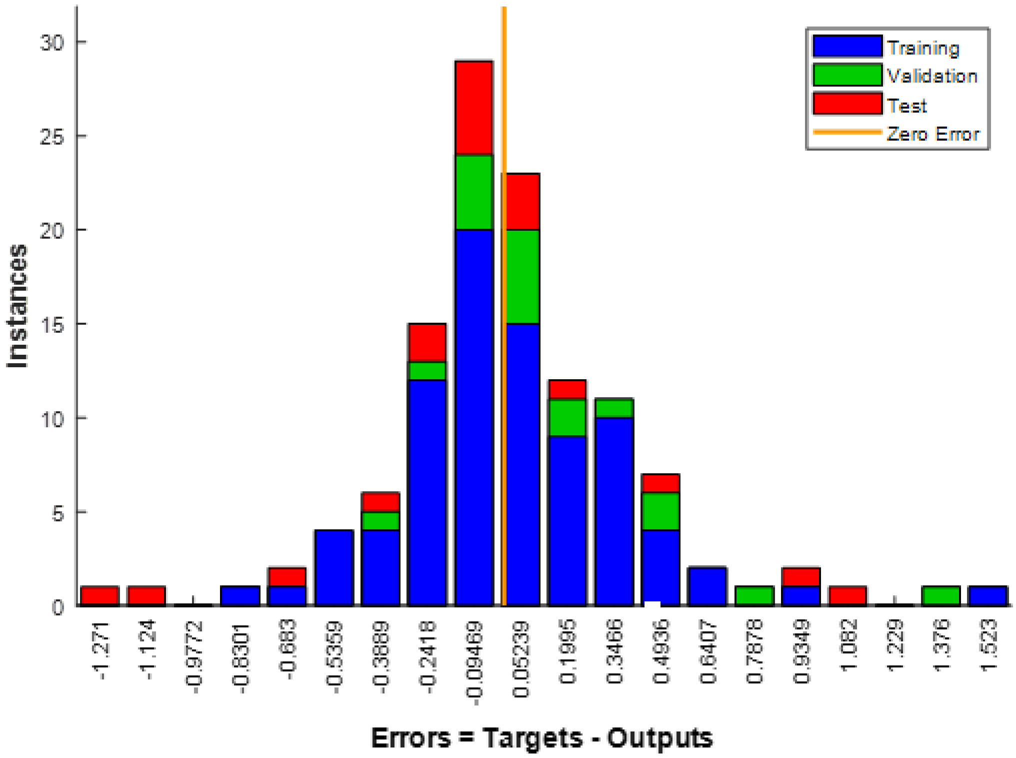


Fig. 4.15 Error Histogram chart for the training, testing and validation data sets

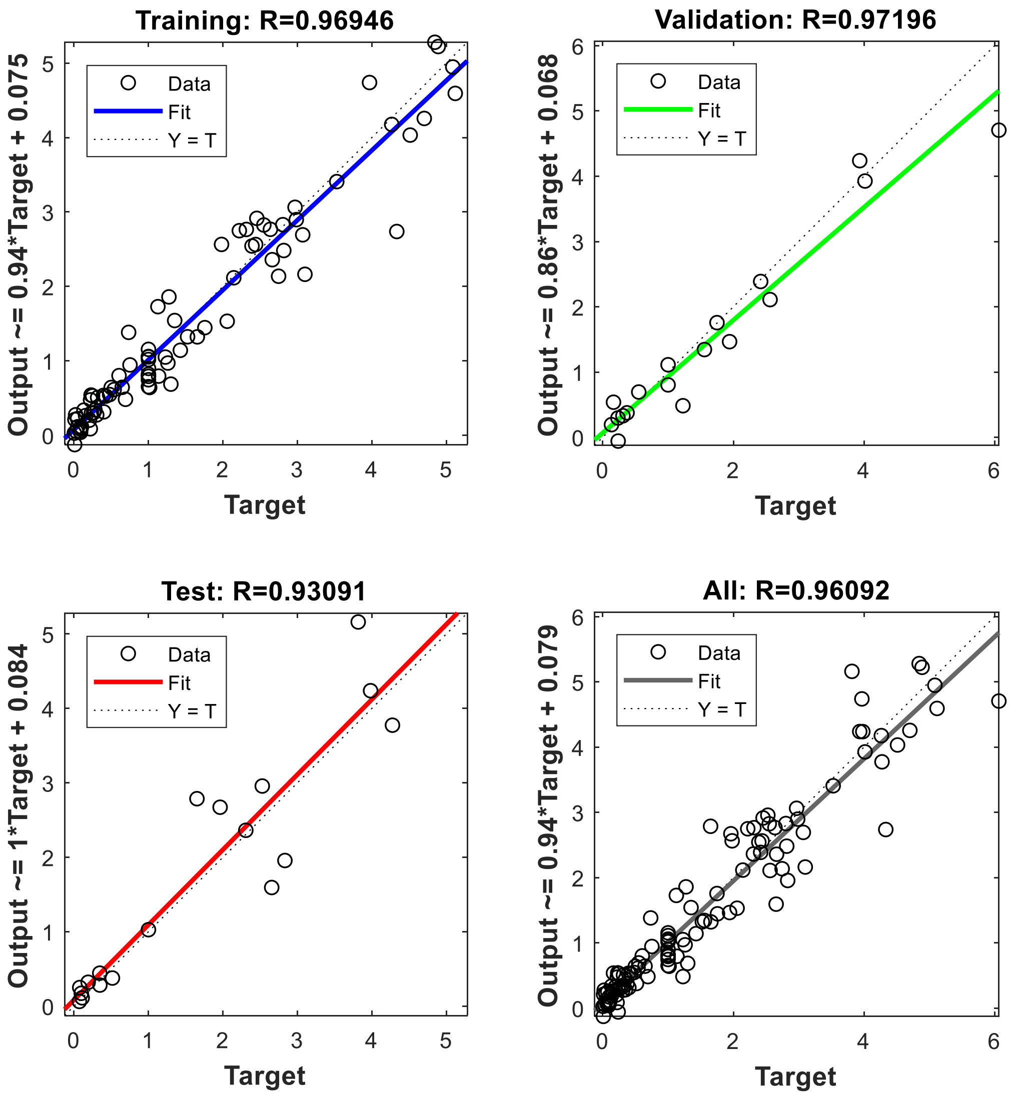


Fig 4.16: Plots of data sets used for ANN training, testing and validation.

Table 4.4: The experimental design matrix along with the artificial neural network prediction and the error difference.

