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EFFECT OF PRETREATMENT TIMES ON THE QUALITY CHARACTERISTICS OF ORANGE FLESHED SWEET POTATO (OFSP) FLOUR

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DECLARATION

This dissertation is presented by Mawuli Akpey as a product of my research undertaken under the supervision of Professor Richard Bani and the co-supervision of Doctor Emmanuel Essien of the Department of Agricultural Engineering, University of Ghana.

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ABSTRACT

Orange Fleshed Sweet Potato (OFSP) flour presents a promising alternative to traditional flours, offering enhanced nutritional benefits, particularly in Vitamin A content. This research delves into the drying characteristics of OFSP slices and the subsequent quality of its flour. The primary focus was to ascertain the impact of chemical and hot water blanching pretreatment durations prior to air drying at varied temperatures.

The OFSP samples, sourced from a farm, underwent a process of washing, peeling, and slicing to a thickness of 3mm. These samples were then subjected to blanching in hot water and ascorbic acid for durations ranging from 1 to 3 minutes, followed by drying at temperatures of 50, 60, and 70°C. Key drying characteristics, such as drying curves, moisture ratio, and effective moisture diffusivity, were meticulously studied. Quality attributes, including color, water absorption capacity, and swelling index, were also analyzed, with color assessment conducted using a HunterLab colorimeter.

Findings revealed that a drying temperature of 70°C resulted in the shortest drying time. Ascorbic acid pretreatment for 3 minutes retained the highest moisture content across all temperatures. Effective moisture diffusivity values oscillated between 1.081 to 1.171×10-9 m²/s, with samples dried at 70°C showcasing higher values. Five thin-layer models were employed to interpret the drying curves, with the Page model proving optimal for temperatures of 50oC and 60°C, and the logarithmic model for 70°C.

The research underscores that varying combinations of pretreatment, duration, and drying temperature can yield diverse outcomes concerning quality criteria. In the broader context of the food industry, the insights from this study can pave the way for the large-scale production of high-

quality OFSP flour, potentially revolutionizing flour-based products with enhanced nutritional profiles.

DEDICATION

I dedicate this research to my family, without whom completion of this thesis would have been impossible.

I also devote this research to everyone who had doubts about not being good enough. You are better and stronger than you think.

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LIST OF ABBREVIATIONS

MR – moisture ratio
W_w – wet material weight
W_d – dried material weight
n – number of constants
N – number of observations
t – time (s)
AA1min – Samples treated in Ascorbic Acid for one minute
AA2min – Samples treated in Ascorbic Acid for two minutes
AA3min – Samples treated in Ascorbic Acid for three minutes
HW1min – Samples treated in Hot Water for one minute
HW2min – Samples treated in Hot Water for two minutes
HW3min – Samples treated in Hot Water for three minutes

Subscripts

exp – experimental
pre – predicted

CHAPTER ONE

1.0 INTRODUCTION

1.1 Drying

Orange Fleshed Sweet Potato (OFSP) is not just a staple food in many regions but also a significant source of essential nutrients, particularly Vitamin A (Mitra, 2012; Wu et al., 2008). The transformation of OFSP into flour form enhances its utility in various culinary applications and extends its shelf life, making it a valuable commodity in both local and global markets (Haruna et al., 2019). However, the inherent value of OFSP flour is not just its nutritional richness but also its potential in addressing malnutrition and food security challenges in vulnerable populations (Bradbury et al., 1985).

The process of converting OFSP into flour is not without its challenges. One of the primary hurdles is the high-water content in OFSP (Neela & Fanta, 2019). Drying, a method used to reduce the moisture content of agricultural products, is crucial for the production of OFSP flour. While drying is arguably the oldest preservation method, its application to OFSP is complex due to the tuber's unique characteristics. The high-water content in OFSP makes the drying process longer and more energy-intensive. Moreover, improper drying can lead to a loss of nutritional value and can affect the quality of the flour (Rashid et al., 2022).

Traditional drying methods, such as sun drying, although cost-effective, expose the OFSP to environmental contaminants and can result in uneven drying. This not only affects the quality of the flour but also its shelf life. With the increasing demand for OFSP flour and its significance in the agricultural and nutritional landscape, there's a pressing need for advanced drying techniques. These methods should ensure the preservation of the nutritional content, improve efficiency, and produce high-quality OFSP flour.

Figure 1: Picture of Open Sun Drying of Different Products

Source: (NaturalResourcesInstitute, 2022)

1.2 Problem statement

The Orange Fleshed Sweet Potato (OFSP) holds significant promise as a nutritional powerhouse, especially in regions grappling with malnutrition and food insecurity. Its rich Vitamin A content and other essential nutrients make it a valuable food source. However, the perishable nature of OFSP limits its shelf life, thereby restricting its broader utilization and potential impact on food systems. One solution to this challenge is the transformation of OFSP into flour, which not only extends its shelf life but also diversifies its applications in the culinary world.

Yet, the conversion of OFSP into flour is fraught with challenges, primarily due to its high-water content. Traditional drying methods, while cost-effective, often compromise the quality and nutritional integrity of the resulting flour. Moreover, these methods can be time-consuming, energy-intensive, and expose the product to environmental contaminants. The absence of optimized drying techniques and a clear understanding of the drying characteristics of OFSP hinders the large-scale production of high-quality OFSP flour.

This research seeks to address the pressing need for a systematic study on the drying characteristics of OFSP. By investigating the effects of various pretreatment times and drying methods, this work aims to optimize the production process of OFSP flour, ensuring its nutritional value is preserved, and its quality is uncompromised.

1.3 Objective

The primary aim of this research is to investigate the drying characteristics of Orange Fleshed Sweet Potato (OFSP) and the subsequent quality of its flour, with a focus on the influence of pretreatment and drying temperature.

1.4 Specific Objectives

The specific aims were;

1. Determine the effect of pretreatment and drying temperature on the drying characteristics of OFSP
2. Determine the effect of pretreatment and drying temperature in the quality characteristics of OFSP
3. Determine the best fit to the experimental data using five thin-layer drying models

An illustration of unstable state heat transfer is blanching, which involves heat conduction within the food and convective heating by steam or hot water. Before drying, blanching is necessary to extend shelf life by halting enzymatic reactions that destroy flavour, colour, and texture. Additionally, blanching helps brighten the colour and prevents vitamin loss while removing entrapped gases, surface debris, and microbial load. If the food is not blanched, enzymes can modify the meal's nutritional value and sensory qualities while it is being stored, and microbes can proliferate when it is thawed and rehydrated.

Drying agricultural produce has benefited humanity for a very long time. The ability to predict the moisture content of agricultural produce under certain conditions and the length of exposure of the product to these conditions is a highly desirable trait for food scientists and engineers. Hence, an enormous amount of study has been conducted concerning drying. Thin layer model development determines a known product's moisture content after exposure to recognised and constant drying conditions.

Different drying systems have been used to dry various agricultural commodities. These models are simulated and helpful in designing new or enhancing already available drying systems. Heat and mass transfer are the main constituents of the thermodynamic process drying undergoes. The heat from a source is conveyed to a product through conduction, convection, radiation, or amalgamation. In order to simulate various drying systems, heat and mass transfer equations must be solved, such as those that explain the moisture and heat exchange between the air and the product. These particular equations are based on energy and mass conservation governing laws. A "thin layer" is a layer of material that is entirely exposed to an airstream during the drying process, and the thickness should be uniform, according to the definition given by the Association of Agricultural and Biological Engineers (ASABE). No more than three layers of particles should be present (ASABE, 2011). The utility of thin-layer drying data has been constrained by the many techniques engineers employ when carrying out tests, analysing data, and presenting their reports.

The heat needed for drying is intended to remove moisture from the product's surface using an outside drying medium, often air. Several biological products that are dried as single particles under consistent environmental conditions exhibit a constant rate of drying loss during their first drying period. A falling rate follows this period of constant rate drying. During the falling rate drying phase, complete drying typically happens, continuously decreasing the drying rate. However, predicting the drying rate during the falling rate is more complicated. The product's internal transfer mechanisms must also be considered in addition to the external transfer mechanisms.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Orange Flesh Sweet Potato

Orange Flesh Sweet Potato (OFSP) (Ipomea batatas L.) is a variety of sweet potatoes with orange tubers. OFSP plays a significant role in the lives of the lower class, children and especially pregnant women who require essential nutrients. OFSP is gradually becoming the most popular and preferred variety of sweet potato because of its distinctive properties, including significant amounts of Vitamin A and beta (ß) carotene (Mitra, 2012; Wu et al., 2008). Roots and tubers are consumed by the majority of people around the globe., with a global average per capita consumption of 199.4 kilograms per year (2013-2015) (Outlook et al., 2019) and projected to reach 21 kilograms per year by 2025, as well as to contribute to animal feed and industrial demands (Scott et al., 2020). The roots of OFSP have a high carbohydrate content and produce the most edible energy per hectare per day ratio, with the leaves containing essential nutrients (Bradbury et al., 1985). The root crop contains cholesterol-reducing elements and antioxidant nutrients, which can assist in the reduction of coronary heart diseases (Babatunde et al., 2019).

Figure 2: Neatly harvested OFSP Tuber ready for export

Apart from being boiled or cooked, Orange Flesh Sweet Potato can be processed into flour (Haruna et al., 2018). Processing the sweet potato into flour allows the product to be handled relatively easily and prevents early spoilage, reducing post-harvest losses. This flour can be used in soups as a thickener and as a composite or substitute flour in the baking industry (Haruna et al., 2019). Certain qualities, like the colour and flavour of sweet potato flour, have been relatively high when used in processed foods such as bread (Bradbury et al., 1985).

Figure 3: Sliced OFSP Tuber

Orange Flesh Sweet Potato is highly perishable due to its high moisture content. Therefore, there is a need to reduce the moisture content of the product by supplying enough heat through effective drying technology.

2.2 Drying

The heat from the sun is typically used to dry food products, although this method can take a long time to dry and is vulnerable to microorganism attacks. The drying process might be an accompanying-end-stage activity for granulates and immediate goods, or it can be an end-stage operation for dehydrated slices, dice, strips, flakes, and starches (for chips and fresh fries as pre-drying before frying in modern technologies) (Sablani & Mujumdar, 2006). In order to produce this desired product, many drying techniques are used. In agriculture, drying is a phenomenon caused by the simultaneous transfer of mass and heat within the product and between the product's surface and its surroundings.

2.2.1 Mechanism of Drying

Food material is dried using a kinetic mechanism that depends on water molecules moving through the food product. It is a time-dependent technique. The four drying stages are the warm-up phase, the constant rate phase, the dropping rate phase, and the total moisture removal. A wet food item may take a while to achieve the equilibrium temperature it adopts with the drying medium after entering the dryer and absorbing heat for a short period of time. A little moisture may be lost during the warm-up phase. In many cases, especially when drying materials at or below room temperature, there is no discernible warm-up period preceding drying (Mercer, 2018).

Moisture evaporates at a consistent and uniform pace due to the saturation of moisture at the surface. This will continue to happen so long as there is sufficient moisture flow from the middle of the wet material to compensate for moisture loss from evaporation at the surface.Water at the material's surface can be vaporised while the rate is constant. This timeframe is determined by the air temperature, humidity, exposed surface area, and moisture absorption rate at the surface (Karthikeyan and Murugavelh, 2018; Mercer, 2018).

A declining rate results when a surface moisture repository develops and prevents internal moisture from reaching the surface quickly enough to replace the surface moisture repository. As a result, moisture starts to seep out of the material's pores and evaporate at the surface with the help of a hot air dryer as the drying rate gradually slows down. Hydration process is diffusion-controlled during this drying stage, while the drying rate is determined by the material's physical characteristics, temperature, and moisture content (Karthikeyan and Murugavelh, 2018; Mercer, 2018).

Over a period, the amount of moisture within the product diminishes, finally approaching zero. Figure 4 describes the time-based drying curve dependent on moisture content. As a result of water loss during drying, it is possible to plot the material's weight with time similarly (Mercer, 2018).