ANN CONNECTION	R^2	MSE	RMSE	SSE
3-10-2-2	0.9	0.017240179	0.131301864	1.034
	0.956768	0.2932	0.541479	17.592

4.4 Statistical analysis

A two-way analysis of variance was performed on the experimental data at a 5% significance level ($p<0.05$). The two-way ANOVA was conducted to examine the effect of pre-treatments and temperature increase on quality characteristics of sweet potatoes. There was a statistically significant interaction between the effects of treatments and temperature increase on the quality characteristics, $F(6, 24) = 14.932$, $p = .000$ (electrical conductivity), $F(6, 24) = 85.612$, $p = .000$ (Ascorbic acid), $F(6, 24) = 14.932$, $p = .000$

The Tukey's post-hoc tests, test of between subjects effects showed that the combination of temperature variation and pre-treatments had a significant difference ($p<0.05$) on the electrical conductivity, colour difference, L value, a value, b value, ascorbic acid, microstructure characteristics but there was no significant difference in the quality characteristics of shrinkage, bulk density and texture. In the appendix section, tables of the statistical analysis result are presented to further illustrate the significance level of temperature variation, pre-treatments and the combination of both variables on the frying quality characteristics of sweet potatoes.

A two-way ANOVA was performed to analyse the effect of temperature and pre-treatments on the quality characteristics of fried sweet potatoes.

The two-way ANOVA revealed that there was a significant difference in the interaction between the effects of temperature and pre-treatment on the electrical conductivity $F(6,24)= (14.931)$, $p= (0.000)$, the ascorbic acid $F(6,24)=(85.612)$, $p=(0.000)$, L value $F(6,24)=(15905.368)$, $p= (0.000)$, a value $F(6,24)=(28684.774)$, $p-(0.000)$, b value $F(6,24)=(111763.018)$, $p=(0.000)$, colour difference $F(6,24)=(11790.465)$, $p=(0.000)$. There was no statistically significant difference in the interaction between the effects of temperature and pre-treatments on the shrinkage $F(6,24)=(0.036)$, $p=(1.000)$, the texture $F(6,24)=(0.162)$, $p=(0.984)$ and the bulk density $F(6,24)=(2.274)$, $p=(0.070)$.

Simple main effects analysis showed that independent variable (treatment) did have a statistically significant effect on electrical conductivity ($p=0.000$), ascorbic acid ($p=0.000$), texture ($p=0.003$), L value ($p=0.000$), a value ($p=0.000$), b value ($p=0.000$), colour difference ($p=0.000$) but did not have a statistically significant difference on the shrinkage ($p=0.597$) and the bulk density ($p=0.093$).

Simple main effects analysis showed that independent variable (temperature) also did have a statistically significant effect on electrical conductivity ($p=0.000$), ascorbic acid (p=0.000), bulk density (p=0.011), L value (p=0.000), a value (p=0.000), b value (p=0.000), colour difference (p=0.000) but did not have a statistically significant difference on the shrinkage (p=0.594) and the texture (p=0.191).

CHAPTER 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Microwave-assisted blanching pre-treatments had an effect on the kinetics of moisture transfer and oil uptake during deep fat frying of sweet potatoes.

The moisture content of all pre-treated and untreated samples decreased as the frying temperature and time increased. However, the fried sample fried for 10 minutes at 170°C pre-treated in hot water and microwave blanching had the lowest moisture ratio, whereas the hot water and microwave blanched sample also had the highest moisture ratio at 2 minutes, 130°C frying. The effective moisture diffusivity rate values in this study ranged between 1.212 $\times 10^{-6}$ to 9.999 $\times 10^{-7} m^2/s$ and the activation energy values for moisture ratio ranged from 0.96 -117.14KJ/mol.

In comparison to the other pre-treated and untreated samples, the OSMW fried sample had the highest activation energy for moisture loss, whereas the control (CT) samples had the lowest activation energy. The oil content of samples pre-treated with OSMW reduced as the frying temperature and time increased. Oil uptake decreased as temperature increased from 130°C to 150°C, then increased as temperature increased to 170°C, but oil uptake in the HWMW sample increased at all temperature rates. The OSMW blanched samples showed the least amount of oil uptake when fried at 130, 150 and 170°C for 2, 4 and 6 minutes, respectively.

The quality characteristics of fried sweet potatoes examined in this study were also significantly affected by the microwave-assisted blanching pre-treatments. The texture (hardness) of fried samples became crisper as the temperature of frying increased from 130°C to 170°C, the OSMW (170°C) sample had the highest hardness value (13.841g/mm) compared to the untreated and pre-treated samples, the HWMW had the lowest hardness values compared to other pre-treatments. The study also showed that the electrical conductivity of the fried samples at all frying conditions increased with increase in frying temperature, the OSMW (170°C) had the highest electrical conductivity of 200.67 µs/cm and lowest electrical conductivity 159 µs/cm at the CT (170°C). The microwave-assisted blanching and other pre-treatments had significant effects on the ascorbic acid value retention of the fried sweet potatoes for the untreated and the pre-treated samples. The MW (170°C) sample had the lowest ascorbic value of

0.235mg while the OSMW (170°C) sample had the highest ascorbic value of 0.46mg. Bulk density of fried samples also ranged from 0.44 to 0.53g/cm^3. The microstructure analysis also revealed that the untreated samples had the highest oil retention in comparison with the pre-treated samples. Furthermore, as the frying temperature increased, the colour difference values of the samples increased as well. The OSMW (170°C) sample had the highest colour difference of 49.49 while the control sample had the lowest colour difference of 33.46. The shrinkage values for the deep-fried sweet potatoes ranged from 5.7 to 27.6mm.

The OSMW pre-treatment proved to efficiently increase moisture loss rate and reduce oil absorption of deep-fried sweet potatoes. The study also showed that the OSMW pre-treatment had significant effects in the improvement of the quality characteristics of fried sweet potatoes.

5.2 Recommendations

The following are recommendations for the application of the results and findings. It also include recommendations for further studies.

i. The frying time can be reduced while frying temperature is increased and vice-versa to avoid undesirable colour characteristics.

ii. The effect of prolonged osmotic solution soaking and microwave blanching time, power and temperature, on the quality attributes of fried sweet potatoes can be evaluated.

iii. Other potato varieties can be used in evaluating the effectiveness of these parameters.

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APPENDICES

Appendix I: Design matrix with experimental and predicted response values of ANN.

Run Order/Training sets	Frying time(min)	Blanching treatments	Frying temperature (C)	Moisture ratio Experimented	Moisture ratio Predicted	Oil uptake Experimented	Oil uptake Predicted
1	2	Control	130	1.000	0.960	4.016	3.925
2	4	Control	130	0.647	0.671	3.968	4.188
3	6	Control	130	0.305	0.231	4.89	4.730
4	8	Control	130	0.207	0.200	4.845	4.631
5	10	Control	130	0.098	0.300	3.816	4.213
6	2	Control	150	1.000	0.930	4.514	4.404
7	4	Control	150	0.605	0.720	5.119	4.563
8	6	Control	150	0.400	0.554	5.086	4.596
9	8	Control	150	0.236	0.215	6.066	4.722
10	10	Control	150	0.091	0.148	4.703	4.318
11	2	Control	170	1.000	0.718	4.266	3.998
12	4	Control	170	0.551	0.433	3.935	4.029
13	6	Control	170	0.346	0.390	3.982	3.856
14	8	Control	170	0.190	0.346	4.276	3.652
15	10	Control	170	0.089	0.140	3.528	3.579
16	2	MW	130	1.000	0.859	1.981	3.072
17	4	MW	130	0.395	0.677	2.968	3.002
18	6	MW	130	0.234	0.223	2.455	3.395
19	8	MW	130	0.077	0.087	1.962	3.333
20	10	MW	130	0.048	0.167	2.817	2.883
21	2	MW	150	1.000	1.013	2.307	3.024

22	4	MW	**150**	0.540	**0.541**	2.985	3.189
23	6	MW	150	0.348	0.326	2.528	3.099
24	8	MW	150	0.219	0.016	2.549	3.224
25	10	MW	150	0.082	0.058	2.39	3.078
26	2	MW	170	1.000	0.807	2.662	2.491
27	4	MW	170	0.318	0.387	2.22	2.614
28	6	MW	170	0.156	0.295	2.637	2.573
29	8	MW	170	0.083	0.266	2.145	2.524
30	10	MW	170	0.072	0.094	2.655	2.607
31	2	HWMW	130	1.000	0.908	1.757	1.970
32	4	HWMW	130	0.692	0.706	1.127	2.116
33	6	HWMW	130	0.516	0.326	2.832	2.610
34	8	HWMW	130	0.281	0.066	3.101	2.912
35	10	HWMW	130	0.233	0.117	2.562	2.544
36	2	HWMW	150	1.000	1.126	1.557	2.009
37	4	HWMW	150	0.429	0.439	2.747	2.593
38	6	HWMW	150	0.263	0.238	3.071	2.730
39	8	HWMW	150	0.101	0.022	2.804	2.904
40	10	HWMW	150	0.030	0.118	4.334	2.865
41	2	HWMW	170	1.000	0.875	2.057	2.073
42	4	HWMW	170	0.309	0.498	2.418	2.266
Testing Sets							
43	6	HWMW	170	0.110	0.212	1.651	2.375
44	8	HWMW	170	0.009	0.108	2.314	2.313
45	10	HWMW	170	0.005	-0.060	2.439	2.280
46	2	OSMW	130	1.000	1.104	1.227	1.593
47	4	OSMW	130	0.479	0.742	0.752	1.575

48	6	OSMW	130	0.249	0.419	1.137	1.452
49	8	OSMW	130	0.230	0.030	1.016	1.411
50	10	OSMW	130	0.164	0.012	1.228	0.899
51	2	OSMW	150	1.000	1.216	0.734	1.605
Validation Sets							
52	4	OSMW	**150**	0.500	**0.562**	1.352	1.997
53	6	OSMW	150	0.223	0.210	1.656	1.873
54	8	OSMW	150	0.134	0.022	1.261	1.474
55	10	OSMW	150	0.022	0.196	1.301	1.212
56	2	OSMW	170	1.000	0.851	1.275	1.867
57	4	OSMW	170	0.372	0.578	1.749	1.735
58	6	OSMW	170	0.134	0.081	1.942	1.533
59	8	OSMW	170	0.050	0.070	1.525	0.985
60	10	OSMW	170	0.013	0.164	1.428	0.566

Appendix II: Mean difference values

Treatment	Colour difference	Ascorbic acid	Electrical conductivity	shrinkage	L value	A value	B value	Bulk density
CT1	36.46 ± 0.01^{d}	-	159.00 ± 1.73^{d}	6.03 ± 1.72^{a}	45.76±0.01	-1.31±0.02	8.76±0.01	0.47 ± 0.05^{ab}
CT2	38.53 ± 0.01^{g}	-	166.00 ± 1.00^{fg}	5.87 ± 0.91^{a}	49.88±0.01	-0.08±0.02	12.98±0.01	0.49 ± 0.03^{ab}
CT3	47.46 ± 0.01^{h}	0.35 ± 0.01^{c}	183.00 ± 1.00^{h}	5.40 ± 0.50^{a}	59.31±0.01	-6.29±0.01	10.24±0.00	0.49 ± 0.03^{ab}
MW1	39.68 ± 0.06^{d}	-	171.00 ± 2.00^{c}	6.60 ± 3.61^{a}	51.15±0.05	-0.74±0.01	12.79±0.01	0.46 ± 0.04^{ab}
MW2	44.07 ± 0.01^{e}	-	170.00 ± 1.73^{bc}	6.47 ± 2.25^{a}	55.17±0.01	-2.29±0.02	14.37±0.00	0.46 ± 0.03^{ab}
MW3	47.27 ± 0.02^{h}	0.24 ± 0.00^{b}	188.33 ± 0.58^{e}	6.40 ± 0.68^{a}	57.90±0.01	-3.87±0.01	15.98±0.02	0.49 ± 0.03^{ab}
HWMW1	38.75 ± 0.01^{b}	-	176.00 ± 1.00^{a}	6.17 ± 1.26^{a}	50.64±0.01	-1.33±0.01	11.08±0.00	0.51 ± 0.02^{ab}
HWMW2	44.40 ± 0.01^{f}	-	186.33 ± 0.58^{b}	5.10 ± 2.25^{a}	55.22±0.01	1.34±0.01	15.42±0.01	0.45 ± 0.01^{a}
HWMW3	47.56 ± 0.01^{i}	0.25 ± 0.03^{b}	193.67 ± 1.53^{f}	5.07 ± 0.75^{a}	59.28±0.01	-6.42±0.01	10.80±0.01	0.49 ± 0.01^{ab}
OSMW1	39.70 ± 0.07^{a}	-	177.67 ± 2.89^{d}	6.33 ± 1.70^{a}	51.20±0.08	-1.19±0.03	12.60±0.02	0.52 ± 0.02^{ab}
OSMW2	46.95 ± 0.01^{c}	-	189.67 ± 1.53^{ef}	5.97 ± 1.75^{a}	58.53±0.01	-4.63±0.02	12.36±0.01	0.46 ± 0.00^{a}
OSMW3	49.40 ± 0.01^{i}	0.46 ± 0.01^{d}	200.67 ± 1.53^{g}	5.60±2.44	60.02±0.01	-4.04±0.02	16.30±0.01	0.54 ± 0.03^{b}

The different lowercase letters (a–i) indicate significant differences within different treatments ($p < 0.05$)

Appendix III: Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	1.000	117156414.878[b]	9.000	16.000	.000
	Wilks' Lambda	.000	117156415.121[b]	9.000	16.000	.000
	Hotelling's Trace	65900483.506	117156415.121[b]	9.000	16.000	.000
	Roy's Largest Root	65900483.506	117156415.121[b]	9.000	16.000	.000
Treatments	Pillai's Trace	2.978	269.095	27.000	54.000	.000
	Wilks' Lambda	.000	4870.377	27.000	47.371	.000
	Hotelling's Trace	136819.417	74321.659	27.000	44.000	.000
	Roy's Largest Root	134951.964	269903.928[c]	9.000	18.000	.000
Temperature	Pillai's Trace	2.000	36793.451	18.000	34.000	.000
	Wilks' Lambda	.000	65627.609[b]	18.000	32.000	.000
	Hotelling's Trace	139919.785	116599.820	18.000	30.000	.000
	Roy's Largest Root	129387.969	244399.496[c]	9.000	17.000	.000
Treatments * Temperature	Pillai's Trace	5.558	29.347	54.000	126.000	.000
	Wilks' Lambda	.000	926.526	54.000	86.178	.000
	Hotelling's Trace	97923.614	25992.070	54.000	86.000	.000
	Roy's Largest Root	93516.522	218205.218[c]	9.000	21.000	.000

a. Design: Intercept + Treatments + Temperature + Treatments * Temperature

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

Appendix IV: Levene's Test of Equality of Error Variances[a]