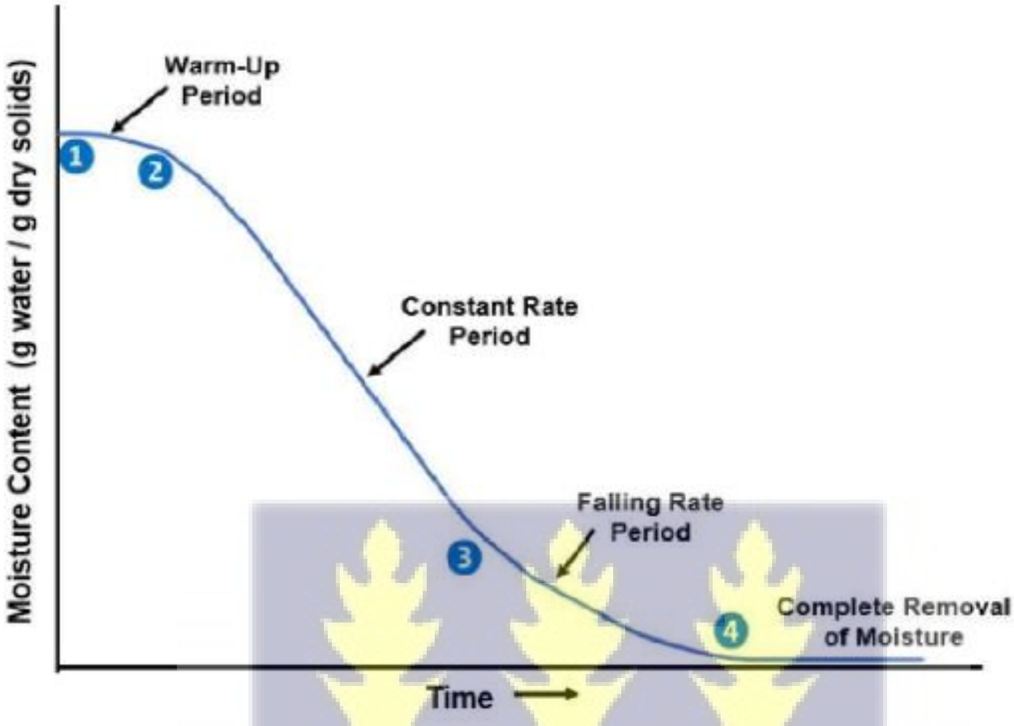

Figure 4:Typical drying curve displaying drying times

(Source: Mercer, 2018)

2.2.2 Mathematical Models

Several mathematical models have been constructed to characterise the drying process for various products. Models are required for the process design, optimisation, energy integration, and control of dryers since they can significantly increase production costs and degrade dried product quality.

The sample size, drying temperature, moisture content, and the characteristics of the material to be dried all influence the drying rate. Thin layer drying involves drying crops under the premise that the air volume to crop volume is infinitely significant (Tiwari *et al.*, 2016).

Moisture ratio (MR) vs time variation is necessary for thin-layer drying formulae (t). The following expression determines the moisture ratios during drying under various circumstances (Zhang et al., 2019):

$$MR = \frac{M_t - M_e}{M_o - M_e}$$

1

Where M_e is the equilibrium moisture content, roughly equal to zero, M_o is the initial moisture content, and M_t is the moisture content at any time t.

The drying behaviour of various agricultural products in the time of dropping rates is predicted using three primary relationships: theoretical, semi-theoretical, and empirical models. The resistance to internal moisture transport is the only factor theoretical models consider (Henderson, 1974). Fick's second law of diffusion is the foundation for the theoretical models (Panchariya et al., 2002). However, these models are inefficient and tend to be complex in practicability. This inefficiency is because they tend to make many assumptions, which usually leads to a significant amount of errors, restraining their applications in the design of dryers (Bruce, 1985). An approach that makes use of experimental data is the empirical technique.

The drying empirical models show that the average moisture content and drying time are directly correlated (Fernando & Amarasinghe, 2016). Empirical models aid in the understanding of the trend of both dependent and independent experimental variables. The empirical models, however, do not consider the drying process's fundamentals and can only describe the drying curve for a specific drying condition, not the processes (heat and mass transfer) that take place during drying (Irudayaraj et al., 1992); consequently, their parameters have no physical significance. Semi-theoretical models have been developed to make it easier to use and fit the drying data from experiments conducted on dried foodstuff (Kemp, 2011). These models are often based on the mass transfer application of Newton's Law of Cooling.

When implementing this law, it is presumed that the environment is isothermal and that the product's surface is the only place resistance to moisture transfer exists. However, these models only function in the range at which they were built for temperature, relative humidity, air velocity, and moisture. Semi-theoretical models do not take the forms of the dried material into account because of the short time requirement (Parry, 1985).

Table 1 below provides a list of some of the mathematical models that have been utilised to explain drying kinetics and determine the MR during thin layer drying. One of the simplest models to explain moisture transfer in food products is the Lewis model. The main flaw in this model is that it frequently overestimates the early phases and underestimates the late stages of drying. Lewis proposed a comparison between the law of heat transfer from a body completely submerged in a cold fluid and the transfer of moisture from biological materials.

Table 1: Mathematical models describing drying kinetics

MODEL	**MODEL EQUATION**	**REFERENCE**
Lewis (Hossain et al., 2007),	$MR = exp(- k*t)$ 2	(Westerman et al., 1973)
Page (Rafiee et al., 2008)	$MR = exp(k*t^n)$ 3	(Overhults et al., 1973)
Henderson & Pabis (Shittu and Raji, 2011)	$MR = a\ exp(- k*t)$ 4	(Yurtlu, 2011)
Logarithmic (Kayisoglu and Ertekin, 2011)	$MR = a\ exp(-k*t) + c$ 5	(Yaldyz & Can, 2007)

Midilli et al. (Midilli et al., 2002)	$MR = a \exp(-k*t^n) + b*t$ 6	(Midilli et al., 2002)

Where;

MR = Moisture Ratio (Dimensionless)

k = drying constant (s^{-1})

t = time (s)

a, b, c = Model's regression fit terms

By introducing a dimensionless empirical constant (n) to the time term, the Lewis model is empirically modified in the Page model to address its flaws. The model in this scenario performs better at predicting moisture loss since this parameter modulates time.

The Henderson and Pabis model is one of many possible approaches to solving Fick's second law. At the beginning of the drying process, this model accurately forecasts the drying rate, although it occasionally seems less successful for the final phases of the process.

For studies on thin-layer drying, the logarithmic model is frequently utilised. It is the Henderson & Pabis model's logarithmic form with the addition of a helpful term. The Midilli et al. model is composed of an exponential and a linear term describing the moisture ratio as a function of drying time. This model is similar to the Henderson & Pabis model with an addition of an empirical term "t".

Statistical criteria such as coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE) are used to test the reliability of the models. These criteria are represented by equations 1, 2, and 3 below. R^2 is employed in statistical models whose primary goal is to forecast future events based on relevant data. It determines how well the model is likely to anticipate future events. The coefficient of determination is likely not to be 0 or 1 but rather a value in between. To assess how well each model fits the data, the reduced chi-square is calculated as the mean square of the differences between experimental and projected values. The discrepancy between values predicted by the model or an estimator and observed values from the thing being modelled or estimated is typically measured by the root mean square error.

$$R^2 = 1 - \frac{SS_{\mathrm{res}}}{SS_{\mathrm{tot}}}$$

7

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp.i} - MR_{pre,i})^2}{N-n}$$

8

$$\mathrm{RMSE} = \sqrt{\left(\frac{\sum_{i=1}^{N}(MR_{exp.i} - MR_{pre,i})^2}{N-n}\right)}$$

9

Where;

SS_{res} = residual sum of squares

SS_{tot} = total sum of squares

MR_{exp} = experimental moisture ratio

MR_{pre} = predicted moisture ratio

A good fit is said to occur between experimental and predicted values of a model when R^2 is high and χ^2, and RMSE are low (Erbay and Icier, 2010).

2.2.3 Effective Moisture Diffusivity

Regardless of the mechanism at play, the term "moisture effective diffusivity" characterizes the rate of moisture migration (*Deff*). By modeling the moisture transport pathways with Fick's second law, the effective moisture diffusivity of a number of foods that are being dried is ascertained experimentally (Wang *et al.*, 2018):

$$\frac{\partial M}{\partial t} = D_{eff}\nabla^2 M$$

10

Equation 1 is resolved analytically using Equation 2's solution, assuming that shrinkage, diffusion coefficient, and initial moisture distribution are ignored at constant temperatures (Chong *et al.*, 2008):

$$MR = \frac{Mt - Me}{Mo - Me} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)} \exp\left(-\frac{(2n+1)\pi^2}{4L^2} Deff.t\right)$$

11

L is half the thickness of the slice sample (m), and D_{eff} is the effective diffusivity (m^2/s). This equation can be condensed to:

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 Deff.t}{4L^2}\right)$$

12

The slope (k) of the graph of lnMR against drying time would be used to calculate the Deff of the OFSP slices. A straight line with a negative slope is produced when lnMR is plotted against drying time, and k is related to Deff by:

$$k = \frac{\pi^2 * Deff . * t}{4L^2}$$

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2.3 Pretreatment

Pretreatments reduce drying time by relaxing tissue structure, inhibiting enzymes, and producing high-quality dried products to prevent colour loss (Al-khusaibi et al., 2005). It has been demonstrated that pretreatment prior to drying can help minimise undesired changes like colour and texture in some agricultural products. The most common and commercially used pretreatments are sodium and potassium hydroxides, potassium carbonate, potassium meta bisulphate, methyl and ethyl ester emulsions, and ascorbic acid (Adedeji et al., 2008; Bingol et al., 2008; Marousis & Raouzeos, 1988). Blanching is the most popular pretreatment technique in the food business because it is simple to apply, effective at neutralising harmful bacteria and enzymes, and successfully preserving food flavour and colour (Abano, 2020).

2.3.1 Blanching

In addition to helping with color preservation, microbial growth decrease, product cleaning, product pre-heating before processing, and gas exhausting from plant tissue, blanching is an enzyme-deactivation phenomena that occurs under heat (Arroqui et al., 2002; Shaheen et al., 2012). The food product is blanched by submerging it in hot water, boiling solutions, or steam containing salt or acid. The blanching procedure lowers the amount of potentially harmful bacteria on the food's surface, which helps with following preservation procedures (Fellows, 2017). The release of carotenoids is also aided by blanching, which raises their bioavailability and extractability. With no discernible difference in flavour, blanching before pretreatment in eggplants lowered phytochemical and anti-nutritional qualities in the eggplant powders while improving their colour (Joel et al., 2019).

In a study by Harjeet et al. in 2020, European plums were pretreated by dipping in Ascorbic Acid (AA), Citric Acid (CA) and Potassium metabisulfite (KMS) (Brar et al., 2020). Except for samples treated with CA, where there was no discernible change, samples treated with AA and KMS solution prior to drying were shown to have shorter drying times than the control. For samples treated with AA and KMS, a reduction in moisture ratio of at least 10% was seen in the majority of samples. This increase in moisture loss in treated plums can be attributed to a rise in mass transfer across membranes due to increased permeability of the waxy layer on the samples' surfaces. Treatment with AA and CA made the cell membrane more permeable and increased the water diffusivity. Fruits and vegetables are preserved with CA, an organic acid. Due to pectin's ability to dissolve in acid and aid in removing water when present, it speeds up the drying process.

However, AA is an antioxidant that transforms o-quinones into colourless dihydroxy phenols and creates a barrier to diffusion into the final product. As a result, at higher temperatures, it cannot penetrate the cellular matrix sufficiently. Compared to untreated samples, acid pretreatment produced increased Effective Moisture Diffusivity values. The effects of AA, Salt Solution (SS), Lemon Juice (LJ), and Honey Dip (HD) on the kinetics of drying and sensory properties of dried mango were also investigated by Abano et al. in 2013 (Abano et al., 2013). Following the control (CO) samples (17.29% wb), the SS samples (16.95% wb), the LJ samples (12.28% wb), and then the AA pretreatment samples (11.91% wb), it was discovered that the HD pretreated sample retained the largest amount of moisture after 14 hours of drying (20.09% wb). The leaching effects of AA on the fruit tissues may have contributed to the low moisture content in AA-dried products by making it more straightforward for water to disperse during drying. This behaviour is in line with Fuente-Blanco et al. (2006), who found that the pretreatment impacts the fruit tissues and facilitates water diffusion during air drying.