Quality characteristics	F	df1	df2	Sig.
Electrical conductivity	1.682	11	24	.139
Shrinkage	2.290	11	24	.043
Texture (Hardness)	7.310	11	24	.000
Ascorbic acid	13.923	11	24	.000
Bulk density	2.598	11	24	.024
L value	9.901	11	24	.000
A value	1.062	11	24	.428
B value	4.071	11	24	.002
Colour difference	7.836	11	24	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Treatments + Temperature + Treatments * Temperature

Appendix V: Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Electrical conductivity	4995.556[a]	11	454.141	187.921	.000

	Shrinkage	2270.068[b]	11	206.370	.291	.982
	Texture (Hardness)	439.090[c]	11	39.917	2.034	.071
	Ascorbic acid	.939[d]	11	.085	676.547	.000
	Bulk density	.024[e]	11	.002	2.879	.015
	L value	720.170[f]	11	65.470	90303.486	.000
	A value	156.990[g]	11	14.272	53519.207	.000
	B value	185.465[h]	11	16.860	159730.335	.000
	Colour difference	807.850[i]	11	73.441	94424.021	.000
Intercept	Electrical conductivity	1167840.444	1	1167840.444	483244.322	.000
	Shrinkage	8100.000	1	8100.000	11.415	.002
	Texture (Hardness)	1742.491	1	1742.491	88.786	.000
	Ascorbic acid	.421	1	.421	3335.755	.000
	Bulk density	8.434	1	8.434	10987.184	.000
	L value	106949.711	1	106949.711	147516842.762	.000
	A value	281.065	1	281.065	1053994.594	.000
	B value	5904.386	1	5904.386	55936284.632	.000
	Colour difference	66880.856	1	66880.856	85989672.229	.000
Treatments	Electrical conductivity	2177.333	3	725.778	300.322	.000
	Shrinkage	1361.678	3	453.893	.640	.597
	Texture (Hardness)	350.270	3	116.757	5.949	.003
	Ascorbic acid	.032	3	.011	85.612	.000
	Bulk density	.006	3	.002	2.399	.093
	L value	115.223	3	38.408	52975.881	.000
	A value	5.360	3	1.787	6700.399	.000
	B value	72.948	3	24.316	230363.228	.000

	Colour difference	147.453	3	49.151	63194.076	.000
Temperature	Electrical conductivity	2601.722	2	1300.861	538.287	.000
	Shrinkage	756.463	2	378.231	.533	.594
	Texture (Hardness)	69.759	2	34.880	1.777	.191
	Ascorbic acid	.842	2	.421	3335.755	.000
	Bulk density	.008	2	.004	5.413	.011
	L value	535.759	2	267.880	369489.245	.000
	A value	105.734	2	52.867	198250.719	.000
	B value	41.733	2	20.867	197682.947	.000
	Colour difference	605.375	2	302.687	389169.604	.000
Treatments * Temperature	Electrical conductivity	216.500	6	36.083	14.931	.000
	Shrinkage	151.927	6	25.321	.036	1.000
	Texture (Hardness)	19.061	6	3.177	.162	.984
	Ascorbic acid	.065	6	.011	85.612	.000
	Bulk density	.010	6	.002	2.274	.070
	L value	69.188	6	11.531	15905.368	.000
	A value	45.896	6	7.649	28684.774	.000
	B value	70.783	6	11.797	111763.018	.000
	Colour difference	55.022	6	9.170	11790.465	.000
Error	Electrical conductivity	58.000	24	2.417		
	Shrinkage	17029.932	24	709.580		
	Texture (Hardness)	471.017	24	19.626		
	Ascorbic acid	.003	24	.000		
	Bulk density	.018	24	.001		
	L value	.017	24	.001		

	A value	.006	24	.000
	B value	.003	24	.000
	Colour difference	.019	24	.001
Total	Electrical conductivity	1172894.000	36	
	Shrinkage	27400.000	36	
	Texture (Hardness)	2652.597	36	
	Ascorbic acid	1.363	36	
	Bulk density	8.477	36	
	L value	107669.899	36	
	A value	438.061	36	
	B value	6089.853	36	
	Colour difference	67688.725	36	
Corrected Total	Electrical conductivity	5053.556	35	
	Shrinkage	19300.000	35	
	Texture (Hardness)	910.107	35	
	Ascorbic acid	.942	35	
	Bulk density	.043	35	
	L value	720.188	35	
	A value	156.996	35	
	B value	185.467	35	
	Colour difference	807.869	35	

a. R Squared = .989 (Adjusted R Squared = .983)

b. R Squared = .118 (Adjusted R Squared = -.287)

c. R Squared = .482 (Adjusted R Squared = .245)

d. R Squared = .997 (Adjusted R Squared = .995)

e. R Squared = .569 (Adjusted R Squared = .371)
f. R Squared = 1.000 (Adjusted R Squared = 1.000)
g. R Squared = 1.000 (Adjusted R Squared = 1.000)
h. R Squared = 1.000 (Adjusted R Squared = 1.000)
i. R Squared = 1.000 (Adjusted R Squared = 1.000)

Appendix VI: Parameter estimates

Parameter Estimates							
						95% Confidence Interval	
Dependent Variable	Parameter	B	Std. Error	t	Sig.	Lower Bound	Upper Bound
Electrical conductivity	Intercept	200.667	.898	223.577	.000	198.814	202.519
	[Treatments=1.00]	-17.667	1.269	-13.918	.000	-20.286	-15.047
	[Treatments=2.00]	-12.333	1.269	-9.717	.000	-14.953	-9.714
	[Treatments=3.00]	-7.000	1.269	-5.515	.000	-9.620	-4.380
	[Treatments=4.00]	0[a]	.	.	.	.	.
	[Temperature=130.00]	-23.000	1.269	-18.120	.000	-25.620	-20.380
	[Temperature=150.00]	-11.000	1.269	-8.666	.000	-13.620	-8.380
	[Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=1.00] * [Temperature=130.00]	-1.000	1.795	-.557	.583	-4.705	2.705
	[Treatments=1.00] * [Temperature=150.00]	-6.000	1.795	-3.343	.003	-9.705	-2.295
	[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=2.00] * [Temperature=130.00]	5.667	1.795	3.157	.004	1.962	9.371
	[Treatments=2.00] * [Temperature=150.00]	-7.333	1.795	-4.085	.000	-11.038	-3.629
	[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.

	[Treatments=3.00] * [Temperature=130.00]	5.333	1.795	2.971	.007	1.629	9.038
	[Treatments=3.00] * [Temperature=150.00]	3.667	1.795	2.043	.052	-.038	7.371
	[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
Shrinkage	Intercept	20.000	15.379	1.300	.206	-11.742	51.742
	[Treatments=1.00]	2.857	21.750	.131	.897	-42.032	47.747
	[Treatments=2.00]	-11.429	21.750	-.525	.604	-56.318	33.461
	[Treatments=3.00]	7.619	21.750	.350	.729	-37.270	52.508
	[Treatments=4.00]	0[a]	.	.	.	.	.
	[Temperature=130.00]	-10.476	21.750	-.482	.634	-55.366	34.413
	[Temperature=150.00]	-5.238	21.750	-.241	.812	-50.127	39.651
	[Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=1.00] * [Temperature=130.00]	1.429	30.759	.046	.963	-62.055	64.912
	[Treatments=1.00] * [Temperature=150.00]	-1.429	30.759	-.046	.963	-64.912	62.055

	[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=2.00] * [Temperature=130.00]	1.905	30.759	.062	.951	-61.578	65.388
	[Treatments=2.00] * [Temperature=150.00]	4.286	30.759	.139	.890	-59.197	67.769
	[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=3.00] * [Temperature=130.00]	-5.238	30.759	-.170	.866	-68.721	58.245
	[Treatments=3.00] * [Temperature=150.00]	4.762	30.759	.155	.878	-58.721	68.245
	[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
Texture (Hardness)	Intercept	14.553	2.558	5.690	.000	9.274	19.832
	[Treatments=1.00]	-9.818	3.617	-2.714	.012	-17.284	-2.353
	[Treatments=2.00]	-6.509	3.617	-1.800	.085	-13.975	.956
	[Treatments=3.00]	-9.039	3.617	-2.499	.020	-16.504	-1.573
	[Treatments=4.00]	0[a]	.	.	.	.	.

[Temperature=130.00]	-5.843	3.617	-1.615	.119	-13.309	1.622
[Temperature=150.00]	-2.419	3.617	-.669	.510	-9.884	5.047
[Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=1.00] * [Temperature=130.00]	2.834	5.115	.554	.585	-7.724	13.392
[Treatments=1.00] * [Temperature=150.00]	2.505	5.115	.490	.629	-8.053	13.063
[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=2.00] * [Temperature=130.00]	3.613	5.115	.706	.487	-6.945	14.171
[Treatments=2.00] * [Temperature=150.00]	3.116	5.115	.609	.548	-7.442	13.674
[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=3.00] * [Temperature=130.00]	4.146	5.115	.810	.426	-6.412	14.704
[Treatments=3.00] * [Temperature=150.00]	1.788	5.115	.350	.730	-8.770	12.346
[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.

	[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
Ascorbic acid	Intercept	.463	.006	71.352	.000	.449	.476
	[Treatments=1.00]	-.118	.009	-12.831	.000	-.137	-.099
	[Treatments=2.00]	-.228	.009	-24.827	.000	-.247	-.209
	[Treatments=3.00]	-.208	.009	-22.682	.000	-.227	-.189
	[Treatments=4.00]	0[a]	.	.	.	.	.
	[Temperature=130.00]	-.463	.009	-50.453	.000	-.482	-.444
	[Temperature=150.00]	-.463	.009	-50.453	.000	-.482	-.444
	[Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=1.00] * [Temperature=130.00]	.118	.013	9.073	.000	.091	.144
	[Treatments=1.00] * [Temperature=150.00]	.118	.013	9.073	.000	.091	.144
	[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=2.00] * [Temperature=130.00]	.228	.013	17.555	.000	.201	.254
	[Treatments=2.00] * [Temperature=150.00]	.228	.013	17.555	.000	.201	.254
	[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=3.00] * [Temperature=130.00]	.208	.013	16.039	.000	.181	.235

	[Treatments=3.00] * [Temperature=150.00]	.208	.013	16.039	.000	.181	.235
	[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
Bulk density	Intercept	.537	.016	33.573	.000	.504	.570
	[Treatments=1.00]	-.052	.023	-2.307	.030	-.099	-.005
	[Treatments=2.00]	-.052	.023	-2.307	.030	-.099	-.005
	[Treatments=3.00]	-.045	.023	-1.988	.058	-.092	.002
	[Treatments=4.00]	0[a]	.	.	.	.	.
	[Temperature=130.00]	-.019	.023	-.862	.397	-.066	.027
	[Temperature=150.00]	-.082	.023	-3.647	.001	-.129	-.036
	[Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=1.00] * [Temperature=130.00]	.007	.032	.215	.832	-.059	.073
	[Treatments=1.00] * [Temperature=150.00]	.086	.032	2.684	.013	.020	.152
	[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.

	[Treatments=2.00] * [Temperature=130.00]	-.008	.032	-.259	.798	-.074	.058
	[Treatments=2.00] * [Temperature=150.00]	.061	.032	1.899	.070	-.005	.127
	[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=3.00] * [Temperature=130.00]	.036	.032	1.132	.269	-.030	.102
	[Treatments=3.00] * [Temperature=150.00]	.038	.032	1.200	.242	-.028	.104
	[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
L value	Intercept	60.020	.016	3860.892	.000	59.988	60.052
	[Treatments=1.00]	-.707	.022	-32.143	.000	-.752	-.661
	[Treatments=2.00]	-2.123	.022	-96.582	.000	-2.169	-2.078
	[Treatments=3.00]	-.737	.022	-33.508	.000	-.782	-.691
	[Treatments=4.00]	0[a]	.	.	.	.	.
	[Temperature=130.00]	-8.823	.022	-401.337	.000	-8.869	-8.778
	[Temperature=150.00]	-1.490	.022	-67.774	.000	-1.535	-1.445

[Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=1.00] * [Temperature=130.00]	-4.730	.031	-152.133	.000	-4.794	-4.666
[Treatments=1.00] * [Temperature=150.00]	-7.940	.031	-255.377	.000	-8.004	-7.876
[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=2.00] * [Temperature=130.00]	2.073	.031	66.685	.000	2.009	2.138
[Treatments=2.00] * [Temperature=150.00]	-1.233	.031	-39.668	.000	-1.298	-1.169
[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=3.00] * [Temperature=130.00]	.177	.031	5.682	.000	.112	.241
[Treatments=3.00] * [Temperature=150.00]	-2.570	.031	-82.660	.000	-2.634	-2.506
[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.
[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.