Agricultural products acquire the ability to exchange gas, including water in the form of vapour, with the environment, so it is essential to study the relationships between the product, relative air humidity, and temperature through hygroscopicity in order to minimise physical, chemical, and microbiological changes that occur after harvesting. Designing projects for post-harvest systems requires an understanding of equilibrium moisture content. The diffusion coefficient is one of the critical drying parameters. The value of the coefficient of food, a material property, is determined by the circumstances present in the material. Effective moisture diffusivity refers to all potential processes for transferring moisture within the meal, including liquid and vapour diffusion, capillary action, and hydrodynamic flow. Designing and modelling mass-transfer processes, including dehydration, adsorption, and desorption of moisture during storage requires knowledge of effective moisture diffusivity.

2.4 Functional Properties

Functional properties are the fundamental physiochemical characteristics of foods that reflect the intricate relationships between the molecular makeup, physiochemical characteristics, and structural makeup of food components with the environmental and measurement conditions (Chandra et al., 2015; Kaur & Singh, 2006; Siddiq et al., 2009). Functional features are needed to assess how new proteins, fats, carbohydrates (starch and sugars), and fibres may function in particular food systems and to show whether they may be utilised to supplement or replace traditional protein sources (Chandra et al., 2015; Kaur & Singh, 2006) fat, carbohydrates (starch and sugars), and fibre. Functional qualities also explain how components behave during preparation and cooking and influence the final product's appearance, texture, and flavour. Swelling, water and oil absorption, foam capacity and stability, gelatinisation, bulk density, dextrinisation, preservation, denaturation, coagulation, gluten formation, jelling, shortening, plasticity, flakiness, moisture retention, aeration, and sensory attributes are just a few examples of functional properties.

2.4.1 Water Absorption Capacity

The quantity of water (moisture) absorbed by food or flour to attain the necessary consistency and produce high-quality food items is known as the water absorption capacity (WAC), often referred to as water absorption. The ideal amount of water that should be added to a dough before it gets too sticky is known as the threshold amount. Water absorption can harm the quality of food products if it is very low or high. The weight of the food or flour is frequently used to describe water absorption. For instance, a 60% water absorption rate means 100 pounds of flour are hydrated using 60 pounds of water. The gluten-forming proteins glutenin and gliadin, as well as the ruined starch and other components, are hydrated when water and flour are combined. When the molecules of protein and starch engage hydrophilically and form hydrogen bonds with the molecules of water, the hydration process is accomplished by rubbing up against one another and coming into contact with water molecules. Pressure, the beating arm, the water flow, and the type of mixer are process variables that remove the hydrated surface layer from the particles and expose a new layer to the extra water so the water diffusion process can continue. These aspects of baking and bread can be affected by water absorption: Bread crumb fracture stress, loaf volume, bread yield, characteristics of the finished goods, machinability, and shelf life (Puhr & D'Appolonia, 1992; Zghal et al., 2001). Water absorption levels frequently range from 60–62% in a formula for basic white bread to 80–90% in a formula for artisan Ciabatta to 50–54% in a recipe for cookies. Any increase in the flour's enzyme activity when sprouted flour will boost the food's ability to absorb water and produce the Maillard reaction.

Many food ingredients with a high WAC value have a strong affinity for water molecules, including proteins, carbohydrates (particularly polysaccharides), polar amino acid residues (Sreerama et al., 2012), and other hydrophilic constituents. According to Kuntz (Kuntz, 1971), the lesser availability of polar amino acids in specific flours may be the source of the poorer water absorption in those flours. The increase in amylose solubility and leaching and the loss of the starch's crystalline structure may also contribute to the increase in the WAC of flour. Given the high WAC of some composite flours, it is possible to create various dishes, including dough, sausage, processed cheese, and bakery goods, by combining various flours. The flour with a high water absorption rate may contain more hydrophilic ingredients, including polysaccharides. Protein can interact with the water in food since it is both hydrophobic and hydrophilic. According to a report from Butt and Batool from 2010, the observed variance in WAC of various meals and flours may be caused by the protein's structural properties, concentration, and degree of contact with water (Batool & Butt, 2010). Water absorption capacity is a crucial functional requirement for food, especially when handling dough. (Iwe et al., 2016). WAC may be impacted by reduced associative forces preserving the granular structure and the loose connection of amylopectin and amylose in the starch granules. The ability to absorb water is crucial in applications such as bulking, baking, and product uniformity (Iwe et al., 2016).

2.4.2 Swelling Index

The volume in millilitres occupied by the swelling of one gram (1 g) of food material under particular circumstances is known as the swelling index (SI), also known as swelling capacity (SC). Its conclusion is based on adding water or an agent that causes swelling, as specified in the test protocol for each unique food material (whole, pulverised, or cut). The number of associative forces present in the starch granules is indicated by the swelling capacity, which measures the starch's propensity to absorb water and swell some food products, such as bread goods; swelling capacity (index) is regarded as a quality indicator. It shows the non-covalent bonding between the molecules in the starch granules and a contributing element to the -amylose and amylopectin ratios (Iwe et al., 2016). The species variety, processing method, and flour particle size all impact its swelling capacity (index) (Chandra & Singh, 2013). The swelling capacity (index) of meals and flours is increased by high starch content, mainly when the starch contains more branching amylopectin. Amylose, a linear chain, and amylopectin, a branching chain, are both chains of glucose molecules that make up starch. Granules, which are incredibly tiny packets of starch, are common. Depending on the source of the plant, different amounts and ratios of amylose and amylopectin can be found in starch. This explains why the swelling capacities of various flours from various (plant) sources and species vary.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

Orange Fleshed Sweet Potatoes were obtained from MAPHLIX Trust Limited, a farm located in Tadzewu in the Volta region of Ghana. The potatoes were 2 days old after harvest and were in good condition free of injuries and bruises. The potatoes were weighed, sorted, and carefully peeled manually before drying. Ascorbic acid was obtained from Micrite Group Ghana Limited, a major supplier of industrial flavours and food chemicals located in Tema in the Greater Accra Region of Ghana.

3.1.1 Equipment and instruments used

Memmert Universal oven UN and UF with single display manufactured from Germany, plastic containers (big and small sizes), The HunterLab MiniscanTM XE Colorimeter Model 45/0 LAV (Hunter Associates Inc., Reston, VA, USA), balance, thermometer, stopwatch, and tissue paper.

3.1.2 Moisture Content Determination

3 g of the fresh and dried OFSP samples were weighed after being dried at 105 °C for 18 hours in a hot air oven (Memmert Universal oven), which established the moisture content as a wet basis (w.b.%) percentageSamples were removed, allowed to cool, and then weighed. As a percentage of the mass of the sample obtained, the moisture content was computed (AOAC 2005). Wet base moisture content was represented as (Wang et al., 2018);

$$Moisture\ content, M.C\ \%\ (w.b) = \frac{Ww - Wd}{Ww} \times 100\%$$

Where W_w is the weight of water lost in the potatoes and W_d is the weight of the dried potato slices.

3.1.2 Statistical Data Analysis

Data were given as the mean of three determinations from the laboratory analyses, which were carried out in triplicate. Analysis of Variance was used to analyze the data (ANOVA) using Python software (Version 3.10) especially the Numpy and Pandas libraries. Using Numpy's numpy.polyfit() function, drying experiment statistical analysis was carried out to determine which curve fits the data best.

3.1.3 Pretreatments

Two different pretreatments were applied to the samples to inactivate enzymes. The pretreatment methods examined in this study are listed in Table 2 below.

Table 2: Pre-treatment methods and Description

Treatment	**Description**
Control	The samples were not treated with anything (control).
Blanching	Fifty (50) grams of sample was blanched by immersing in hot water at 80+-1C for one (1), two (2) and three (3) minutes, respectively. The samples were blanched before blotted with tissue paper to remove any superficial water.
Ascorbic Acid	Fifty (50) grams sample was pretreated with a solution of ascorbic acid (2000ppm) at 50C for one (1), two (2) and three (3) minutes, respectively. The samples were blanched before blotted with tissue paper to remove any superficial water.

3.1.4 Drying Procedure

After pretreatment, the samples were dried at three (3) distinct temperatures, 50, 60, and 70^{o}C, respectively. Prior to the drying experiment, the dryer was left running at a low speed for an hour. Initially, the masses of the samples were checked every thirty (30) minutes; after that, they were checked at intervals of one (1) hour, and so on, until a consistent mass was discovered using a digital balance. It took around 30 seconds to remove, weigh, and return the samples to the oven to reduce the amount of air moisture sorption during weighing.

3.1.5 Milling Procedure

The slices of orange-fleshed sweet potato dried under the oven dryer and the solar tent dryer were milled respectively into flour by the hammer mill (Christy & Norris lab mill pulverizers & grinders, serial number 16-3343). Illustrations of the milled samples are found in appendix 5, 6, and 7 respectively.

3.1.6 Drying Kinetics

Three replicates of the experiment were run. The gathered information was utilised to draw a drying curve. The five semi-empirical equations listed in Table 1 were then used to fit these drying curves to the experimental data.

3.1.7 Color Determination

The procedure for determining the colour of the potatoes was followed as described by Afoakwa (2010). It was calibrated with a white ceramic reference standard using the HunterLab MiniscanTM XE Colorimeter Model 45/0 LAV (Hunter Associates Inc., Reston, VA, USA). Images of the flour surfaces in colour were transformed to XYZ tristimulus values, which were then translated into the CIELAB system: L*, with luminance values ranging from 0 (black) to 100 (white); and a* (green to red) and b* (blue to yellow) with values between 120 and +120

3.1.8 Water Absorption Capacity

The procedure to ascertain the water absorption capacity was detailed by a study in 2010 (Omojola et al., 2010). The starch samples (5% w/v) were diluted in a centrifuge tube that had been pre-weighed. After 2 minutes of agitation in a vortex mixer, the supernatant was removed, and the weight of the tube's hydrated sample was measured. The amount of water bound to 100 grams of dry starch was used to determine and express the weight.

3.1.9 Swelling Power/ Swelling Index

The solubility index was determined using the procedure outlined by a study in 2012 (Afolayan & Omojola, 2012). A test tube containing the starch sample (0.1g) and 10ml of distilled water was filled. The mixture was continuously shaken for 30 minutes while being heated in a water bath at a temperature of 50C. The test tube was then carefully decanted after the supernatant had been removed by centrifuging it at 1500 rpm for 0 minutes, and the weight of the starch paste was recorded. Following is how the swelling power was determined:

$$\text{Swelling power} = \frac{Weight\ of\ Starch\ paste}{Weight\ of\ dry\ starch\ sample}$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.0 Drying Kinetics

4.1.1 Moisture Content

In Figures 3, 4, and 5, the data for moisture content loss over time are condensed. Graphs display a general linear trend, which then diminishes nonlinearly. The orientation, accessibility, and bonding of the water molecules in the food sample may be to blame for this phenomena. Only a small percentage of the free moisture is first evaporated when this sample absorbs heat to provide sensible heat, and as drying progresses, the moisture diffuses out. Heat permeates the interior and drives the moisture out, leaving a product with less water.

Figure 5: Memmert Universal Oven

Due to the availability of free moisture, the drying rate rises initially. As the temperature of the air and substance equalises at this point, the Kinetic energy of molecules rises, slowing the drying process until it comes to a halt. More moisture diffuses to the surface as the moisture content drops as a result of evaporation, which reduces the amount of water that needs to evaporate and slows the drying rate.