A value	Intercept	-4.043	.009	-428.860	.000	-4.063	-4.024
	[Treatments=1.00]	-2.247	.013	-168.500	.000	-2.274	-2.219
	[Treatments=2.00]	.170	.013	12.750	.000	.142	.198
	[Treatments=3.00]	-2.373	.013	-178.000	.000	-2.401	-2.346
	[Treatments=4.00]	0[a]	.	.	.	.	.
	[Temperature=130.00]	2.853	.013	214.000	.000	2.826	2.881
	[Temperature=150.00]	-.587	.013	-44.000	.000	-.614	-.559
	[Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=1.00] * [Temperature=130.00]	2.130	.019	112.960	.000	2.091	2.169
	[Treatments=1.00] * [Temperature=150.00]	6.797	.019	360.448	.000	6.758	6.836
	[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=2.00] * [Temperature=130.00]	.280	.019	14.849	.000	.241	.319
	[Treatments=2.00] * [Temperature=150.00]	2.167	.019	114.905	.000	2.128	2.206
	[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=3.00] * [Temperature=130.00]	2.233	.019	118.440	.000	2.194	2.272
	[Treatments=3.00] * [Temperature=150.00]	5.667	.019	300.520	.000	5.628	5.706

	[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
B value	Intercept	16.300	.006	2747.943	.000	16.288	16.312
	[Treatments=1.00]	-6.060	.008	-722.400	.000	-6.077	-6.043
	[Treatments=2.00]	-.317	.008	-37.749	.000	-.334	-.299
	[Treatments=3.00]	-5.503	.008	-656.041	.000	-5.521	-5.486
	[Treatments=4.00]	0[a]	.	.	.	.	.
	[Temperature=130.00]	-3.703	.008	-441.467	.000	-3.721	-3.686
	[Temperature=150.00]	-3.943	.008	-470.077	.000	-3.961	-3.926
	[Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=1.00] * [Temperature=130.00]	2.227	.012	187.692	.000	2.202	2.251
	[Treatments=1.00] * [Temperature=150.00]	6.687	.012	563.637	.000	6.662	6.711
	[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=2.00] * [Temperature=130.00]	.507	.012	42.708	.000	.482	.531

	[Treatments=2.00] * [Temperature=150.00]	2.330	.012	196.402	.000	2.306	2.354
	[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=3.00] * [Temperature=130.00]	3.987	.012	336.047	.000	3.962	4.011
	[Treatments=3.00] * [Temperature=150.00]	8.570	.012	722.389	.000	8.546	8.594
	[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.
	[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
Colour difference	Intercept	49.397	.016	3067.824	.000	49.363	49.430
	[Treatments=1.00]	-1.940	.023	-85.196	.000	-1.987	-1.893
	[Treatments=2.00]	-2.123	.023	-93.247	.000	-2.170	-2.076
	[Treatments=3.00]	-1.840	.023	-80.805	.000	-1.887	-1.793
	[Treatments=4.00]	0[a]	.	.	.	.	.
	[Temperature=130.00]	-9.700	.023	-425.980	.000	-9.747	-9.653
	[Temperature=150.00]	-2.447	.023	-107.447	.000	-2.494	-2.400
	[Temperature=170.00]	0[a]	.	.	.	.	.

[Treatments=1.00] * [Temperature=130.00]	-4.293	.032	-133.321	.000	-4.360	-4.227
[Treatments=1.00] * [Temperature=150.00]	-6.480	.032	-201.223	.000	-6.546	-6.414
[Treatments=1.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=2.00] * [Temperature=130.00]	2.107	.032	65.418	.000	2.040	2.173
[Treatments=2.00] * [Temperature=150.00]	-.757	.032	-23.497	.000	-.823	-.690
[Treatments=2.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=3.00] * [Temperature=130.00]	.897	.032	27.844	.000	.830	.963
[Treatments=3.00] * [Temperature=150.00]	-.710	.032	-22.048	.000	-.776	-.644
[Treatments=3.00] * [Temperature=170.00]	0[a]	.	.	.	.	.
[Treatments=4.00] * [Temperature=130.00]	0[a]	.	.	.	.	.
[Treatments=4.00] * [Temperature=150.00]	0[a]	.	.	.	.	.
[Treatments=4.00] * [Temperature=170.00]	0[a]	.	.	.	.	.

This parameter is set to zero because it is redundant.

Appendix VII: Estimated Marginal Means (Treatments)

				95% Confidence Interval	
Dependent Variable	Treatments	Mean	Std. Error	Lower Bound	Upper Bound
Electrical conductivity	Control	169.333	.518	168.264	170.403
	Microwave	176.444	.518	175.375	177.514
	Hot water + Microwave	185.333	.518	184.264	186.403
	Osmotic dehydration + Microwave	189.333	.518	188.264	190.403
Shrinkage	Control	17.619	8.879	-.707	35.945
	Microwave	5.397	8.879	-12.929	23.723
	Hot water + Microwave	22.222	8.879	3.896	40.548
	Osmotic dehydration + Microwave	14.762	8.879	-3.564	33.088
Texture (Hardness)	Control	3.760	1.477	.712	6.808
	Microwave	7.532	1.477	4.485	10.580
	Hot water + Microwave	4.738	1.477	1.690	7.786
	Osmotic dehydration + Microwave	11.799	1.477	8.751	14.846
Ascorbic acid	Control	.115	.004	.107	.123
	Microwave	.078	.004	.071	.086
	Hot water + Microwave	.085	.004	.077	.093

	Osmotic dehydration + Microwave	.154	.004	.146	.162
Bulk density	Control	.482	.009	.463	.501
	Microwave	.468	.009	.449	.487
	Hot water + Microwave	.483	.009	.464	.502
	Osmotic dehydration + Microwave	.503	.009	.484	.522
L value	Control	51.652	.009	51.634	51.671
	Microwave	54.739	.009	54.720	54.757
	Hot water + Microwave	55.048	.009	55.029	55.066
	Osmotic dehydration + Microwave	56.582	.009	56.564	56.601
A value	Control	-2.559	.005	-2.570	-2.548
	Microwave	-2.302	.005	-2.313	-2.291
	Hot water + Microwave	-3.028	.005	-3.039	-3.017
	Osmotic dehydration + Microwave	-3.288	.005	-3.299	-3.277
B value	Control	10.662	.003	10.655	10.669
	Microwave	14.380	.003	14.373	14.387
	Hot water + Microwave	12.433	.003	12.426	12.440
	Osmotic dehydration + Microwave	13.751	.003	13.744	13.758
Colour difference	Control	39.817	.009	39.797	39.836
	Microwave	43.674	.009	43.655	43.694
	Hot water + Microwave	43.570	.009	43.551	43.589

Osmotic dehydration + Microwave	45.348	.009	45.329	45.367

Appendix VIII: Multiple Comparisons (Treatments), Post Hoc Tests

Tukey HSD

Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Electrical conductivity	Control	Microwave	-7.1111*	.73283	.000	-9.1327	-5.0895
		Hot water + Microwave	-16.0000*	.73283	.000	-18.0216	-13.9784
		Osmotic dehydration + Microwave	-20.0000*	.73283	.000	-22.0216	-17.9784
	Microwave	Control	7.1111*	.73283	.000	5.0895	9.1327
		Hot water + Microwave	-8.8889*	.73283	.000	-10.9105	-6.8673
		Osmotic dehydration + Microwave	-12.8889*	.73283	.000	-14.9105	-10.8673
	Hot water + Microwave	Control	16.0000*	.73283	.000	13.9784	18.0216
		Microwave	8.8889*	.73283	.000	6.8673	10.9105
		Osmotic dehydration + Microwave	-4.0000*	.73283	.000	-6.0216	-1.9784
	Osmotic dehydration + Microwave	Control	20.0000*	.73283	.000	17.9784	22.0216
		Microwave	12.8889*	.73283	.000	10.8673	14.9105
		Hot water + Microwave	4.0000*	.73283	.000	1.9784	6.0216