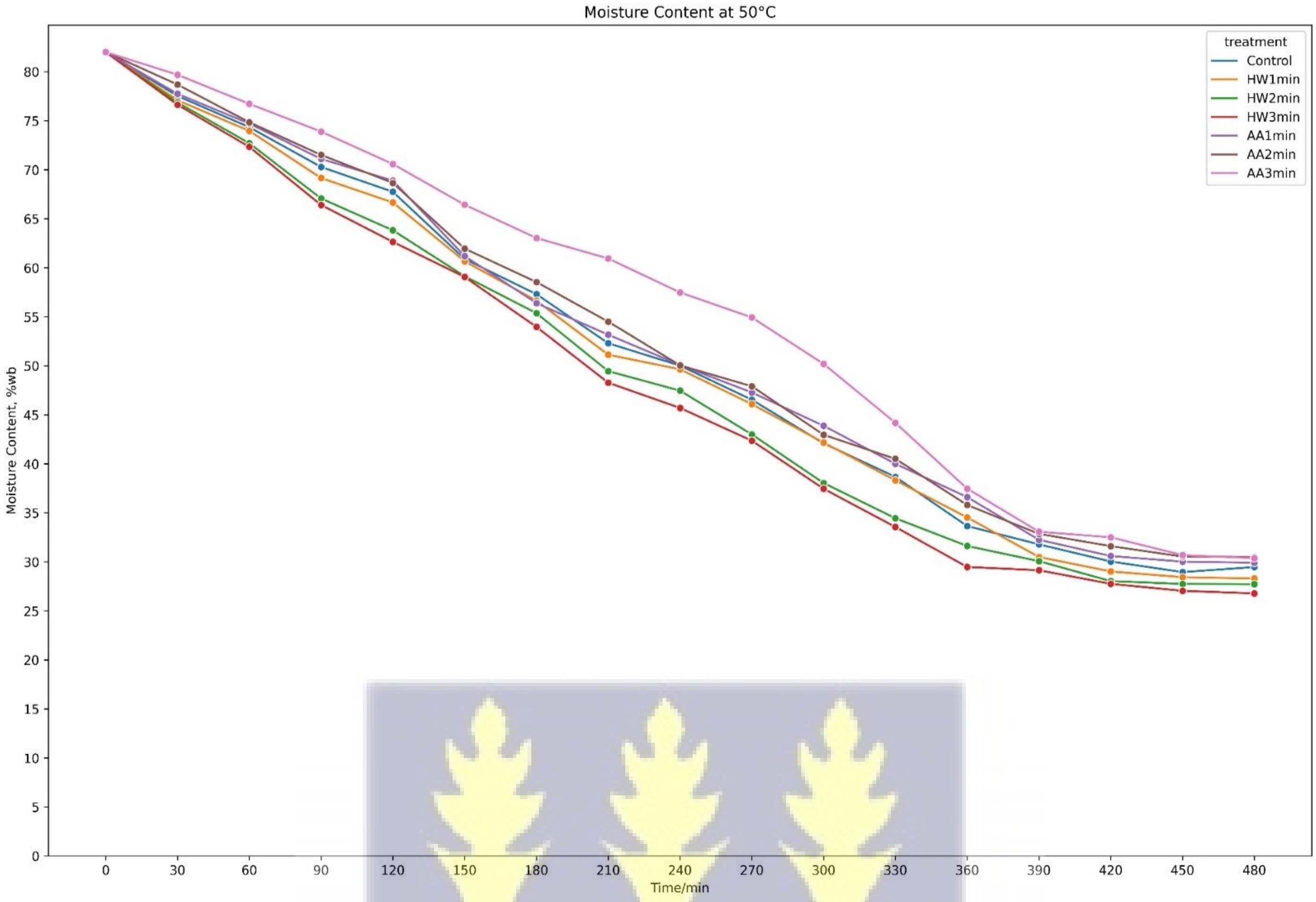


Figure 6: Moisture content variation with time for drying at 50°C

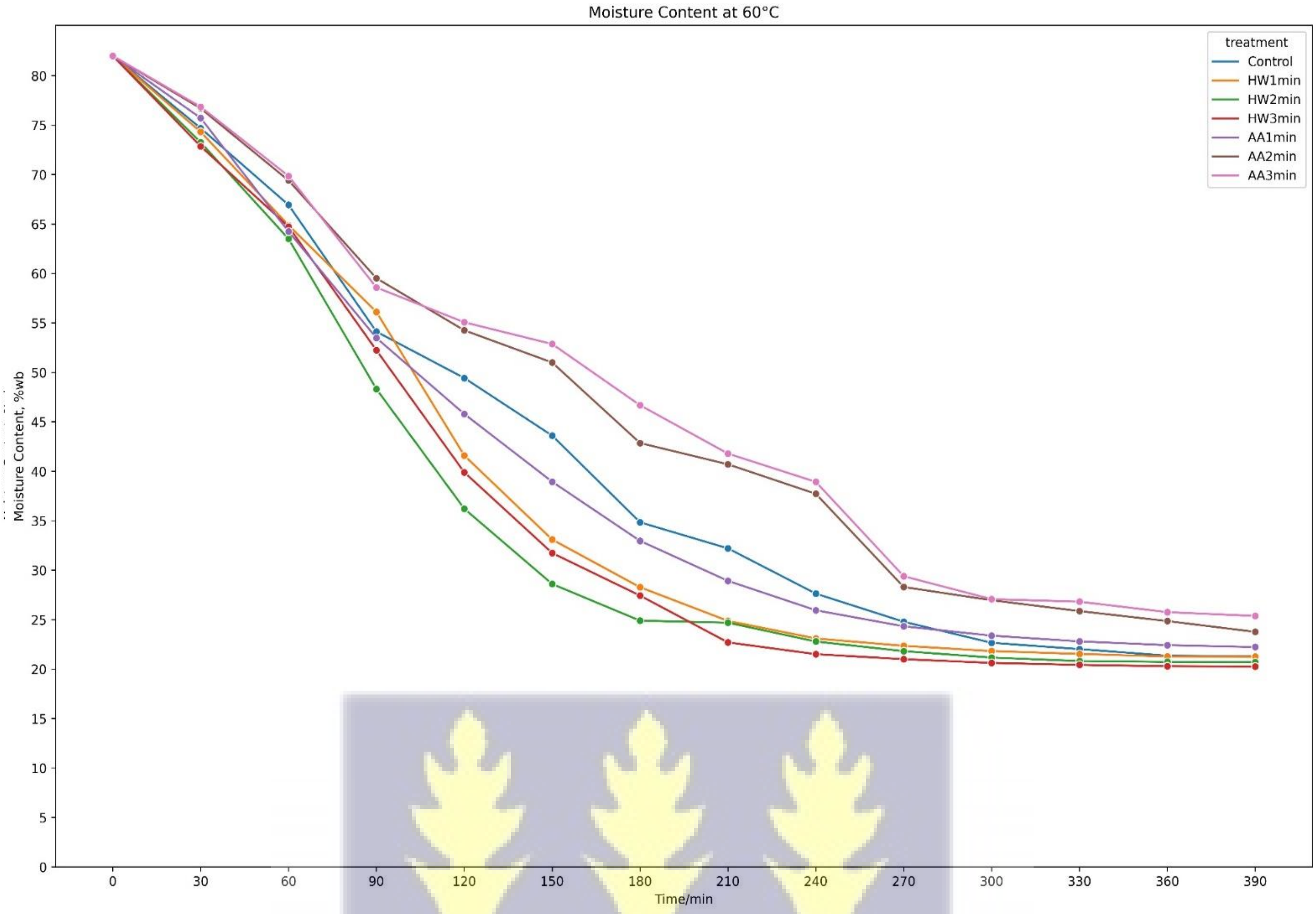
It was discovered that blanched samples lost moisture more quickly in hot water than unblanched samples. This behaviour was brought on by the structure of suffering that might help remove moisture. Samples pretreated with ascorbic acid lost less moisture than unblanched samples. This may be caused by the gelatinisation of the starch, structural alterations, and water absorption during blanching. Increased gelatinisation may change the internal barrier to moisture transport and impact cell structure.

Because of the greater driving force, samples dried at higher temperatures dried more quickly, and vice versa. Increased temperatures resulted in more water being removed, which shortened the time needed to extract the sample's moisture. Samples pretreated in hot water for three minutes and dried at 50°C reported the lowest final moisture content of 25%, with an initial moisture content of 82% w.b. The samples pretreated in ascorbic acid for three minutes had the highest moisture content observed for the same time period and drying temperature. The type of pretreatment had a substantial impact on the moisture loss rate at 50°C drying temperature, according to an analysis of variance performed on the moisture content loss. Analysis of variance performed on the moisture content loss indicated that the pretreatment type significantly affected the moisture loss rate at 50°C drying temperature.

Table 3: Analysis of Variance (ANOVA) of moisture loss for OFSP samples dried at 50°C

Source	**F Value**	**Num DF**	**Den DF**	**Pr > F**
Treatment	48.9748	6.0000	96.0000	0.0000

For each applicable pretreatment, samples dried at a drying temperature of 60°C recorded a typically lower ultimate moisture content than the prior drying temperature. The samples pretreated in hot water for three minutes had the lowest measured final moisture content (21% wb). The figure clearly shows that it took 390 minutes to reach this moisture content. Additionally, a variance analysis of the moisture loss revealed that the pretreatment type substantially impacted.



TablFigure 7: Moisture content variation with time for drying at 60^{o}C

Also, analysis of variance performed on the moisture loss indicated that the pretreatment type significantly affected the moisture loss rate at 60^{o}C.

Table 4: ANOVA of moisture loss for OFSP samples dried at 60^{o}C

Source	**F Value**	**Num DF**	**Den DF**	**Pr > F**
Treatment	24.1418	6.0000	78.0000	0.0000

Samples dried at 70°C drying temperature recorded a minimum moisture content of 19% wb after just 330 minutes. This reading was obtained from samples pretreated in hot water for three minutes. Samples pretreated in ascorbic acid for three minutes again recorded the highest moisture content for the exact temperature at the end of the drying process with a value of 25% wb.

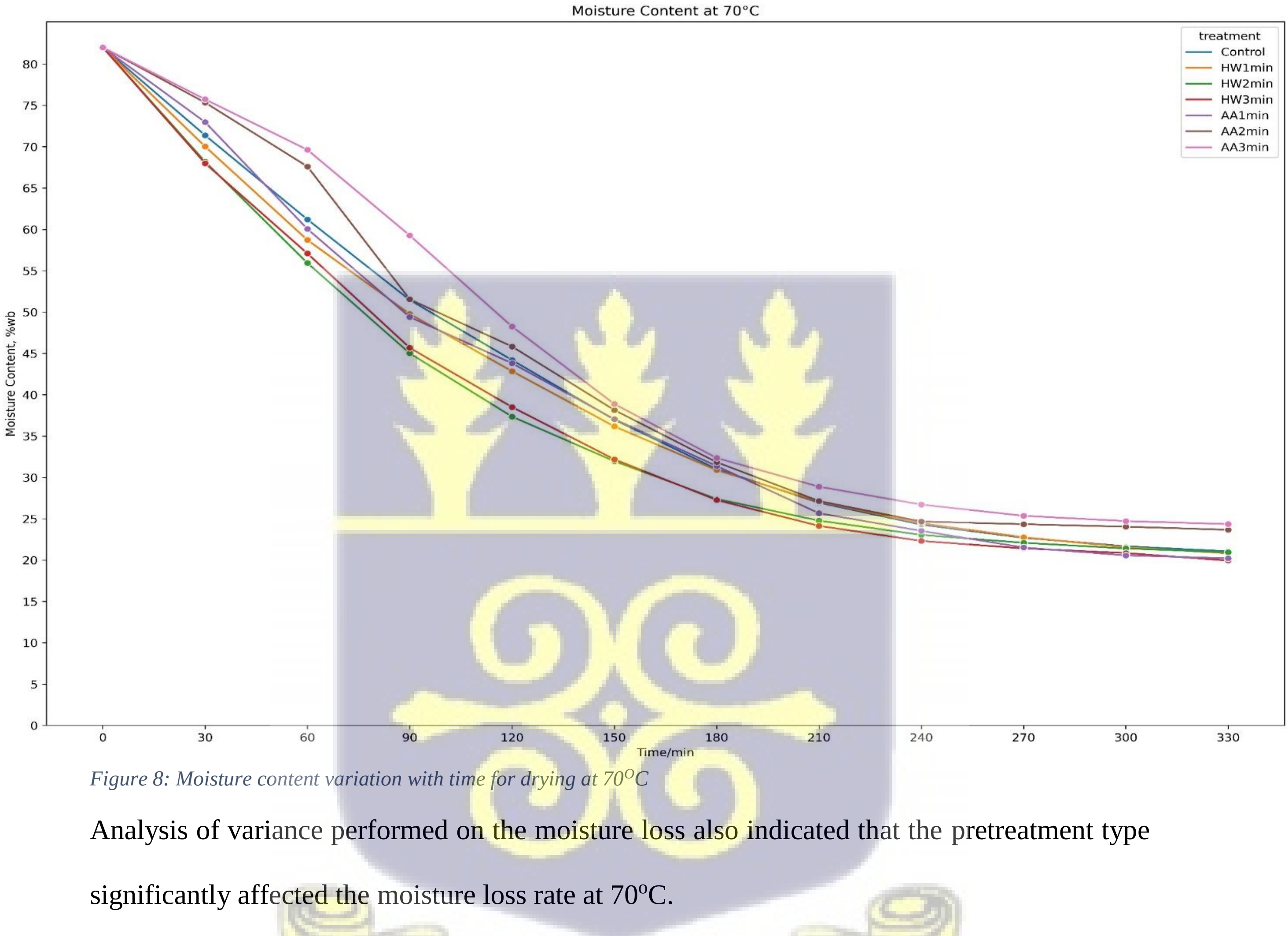


Figure 8: Moisture content variation with time for drying at 70^{O}C

Analysis of variance performed on the moisture loss also indicated that the pretreatment type significantly affected the moisture loss rate at 70°C.

Table 5: ANOVA of moisture loss for OFSP samples dried at 70°C

Source	**F Value**	**Num DF**	**Den DF**	**Pr > F**
Treatment	20.8416	6.0000	66.0000	0.0000

4.1.2 Effective Moisture Diffusivity

The complex process of moisture migration frequently involves one or more transport modes, including hydrostatic pressure differences, surface diffusion, liquid diffusion, and vapour diffusion. The equilibrium concentration of the water at higher temperatures causes the drying rate to increase. Some methods, such as molecular diffusion, capillary flow, Knudsen flow, hydrodynamic flow, or surface diffusion, cause moisture to migrate from the solid to the surface. The idea that effective moisture diffusivity represents all phenomena theories to food process rate underlies the study of the mass transfer phenomenon. The diverse physical structure and content of meals make applying the moisture diffusivity phenomenon hypothesis challenging to food processing.

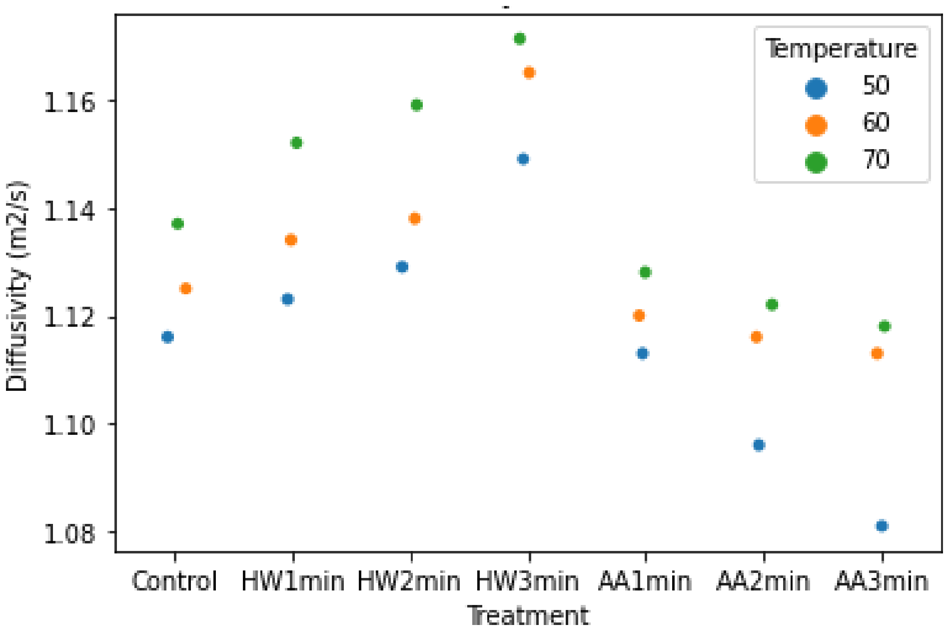


Figure 9: Variation of Effective Moisture Diffusivity with Treatment at different Temperatures

Effective moisture diffusivity increases with increasing drying temperature. Because the water molecules are weakly attached to the food matrix at high temperatures, it uses less energy to remove them than it would at lower temperatures. Since the drying of the potatoes was carried out only at the falling rate stage, it implies that the diffusion phenomenon governed the moisture removal.

4.1 Mathematical Models

The evaluation of many foods' drying times and generalisation of their drying behaviour are aided by thin-layer drying equations. Table 1 displays the results of modelling the experimental MR against time using five mathematical models. Based on the associated coefficient of determination (R^2), root means square error (RMSE), and reduced chi-square distribution (χ^2), MR was assessed using Python software to find the best fit..

4.1.1 Mathematical modelling for the drying processes

Tables 6, 7, and 8 below summarises the treatment and the model equations that best describe the drying process at 50ºC, 60ºC, and 70ºC respectively. For samples dried at 50ºC, the Midilli model yielded the highest values of R^2 and corresponding lowest values of the RMSE and χ^2 for all treatments. For samples dried at 60ºC, the page model yielded the highest values of R^2 and corresponding lowest values of the RMSE and χ^2 six out of seven treatments. The Midilli model was the best fit for the samples treated in ascorbic acid for one minute. For samples dried at 70ºC, The Page and Logarithmic models yielded the the highest values of R^2 and corresponding lowest values of the RMSE and χ^2 for various treatments.

Table 6: Best fit mathematical models for drying OFSP slices after various pretreatments at 50ºC

Treatment	**Model Name**	**Equation**
Control	Midilli	$MR = 0.9678*exp(-0.0045*t^{1.3141}) + 0.0451*t$
Hot Water 1min	Midilli	$MR = 0.9755*exp(-0.0027*t^{1.3849}) + 0.0428*t$
Hot Water 2min	Midilli	$MR = 0.9697*exp(-0.0167*t^{1.0340}) + 0.0329*t$
Hot Water 3min	Midilli	$MR = 0.9699*exp(-0.0168*t^{1.0420}) + 0.0332*t$
Ascorbic Acid 1min	Midilli	$MR = 0.9715*exp(-0.0037*t^{1.3417}) + 0.0415*t$
Ascorbic Acid 2min	Midilli	$MR = 0.9697*exp(-0.0167*t^{0.10340}) + 0.329*t$
Ascorbic Acid 3min	Midilli	$MR = 0.9699*exp(-0.01676*t^{1.0420}) + 0.0332*t$

Table 7: Best fit mathematical models for drying OFSP slices after various pretreatments at 60°C

Treatment	Model Name	Equation
Control	Page	$MR = exp(-0.1201 * t^{0.65316})$
Hot Water 1min	Page	$MR = exp(-0.09629 * t^{0.65218})$
Hot Water 2min	Page	$MR = exp(-0.05369 * t^{0.76623})$
Hot Water 3min	Page	$MR = exp(-0.08419 * t^{0.6987})$
Ascorbic Acid 1min	Midilli	$MR = 0.9986012 * exp(-0.0923117 * t^{0.6580221}) + 1.125e-05 * t$
Ascorbic Acid 2min	Page	$MR = exp(-0.07714 * t^{0.68951}))$
Ascorbic Acid 3min	Page	$MR = exp(-0.78661 * t^{0.04229})$

Table 8: Best fit mathematical models for drying OFSP slices after various pretreatments at 70°C

Treatment	Model Name	Model Equation
Control	Page	$MR = exp(-0.00021 * t^{2.02261})$
Hot Water 1min	Logarithmic	$MR = 0.99885 * exp(-0.01756 * t) + 0.00606$
Hot Water 2min	Logarithmic	$MR = 0.97948\ exp(-0.01977 * t) + 0.01546$
Hot Water 3min	Logarithmic	$MR = 1.00546 * exp(-0.01994 * t) + 0.00615$
Ascorbic Acid 1min	Page	$MR = exp(-0.00865 * t^{1.11324})$
Ascorbic Acid 2min	Page	$MR = exp(-0.1214 * t^{1.04558})$
Ascorbic Acid 3min	Henderson	$MR = 1.02367\ exp(- 0.01508 * t)$

4.2 Quality Characteristics

4.2.1 Colour

Consumers use a variety of basic indicators to assess a product's acceptability, with color perception on food goods being one of them. The color profile aids in identifying minute alterations in general look as well as warning of potentially dangerous food contamination, anomalies, or product degradation. The level of color deterioration that takes place while food products are heated has an impact on how stable and well-liked dried food goods are with consumers.

(a)

(b)

Figure 10: (a)HunterLab Colorimeter (b) Sample readings with colorimeter

In the case of lightness, it was discovered that neither the blanching duration nor the drying temperature had a significant impact on the product's lightness. Although the results were not substantially different, the samples prepared with ascorbic acid recorded greater lightness values than the control and hot water pretreatment samples. Because the enzymes that led to quality degradation were killed during the blanching process, it was considered that the non-enzymatic browning was a crucial component in the color change of OFSP flour.

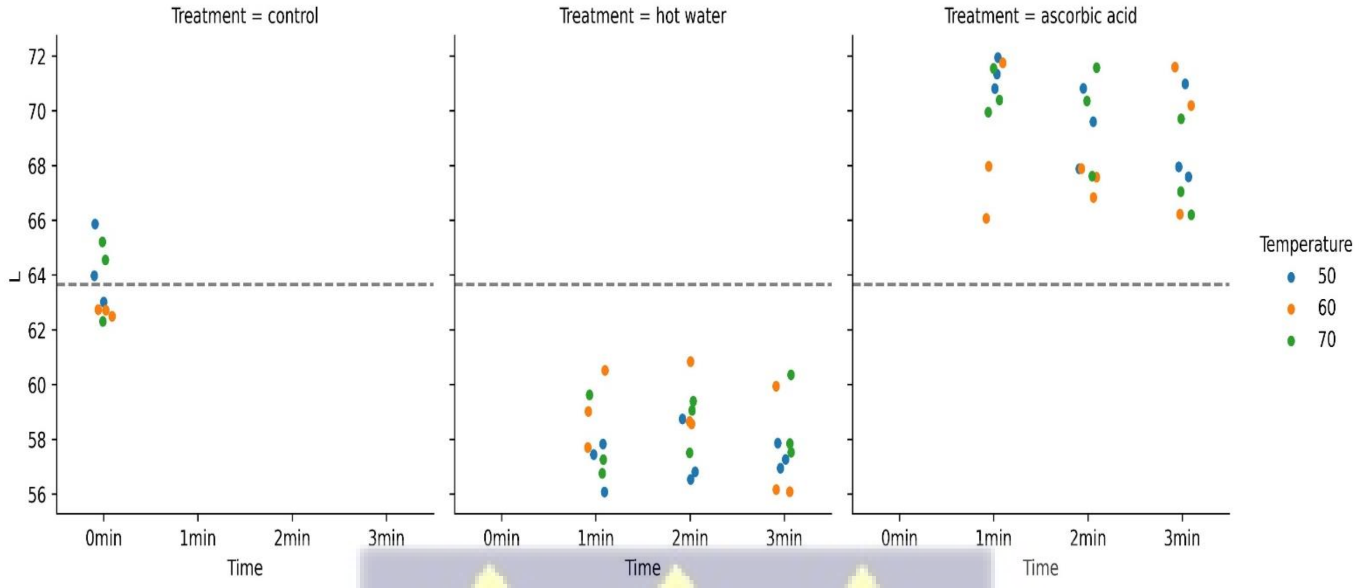


Figure 11: Comparisons of treatment times with drying temperatures on the L property of Colour*

The drying temperature, the length of the blanching period, and their interactions had a substantial impact on the variation in the redness of OFSP flour. It was observed that samples dried at higher temperatures had generally high red values than ones dried at lower temperatures. Regarding the blanching times, especially for samples pretreated in hot water, lower treatment times means higher red values.