Shrinkage	Control	Microwave	12.2222	12.55725	.766	-22.4183	46.8628
		Hot water + Microwave	-4.6032	12.55725	.983	-39.2437	30.0374
		Osmotic dehydration + Microwave	2.8571	12.55725	.996	-31.7834	37.4977
	Microwave	Control	-12.2222	12.55725	.766	-46.8628	22.4183
		Hot water + Microwave	-16.8254	12.55725	.548	-51.4659	17.8151
		Osmotic dehydration + Microwave	-9.3651	12.55725	.878	-44.0056	25.2755
	Hot water + Microwave	Control	4.6032	12.55725	.983	-30.0374	39.2437
		Microwave	16.8254	12.55725	.548	-17.8151	51.4659
		Osmotic dehydration + Microwave	7.4603	12.55725	.933	-27.1802	42.1009
	Osmotic dehydration + Microwave	Control	-2.8571	12.55725	.996	-37.4977	31.7834
		Microwave	9.3651	12.55725	.878	-25.2755	44.0056
		Hot water + Microwave	-7.4603	12.55725	.933	-42.1009	27.1802
Texture (Hardness)	Control	Microwave	-3.7724	2.08837	.295	-9.5333	1.9886
		Hot water + Microwave	-.9779	2.08837	.965	-6.7389	4.7831
		Osmotic dehydration + Microwave	-8.0388*	2.08837	.004	-13.7998	-2.2778
	Microwave	Control	3.7724	2.08837	.295	-1.9886	9.5333
		Hot water + Microwave	2.7944	2.08837	.549	-2.9665	8.5554
		Osmotic dehydration + Microwave	-4.2664	2.08837	.201	-10.0274	1.4946
	Hot water + Microwave	Control	.9779	2.08837	.965	-4.7831	6.7389
		Microwave	-2.7944	2.08837	.549	-8.5554	2.9665

		Osmotic dehydration + Microwave	-7.0608*	2.08837	.012	-12.8218	-1.2999
	Osmotic dehydration + Microwave	Control	8.0388*	2.08837	.004	2.2778	13.7998
		Microwave	4.2664	2.08837	.201	-1.4946	10.0274
		Hot water + Microwave	7.0608*	2.08837	.012	1.2999	12.8218
Ascorbic acid	Control	Microwave	.0367*	.00529	.000	.0221	.0513
		Hot water + Microwave	.0301*	.00529	.000	.0155	.0447
		Osmotic dehydration + Microwave	-.0392*	.00529	.000	-.0538	-.0246
	Microwave	Control	-.0367*	.00529	.000	-.0513	-.0221
		Hot water + Microwave	-.0066	.00529	.609	-.0212	.0080
		Osmotic dehydration + Microwave	-.0759*	.00529	.000	-.0905	-.0613
	Hot water + Microwave	Control	-.0301*	.00529	.000	-.0447	-.0155
		Microwave	.0066	.00529	.609	-.0080	.0212
		Osmotic dehydration + Microwave	-.0693*	.00529	.000	-.0839	-.0547
	Osmotic dehydration + Microwave	Control	.0392*	.00529	.000	.0246	.0538
		Microwave	.0759*	.00529	.000	.0613	.0905
		Hot water + Microwave	.0693*	.00529	.000	.0547	.0839
Bulk density	Control	Microwave	.0134	.01306	.735	-.0226	.0494
		Hot water + Microwave	-.0012	.01306	1.000	-.0372	.0349
		Osmotic dehydration + Microwave	-.0213	.01306	.382	-.0573	.0147
	Microwave	Control	-.0134	.01306	.735	-.0494	.0226

		Hot water + Microwave	-.0146	.01306	.683	-.0506	.0214
		Osmotic dehydration + Microwave	-.0347	.01306	.062	-.0707	.0013
	Hot water + Microwave	Control	.0012	.01306	1.000	-.0349	.0372
		Microwave	.0146	.01306	.683	-.0214	.0506
		Osmotic dehydration + Microwave	-.0201	.01306	.431	-.0561	.0159
	Osmotic dehydration + Microwave	Control	.0213	.01306	.382	-.0147	.0573
		Microwave	.0347	.01306	.062	-.0013	.0707
		Hot water + Microwave	.0201	.01306	.431	-.0159	.0561
L value	Control	Microwave	-3.0867*	.01269	.000	-3.1217	-3.0517
		Hot water + Microwave	-3.3956*	.01269	.000	-3.4306	-3.3605
		Osmotic dehydration + Microwave	-4.9300*	.01269	.000	-4.9650	-4.8950
	Microwave	Control	3.0867*	.01269	.000	3.0517	3.1217
		Hot water + Microwave	-.3089*	.01269	.000	-.3439	-.2739
		Osmotic dehydration + Microwave	-1.8433*	.01269	.000	-1.8783	-1.8083
	Hot water + Microwave	Control	3.3956*	.01269	.000	3.3605	3.4306
		Microwave	.3089*	.01269	.000	.2739	.3439
		Osmotic dehydration + Microwave	-1.5344*	.01269	.000	-1.5695	-1.4994
	Osmotic dehydration + Microwave	Control	4.9300*	.01269	.000	4.8950	4.9650
		Microwave	1.8433*	.01269	.000	1.8083	1.8783
		Hot water + Microwave	1.5344*	.01269	.000	1.4994	1.5695

A value	Control	Microwave	-.2567*	.00770	.000	-.2779	-.2354
		Hot water + Microwave	.4689*	.00770	.000	.4477	.4901
		Osmotic dehydration + Microwave	.7289*	.00770	.000	.7077	.7501
	Microwave	Control	.2567*	.00770	.000	.2354	.2779
		Hot water + Microwave	.7256*	.00770	.000	.7043	.7468
		Osmotic dehydration + Microwave	.9856*	.00770	.000	.9643	1.0068
	Hot water + Microwave	Control	-.4689*	.00770	.000	-.4901	-.4477
		Microwave	-.7256*	.00770	.000	-.7468	-.7043
		Osmotic dehydration + Microwave	.2600*	.00770	.000	.2388	.2812
	Osmotic dehydration + Microwave	Control	-.7289*	.00770	.000	-.7501	-.7077
		Microwave	-.9856*	.00770	.000	-1.0068	-.9643
		Hot water + Microwave	-.2600*	.00770	.000	-.2812	-.2388
B value	Control	Microwave	-3.7178*	.00484	.000	-3.7311	-3.7044
		Hot water + Microwave	-1.7711*	.00484	.000	-1.7845	-1.7578
		Osmotic dehydration + Microwave	-3.0889*	.00484	.000	-3.1022	-3.0755
	Microwave	Control	3.7178*	.00484	.000	3.7044	3.7311
		Hot water + Microwave	1.9467*	.00484	.000	1.9333	1.9600
		Osmotic dehydration + Microwave	.6289*	.00484	.000	.6155	.6422
	Hot water + Microwave	Control	1.7711*	.00484	.000	1.7578	1.7845
		Microwave	-1.9467*	.00484	.000	-1.9600	-1.9333

		Osmotic dehydration + Microwave	-1.3178*	.00484	.000	-1.3311	-1.3044
	Osmotic dehydration + Microwave	Control	3.0889*	.00484	.000	3.0755	3.1022
		Microwave	-.6289*	.00484	.000	-.6422	-.6155
		Hot water + Microwave	1.3178*	.00484	.000	1.3044	1.3311
Colour difference	Control	Microwave	-3.8578*	.01315	.000	-3.8940	-3.8215
		Hot water + Microwave	-3.7533*	.01315	.000	-3.7896	-3.7171
		Osmotic dehydration + Microwave	-5.5311*	.01315	.000	-5.5674	-5.4948
	Microwave	Control	3.8578*	.01315	.000	3.8215	3.8940
		Hot water + Microwave	.1044*	.01315	.000	.0682	.1407
		Osmotic dehydration + Microwave	-1.6733*	.01315	.000	-1.7096	-1.6371
	Hot water + Microwave	Control	3.7533*	.01315	.000	3.7171	3.7896
		Microwave	-.1044*	.01315	.000	-.1407	-.0682
		Osmotic dehydration + Microwave	-1.7778*	.01315	.000	-1.8140	-1.7415
	Osmotic dehydration + Microwave	Control	5.5311*	.01315	.000	5.4948	5.5674
		Microwave	1.6733*	.01315	.000	1.6371	1.7096
		Hot water + Microwave	1.7778*	.01315	.000	1.7415	1.8140

Based on observed means.

The error term is Mean Square (Error) = .001.

*. The mean difference is significant at the .05 level.

Appendix IX: Multiple Comparisons (Temperature), Post Hoc Tests

Tukey HSD

Dependent Variable	(I) Temperature	(J) Temperature	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Electrical conductivity	Temperature 1	Temperature 2	-7.0833*	.63465	.000	-8.6682	-5.4984
		Temperature 3	-20.5000*	.63465	.000	-22.0849	-18.9151
	Temperature 2	Temperature 1	7.0833*	.63465	.000	5.4984	8.6682
		Temperature 3	-13.4167*	.63465	.000	-15.0016	-11.8318
	Temperature 3	Temperature 1	20.5000*	.63465	.000	18.9151	22.0849
		Temperature 2	13.4167*	.63465	.000	11.8318	15.0016
Shrinkage	Temperature 1	Temperature 2	-7.6190	10.87490	.765	-34.7768	19.5387
		Temperature 3	-10.9524	10.87490	.580	-38.1101	16.2054
	Temperature 2	Temperature 1	7.6190	10.87490	.765	-19.5387	34.7768
		Temperature 3	-3.3333	10.87490	.950	-30.4911	23.8244
	Temperature 3	Temperature 1	10.9524	10.87490	.580	-16.2054	38.1101
		Temperature 2	3.3333	10.87490	.950	-23.8244	30.4911
Texture (Hardness)	Temperature 1	Temperature 2	-2.6286	1.80858	.331	-7.1451	1.8879
		Temperature 3	-3.1952	1.80858	.202	-7.7117	1.3213
	Temperature 2	Temperature 1	2.6286	1.80858	.331	-1.8879	7.1451
		Temperature 3	-.5666	1.80858	.947	-5.0831	3.9499
	Temperature 3	Temperature 1	3.1952	1.80858	.202	-1.3213	7.7117
		Temperature 2	.5666	1.80858	.947	-3.9499	5.0831
Ascorbic acid	Temperature 1	Temperature 2	.0000	.00459	1.000	-.0115	.0115
		Temperature 3	-.3243*	.00459	.000	-.3358	-.3129
	Temperature 2	Temperature 1	.0000	.00459	1.000	-.0115	.0115

		Temperature 3	-.3243*	.00459	.000	-.3358	-.3129
	Temperature 3	Temperature 1	.3243*	.00459	.000	.3129	.3358
		Temperature 2	.3243*	.00459	.000	.3129	.3358
Bulk density	Temperature 1	Temperature 2	.0254	.01131	.083	-.0028	.0537
		Temperature 3	-.0108	.01131	.612	-.0390	.0174
	Temperature 2	Temperature 1	-.0254	.01131	.083	-.0537	.0028
		Temperature 3	-.0362*	.01131	.010	-.0645	-.0080
	Temperature 3	Temperature 1	.0108	.01131	.612	-.0174	.0390
		Temperature 2	.0362*	.01131	.010	.0080	.0645
L value	Temperature 1	Temperature 2	-5.0175*	.01099	.000	-5.0450	-4.9900
		Temperature 3	-9.4433*	.01099	.000	-9.4708	-9.4159
	Temperature 2	Temperature 1	5.0175*	.01099	.000	4.9900	5.0450
		Temperature 3	-4.4258*	.01099	.000	-4.4533	-4.3984
	Temperature 3	Temperature 1	9.4433*	.01099	.000	9.4159	9.4708
		Temperature 2	4.4258*	.01099	.000	4.3984	4.4533
A value	Temperature 1	Temperature 2	.9433*	.00667	.000	.9267	.9600
		Temperature 3	4.0142*	.00667	.000	3.9975	4.0308
	Temperature 2	Temperature 1	-.9433*	.00667	.000	-.9600	-.9267
		Temperature 3	3.0708*	.00667	.000	3.0542	3.0875
	Temperature 3	Temperature 1	-4.0142*	.00667	.000	-4.0308	-3.9975
		Temperature 2	-3.0708*	.00667	.000	-3.0875	-3.0542
B value	Temperature 1	Temperature 2	-2.4767*	.00419	.000	-2.4871	-2.4662
		Temperature 3	-2.0233*	.00419	.000	-2.0338	-2.0129
	Temperature 2	Temperature 1	2.4767*	.00419	.000	2.4662	2.4871
		Temperature 3	.4533*	.00419	.000	.4429	.4638

	Temperature 3	Temperature 1	2.0233*	.00419	.000	2.0129	2.0338
		Temperature 2	-.4533*	.00419	.000	-.4638	-.4429
Colour difference	Temperature 1	Temperature 2	-5.5892*	.01139	.000	-5.6176	-5.5607
		Temperature 3	-10.0225*	.01139	.000	-10.0509	-9.9941
	Temperature 2	Temperature 1	5.5892*	.01139	.000	5.5607	5.6176
		Temperature 3	-4.4333*	.01139	.000	-4.4618	-4.4049
	Temperature 3	Temperature 1	10.0225*	.01139	.000	9.9941	10.0509
		Temperature 2	4.4333*	.01139	.000	4.4049	4.4618

Based on observed means.

The error term is Mean Square (Error) = .001.

*. The mean difference is significant at the .05 level.