Table 9: ANOVA of Temperature and Treatment Time Variations on L property of Colour*

	df	sum_sq	mean_sq	F	PR(>F)
Time	3.0	7.589003	2.529668	0.081263	0.969959
Temperature	2.0	2.522066	1.261033	0.041083	0.95977

A complex variety of chemicals is created when reducing sugars and an amino acid interacts in a process known as the Maillard reaction. The Maillard reaction or browning is an essential culinary process for new flavour, aroma and colour development. Higher drying temperatures associated with a greater prevalence of the Maillard reaction, is what caused the results mentioned above. A non-enzymatic browning reaction can also be used to describe this phenomenon. Blanching in hot water decreased the *a* value of potato chips because the substrates of the Maillard's reaction, reducing sugars, are leached out before drying, minimising the non-enzymatic browning reaction and producing fewer red potatoes.

.2

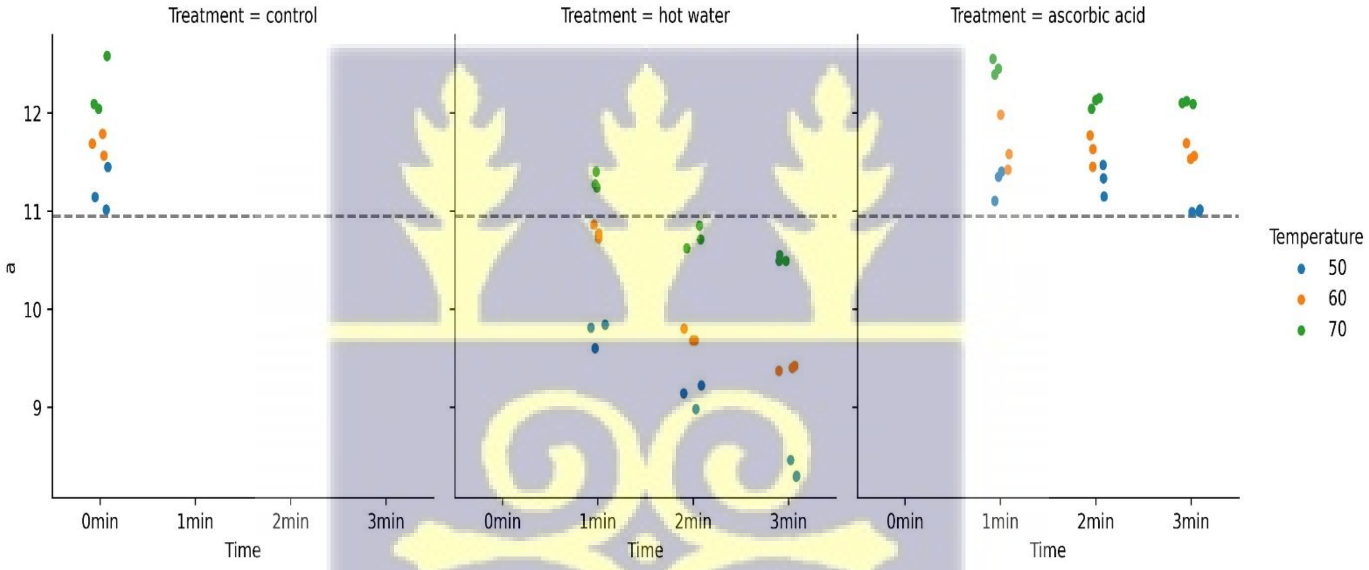


Figure 12: Comparisons of treatment times with drying temperatures on the a property of Colour*

Table 10: ANOVA of Temperature and Treatment Time Variations on a property of Colour*

	df	sum_sq	mean_sq	F	PR(>F)
Time	3.0	10.707685	3.569228	3.27844	0.027087
Temperature	2.0	19.112041	9.556021	10.270009	0.000146

The drying temperature did not significantly affect the *b** value (yellowness) of the OFSP flour. The temperature did not cause a difference in the yellowness. However, the samples blanched in hot water showed a pronounced increase in yellowness after drying. In other words, blanching in hot water showed relative stability of yellowness.

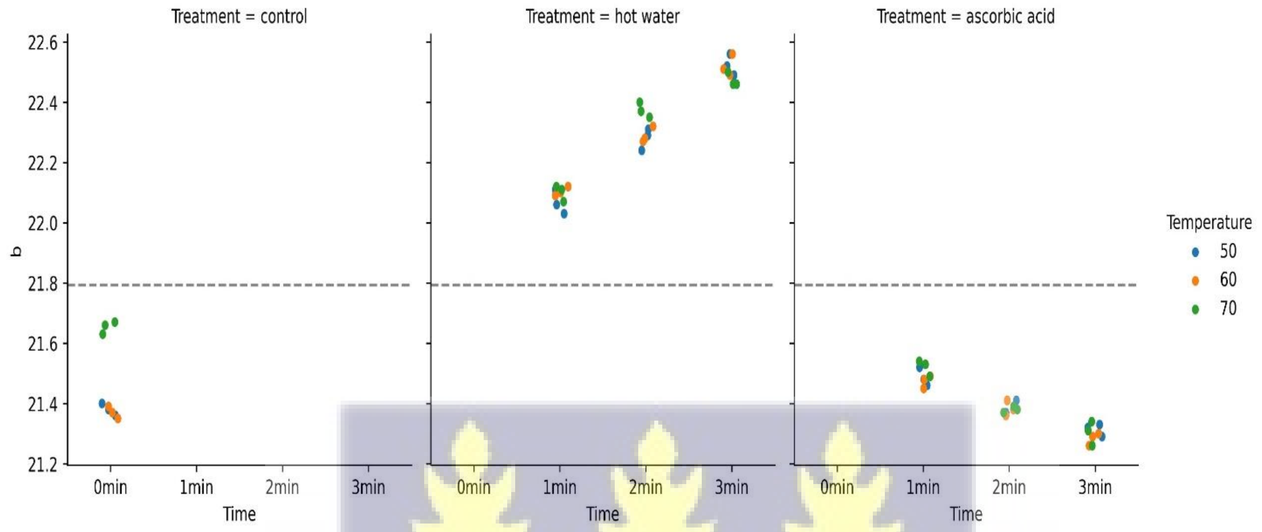


Figure 13: Comparisons of treatment times with drying temperatures on the b property of Colour*

Additionally, it was shown that shorter pretreatment times in hot water resulted in lower *b** values, while samples pretreated in ascorbic acid had lower *b* values for samples that blanched longer. However, these results were not significantly different.

Table 11: ANOVA of Temperature and Treatment Time Variations on b property of Colour*

	df	sum_sq	mean_sq	F	PR(>F)
Time	3.0	1.225087	0.408362	1.965692	0.128953
Temperature	2.0	0.039860	0.019930	0.08896	0.915003

4.2.2 Swelling Index

The swelling index of flour describes the ability of starch to absorb water. The features of several products, including their moisture content, starch retrogradation, and subsequent staling, depend heavily on the swelling index. The findings demonstrate that the drying temperature considerably impacts swelling power. In general, higher swelling index values resulted from higher drying temperatures. The increase in Swelling Index is a sign that there is non-covalent bonding between the molecules of starch (Desale & Sasanatayart, 2017). Increased flour granule association could reduce the swelling index (Ramesh Yadav et al., 2006). The presence of higher amylose content, non-starch carbohydrates and lipid-starch complexes, among others, can reduce the swelling of flour (Avula & Rakesh, 2009). Furthermore, different drying methods of water evaporation from crystals could cause variations in the swelling power of the flours produced (Zeng et al., 2016)

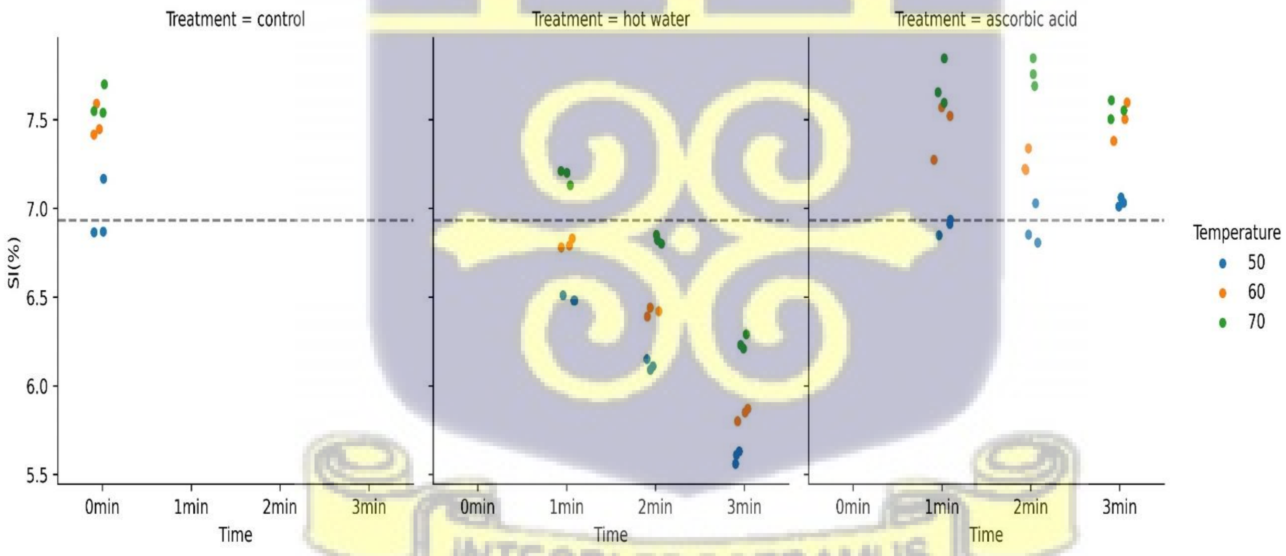


Figure 14: Comparisons of treatment times………… with drying temperatures on the Swelling Index

The length of pretreatment also significantly affected the values of the swelling index. This is very obvious from the samples pretreated in hot water. Samples pretreated for extended periods in hot water produced lower values than samples that blanched for a lesser time at the same temperature.

Table 12: ANOVA of Temperature and Treatment Time Variations on Swelling Index

	df	sum_sq	mean_sq	F	PR(>F)
Time	3.0	3.713324	1.237775	3.670885	0.017089
Temperature	2.0	5.082419	2.541210	8.2300667	0.000694

4.2.3 Water Absorption Capacity

The Water Absorption Capacity of the OFSP flour had a maximum of 3.99% when blanched in hot water for three minutes and a minimum value of 2.74% when pretreated in ascorbic acid. The variation in drying temperature significantly influenced the water absorption response. The samples dried at 70^{o}C had higher absorption than other OFSP flour samples. This could be attributed to the relatively higher drying temperature resulting in much lower equilibrium moisture content (Oyefeso et al., 2021). This result is consistent with the findings of the study by Hayta et al. (2006), which showed that drying increased the capacity of flour to absorb water. Water absorption capacity is a crucial physiochemical characteristic that is significant in baking applications as well as bulking and uniformity of goods, according to Niba et al. (2001).

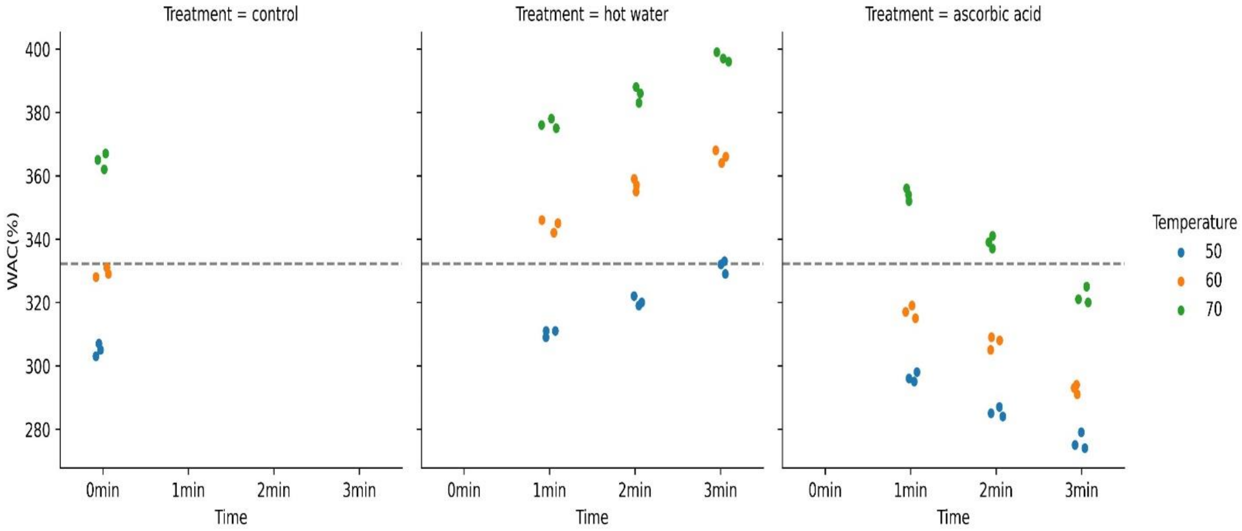


Figure 15: Comparisons of treatment times with drying temperatures on the Swelling Index

Table 13: ANOVA of Temperature and Treatment Time Variations on Water Absorption Capacity

	df	sum_sq	mean_sq	F	PR(>F)
Time	3.0	50.769841	16.923280	0.014413	0.997611
Temperature	2.0	36881.175	18440.587	34.102122	1.280e-10

Water absorption capacity was not significantly affected by the length of pretreatment. Collected data, however, shows that samples that blanched longer in hot water before drying recorded higher values of water absorption capacity than samples that blanched lesser. For samples pretreated in ascorbic acid, samples blanched longer recorded low water absorption capacities than samples blanched in lesser time. However, these results showed a significant difference in their means.

CHAPTER FIVE

5.0 RECOMMENDATIONS AND CONCLUSION

5.1 Recommendations

Based on the findings of this research on the drying characteristics of Orange Fleshed Sweet Potato (OFSP) and the quality of its resulting flour, the following recommendations are put forth:

- Optimized Drying Techniques: Given the significance of drying temperature and pretreatment on the quality of OFSP flour, it is recommended to further explore and optimize drying techniques. This could involve the use of controlled environment chambers or advanced drying equipment to ensure uniform drying and preservation of nutritional content.
- Standardization of Pretreatment Methods: The study highlighted the impact of pretreatment on drying kinetics and flour quality. Future research should aim to standardize pretreatment methods, ensuring consistent results across different batches of OFSP.
- Further Research on Nutritional Preservation: While this study touched upon the quality characteristics of OFSP flour, there's a need for in-depth research on preserving the nutritional content, especially Vitamin A, during the drying process.
- Integration of Technology: The adoption of technology, such as moisture sensors and automated drying systems, can enhance the efficiency and consistency of the drying process. This would ensure high-quality OFSP flour production at a commercial scale.
- Modeling and Simulation: The study identified the best fit using thin-layer drying models. It's recommended to delve deeper into simulation-based studies to predict drying behavior under various conditions, facilitating scalability and industrial application.

By addressing these recommendations, it is hoped that the production and utilization of OFSP flour can be enhanced, contributing to both the agricultural and nutritional sectors.

5.2 Conclusion

The effect of pretreatment and drying temperatures on the color, water absorption capacity, and swelling index of OFSP flour was investigated. Variations in the drying temperature and pretreatment time significantly influenced the rate of moisture loss during drying. Pretreatment time and drying temperatures did not have a significant impact on the L* values of of the flour after drying like it did for the a* values. Pretreatment time also had a significant impact on swelling index but not water absorption capacity. Based on the intended end-use and required qualities of the OFSP flour, this study's findings will serve as a reference to ensure optimal selection of pretreatment time and and drying temperature.

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Appendices

Appendix 1: Summary Characteristics of OFSP Flour

Drying Temperature	Pretreatment	Pretreatment Time/ min	L*	a*	b*	SI	WAC / %
50	Control	0	64.28±1.45	11.20±0.22	21.38±0.02	6.97±0.17	3.05±0.02
50	Hot water	1	57.11±0.92	9.75±0.13	22.07±0.04	6.49±0.02	3.10±0.01
50	Hot water	2	57.36±1.20	9.11±0.12	22.28±0.04	6.12±0.03	3.20±0.02
50	Hot water	3	57.35±0.47	8.35±0.09	22.52±0.04	5.60±0.04	3.31±0.02
50	Ascorbic acid	1	71.36±0.57	11.28±0.16	21.49±0.03	6.90±0.05	2.96±0.02
50	Ascorbic acid	2	69.43±1.48	11.32±0.16	21.39±0.02	6.90±0.12	2.85±0.02
50	Ascorbic acid	3	68.84±1.87	11.00±0.02	21.31±0.02	7.03±0.03	2.76±0.03
60	Control	0	62.64±0.14	11.68±0.11	21.37±0.02	7.48±0.09	3.29±0.03
60	Hot water	1	59.07±1.41	10.78±0.07	22.10±0.02	6.80±0.03	3.44±0.02
60	Hot water	2	59.34±1.29	9.72±0.03	22.29±0.03	6.42±0.03	3.57±0.02
60	Hot water	3	57.39±2.20	9.40±0.29	22.52±0.04	5.84±0.04	3.66±0.02
60	Ascorbic acid	1	68.59±2.89	11.66±0.16	21.47±0.02	7.45±0.16	3.17±0.02
60	Ascorbic acid	2	67.42±0.54	11.62±0.09	21.38±0.03	7.26±0.07	3.07±0.02
60	Ascorbic acid	3	69.33±2.79	11.59±0.30	21.28±0.02	7.49±0.11	2.93±0.02
70	Control	0	64.02±1.53	12.24±0.09	21.65±0.02	7.6±0.09	3.65±0.03
70	Hot water	1	57.87±1.53	11.30±0.11	22.10±0.03	7.18±0.04	3.76±0.02
70	Hot water	2	58.65±1.01	10.73±0.12	22.37±0.03	6.82±0.03	3.86±0.03
70	Hot water	3	58.57±1.55	10.51±0.04	22.47±0.02	6.24±0.04	3.97±0.02
70	Ascorbic acid	1	70.63±0.82	12.46±0.08	21.52±0.03	7.70±0.13	3.54±0.02
70	Ascorbic acid	2	69.85±2.03	12.11±0.06	21.38±0.01	7.76±0.08	3.39±0.02
70	Ascorbic acid	3	63.66±1.83	12.10±0.02	21.30±0.04	7.55±0.05	3.22±0.03

Appendix 2: Mathematical models and respective equations for drying at 50ºC

	Lewis				Page				Henderson				Logarithmic				Midilli			
	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse
Control	k: 0.014688	0.982	0.999349	0.0255	k:0.0108 n:1.0713	0.985	0.00065	0.31767	k: 0.0151 a: 1.0253	0.984	0.00164	0.0405	k=0.01668 a=1.00592 c=0.03120	0.986	0.542	0.082	k=0.0045 a=0.9678 n=1.3141 b=0.0451	0.992	2.3E-08	8.1E-07
HW1min	k: 0.012659	0.981	0.999999	0.0003	k:0.0055 n:1.1885	0.988	1.1E-07	0.38011	k: 0.0132 a: 1.0459	0.983	6.57E-07	0.0008	k=0.01418 a=1.03215 c=0.02250	0.984	0.693	0.043	k=0.0027 a=0.9755 n=1.3849 b=0.0428	0.993	4.8E-08	7.6E-07
HW2min	k: 0.0172	0.997	0.053707	0.2317	k:0.0297 n:0.8721	0.995	8.03E-07	0.0009	k: 0.0171 a: 0.9932	0.996	0.04312	0.2077	k=0.01914 a=0.97410 c=0.03129	0.999	0.854	0.077	k=0.0167 a=0.9697 n=1.0340 b=0.0329	0.999	6.2E-11	9.7E-06
HW3min	k: 0.17892	0.995	0.151677	0.3895	k:0.0309 n:0.8702	0.994	2.52E-06	0.01588	k: 0.0178 a: 0.9945	0.996	0.13028	0.3609	k=0.01989 a=0.97489 c=0.03132	0.998	0.686	0.021	k=0.0168 a=0.9699 n=1.0420 b=0.0332	0.998	9.3E-11	8.5E-07
AA1min	k: 0.0139	0.984	9.89E-06	0.0032	k=0.0078 n=1.1337	0.989	0.19741	0.44431	k= 0.0144 a= 1.0328	0.986	3.6E-05	0.006	k=0.01560 a=1.01704 c=0.02534	0.987	0.447	0.037	k=0.0037 a=0.9715 n=1.3417 b=0.0415	0.995	7.9E-07	3.7E-05
AA2min	k: 0.0172	0.997	0.053707	0.2317	k:0.0078 n:1.1337	0.976	0.10119	0.31818	k: 0.0171 a: 0.9932	0.996	0.04312	0.2077	k=0.01914 a=0.97410 c=0.03129	0.999	0.631	0.075	k=0.0167 a=0.9697 n=1.0340 b=0.0329	0.999	5.4E-11	1.5E-06
AA3min	k: 0.01789	0.996	0.151677	0.3895	k: 0.030911 n: 0.8703	0.994	2.52E-06	1.58E-03	k: 0.0171 a: 0.9945	0.996	0.13028	0.3609	k=0.01989 a=0.97489 c=0.03132	0.998	0.959	0.093	k=0.0167 a=0.9699 n=1.0420 b=0.0332	0.998	6.1E-06	5.5E-06

Appendix 3: Mathematical models and respective equations for drying at 60^{o}C

Models	**Lewis**				**Page**				**Henderson**				**Logarithmic**				**Midilli**			
	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse
Control	k: 0.025	0.991883	0.250605	0.500604	**k:0.10201** **n:0.65316**	**0.999164**	**3.79E-13**	**6.155E-07**	k:0.02487 a:0.97727	0.991648	0.726894	0.852581	k:1.6 a:0.87049 c:0.12952	0.698417	0.000551	0.023469	k:0.092238 n:0.660402 a:0.999681 b:1.13e-05	0.9982	9.51461E-14	3.08458E-07
HW1min	k:0.02319	0.988467	0.027481	0.165773	**k:0.09629** **n:0.65218**	**0.999822**	**6.55E-17**	**8.09E-09**	k:0.02463 a:0.97922	0.993217	0.129871	0.360376	k:1.6 a:0.91563 c:0.08437	0.829017	0.000171	0.013066	k:0.092232 n:0.663602 a:0.999681 b:1.13e-05	0.99986	7.79E-14	2.79E-07
HW2min	k:0.02019	0.995598	0.000104	0.010213	**k:0.05369** **n:0.76623**	**0.999634**	**1.17684E-14**	**1.085E-07**	k:0.01969 a:0.97582	0.994795	3.84E-05	0.006197	k:1.6 a:0.89415 c:0.10585	0.758381	0.000421	0.020518	k:0.092132 n:0.664702 a:0.999581 b: 1.13e-05	0.994083	9.41E-14	3.06834E-07
HW3min	k:0.02515	0.993877	0.224918	0.474256	**k:0.08419** **n:0.6987**	**0.99957**	**9.41469E-14**	**3.068E-07**	k:0.02463 a:0.97922	0.993217	0.129877	0.360385	k:1.6 a:0.91563 c:0.08437	0.829017	0.000171	0.013066	k:0.092292 n:0.655072 a:0.998591 b:1.12e-05	0.997736	5.06262E-14	2.25003E-07
AA1min	k:0.02425	0.997677	0.127075	0.356476	k:0.05758 n:0.78389	0.99854	1.08634E-09	3.296E-05	k:0.02398 a:0.98806	0.99732	0.091967	0.30326	k:1.6 a:0.91285 c:0.08715	0.804837	3.42E-04	0.018499	**k: 0.0923117** **n:0.6580221** **a:0.9986012** **b:1.125e-05**	**0.99761**	**5.4623E-14**	**2.33716E-07**
AA2min	k:0.02111	0.989381	0.000319	0.017872	**k:0.07714** **n:0.68951**	**0.999757**	**3.11E-15**	**5.577E-08**	k:0.02032 a:0.96499	0.98803	7.04E-05	0.008393	k:1.6 a:0.89746 c:0.10255	0.788333	0.000201	0.01417	k:0.0923115 n:.0656002 a:0.998699 b:1.125e-05	0.997785	4.92939E-14	2.22022E-07
AA3min	k:0.01667	0.994949	3.4E-08	0.000184	**k:0.04229** **n:0.78661**	**0.999788**	**2.98E-15**	**5.459E-08**	k:0.01612 a:0.96855	0.993869	7.39E-09	8.6E-05	k:1.6 a:0.87049 c:0.12952	0.698417	0.000551	0.023469	k:0.0924005 n:0.6559722 a:0.9985002 b:1.125e-05	0.997814	4.82947E-14	2.19761E-07

Appendix 4: Mathematical models and respective equations for drying at 70ºC

	Lewis				Page				Henderson				Logarithmic				Midilli			
	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse	Constants	rsq	chi	rmse
Control	k:0.01525	0.950913	2.24E-09	4.73E-05	**k:0.00021** **n:2.02261**	**0.995532**	**5.57E-13**	**7.463E-07**	k:0.01634 a:1.08776	0.951139	3.9E-09	6.24835E-05	k:0.01634 a:1.07856 c:0.0000	0.951139	1.54E-07	0.000392	k:5.358E-05 n:2.33484 a:0.0000 b:0.000139	0.992835	1.16E-09	3.41255E-05
HW1min	k:0.01718	0.998159	3.39E-12	1.84E-06	k:0.01505 n:1.03076	0.998431	3.81E-11	6.17E-06	k:0.01723 a:1.00309	0.998181	3.8E-12	1.94995E-06	**k:0.01756** **a:0.99885** **c:0.00606**	**0.998252**	**1.15E-13**	**3.39E-07**	k:0.009693 n:1.1278 a:0.0000 b:5.333E-05	0.998238	3.82E-11	6.18E-06
HW2min	k:0.01894	0.998072	3.72E-09	6.1E-05	k:0.02681 n:0.91494	0.998206	4.85E-12	2.202E-06	k:0.01877 a:0.98995	0.997903	2.48E-09	4.97691E-05	**k:0.01977** **a:0.97948** **c:0.01546**	**0.998414**	**1.34E-10**	**3.22E-06**	k:0.018161 n:1.00408 a:0.0000 b:5.012E-05	0.998017	1.07E-09	3.27109E-05
HW3min	k:0.01940	0.997852	6.27E-10	2.5E-05	k:0.01331 n:1.0904	0.999143	7.3E-07	0.0008541	k:0.01956 a:1.00916	0.997928	8.64E-10	2.93931E-05	**k:0.01994** **a:1.00465** **c:0.00615**	**0.998002**	**8.83E-13**	**9.4E-07**	k:0.008929 n:1.182828 a:0.0000 b:6.127E-05	0.999317	3.79E-08	0.000194679
AA1min	k:0.01482	0.997266	8.50E-10	2.92E-05	**k:0.00865** **n:1.11324**	**0.99887**	**9.03E-14**	**3.004E-07**	k:0.01453 a:1.15381	0.997176	4.68E-09	6.84105E-05	k:0.01994 a:1.00465 c:0.00615	0.975068	6.25E-08	0.00025	k:0.00509 n:1.22429 a:0.0000 b:4.659E-05	0.998173	8.37E-12	2.8931E-06
AA2min	k:0.01487	0.998273	6.38E-11	7.99E-06	**k:0.01214** **n:1.04558**	**0.998607**	**3.37E-13**	**5.805E-07**	k:0.01493 a:1.00469	0.998264	9.89E-11	9.94485E-06	k:0.01995 a:1.00465 c:0.00615	0.981739	2.19E-08	0.000148	k:0.007851 n:1.13547 a:0.000 b:3.268E-05	0.997872	6.28E-08	0.000250599
AA3min	k:0.01487	0.99586	4.11E-15	6.41E-08	k:0.00686 n:1.17354	0.999218	3.48E-11	5.9E-06	**k:0.01508** **a:1.02367**	**0.995739**	**3.33E-15**	**5.77119E-08**	k:0.01995 a:1.00465 c:0.00615	0.977105	9.12E-09	9.55E-05	k:0.00413 n:1.28334 a:7.5095E-05 b:5.213E-05	0.998876	5.57E-09	7.46324E-05

Appendix 5: Illustrations of Milled OFSP Flour Samples Dried at $50^{o}C$

Illustration 1: Milled Sample Dried at $50^{o}C$ with no Pretreatment

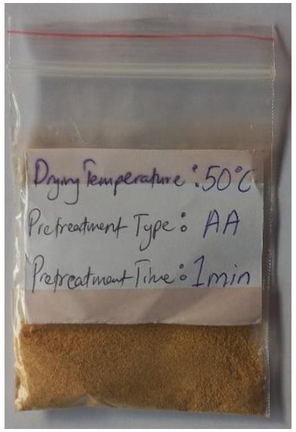

Illustration 2: Milled Sample Pretreated with AA and dried at $50^{O}C$ for 1min

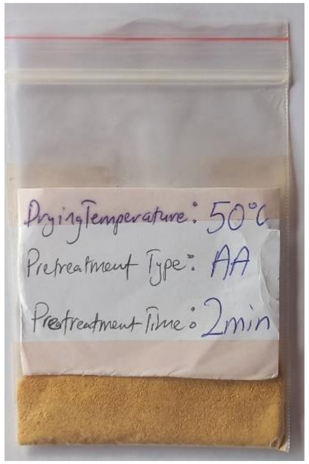

Illustration 3: Milled Sample Pretreated with AA and dried at $50^{O}C$ for 2min

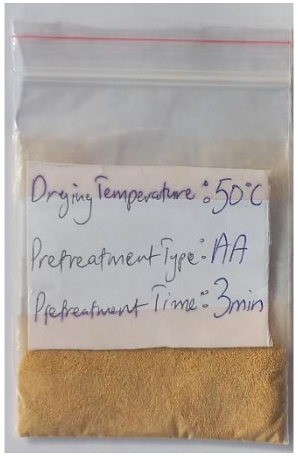

Illustration 4: Milled Sample Pretreated with AA and dried at $50^{o}C$ for 2min

Illustration 5: Milled Sample Pretreated with HW and dried at 50^{o}C for 1min

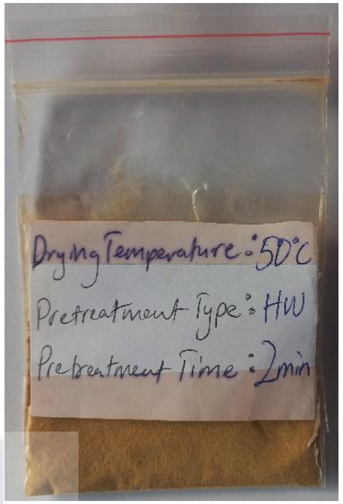

Illustration 6: Milled Sample Pretreated with HW and dried at 50^{0}C for 2min

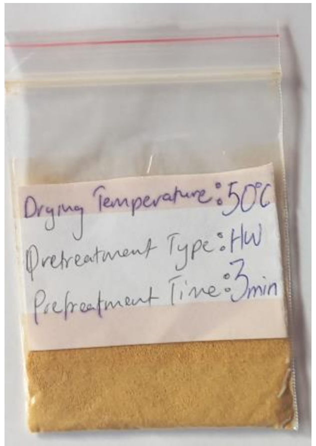

Illustration 7: Milled Sample Pretreated with HW and dried at 50^{O}C for 3min

Appendix 6: Illustrations of Milled OFSP Flour Samples Dried at 60^{o}C

Illustration 8: Milled Sample Dried at 60^{O}C with no Pretreatment

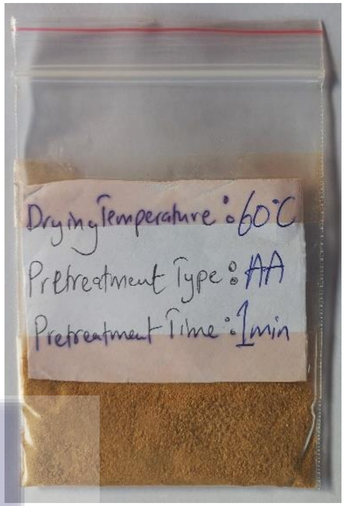

Illustration 9:Milled Sample Pretreated with AA and dried at 60^{O}C for 1min

Illustration 10: Milled Sample Pretreated with AA and dried at 60^{O}C for 2min

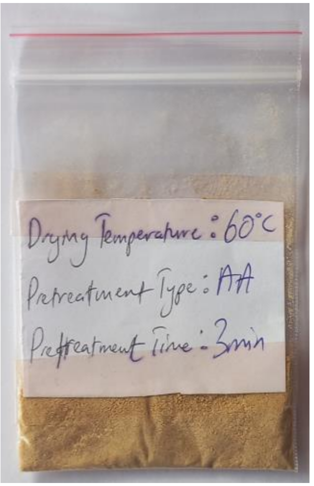

Illustration 11: Milled Sample Pretreated with AA and dried at 60^{O}C for 3min

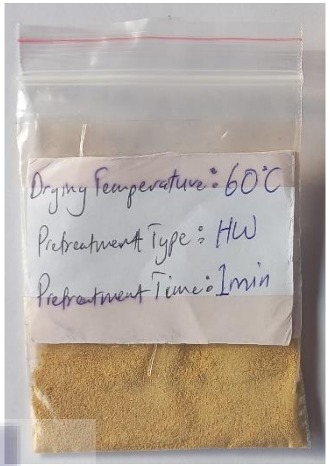

Illustration 12: Milled Sample Pretreated with HW and dried at 60^{O}C for 1min

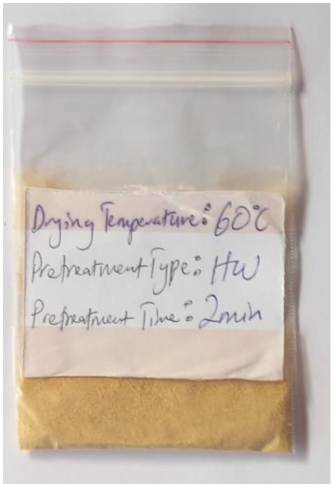

Illustration 13: Milled Sample Pretreated with HW and dried at 60^{O}C for 2min

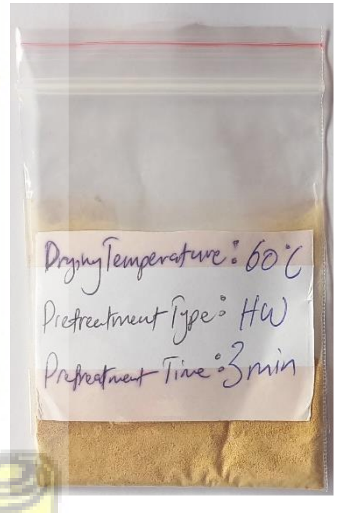

Illustration 14: Milled Sample Pretreated with HW and dried at 60^{O}C for 3min

Appendix 7: Illustrations of Milled OFSP Flour Samples Dried at 70^{o}C

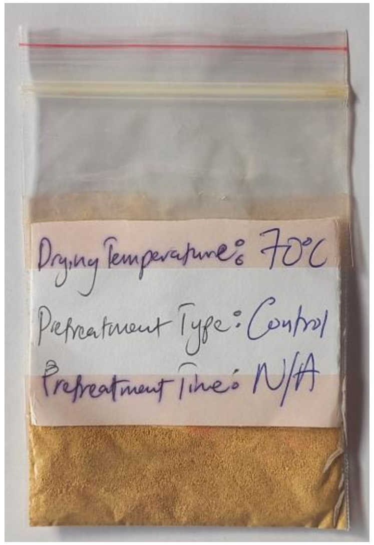

Illustration 15: Milled Sample Dried at 70^{o}C with no Pretreatment

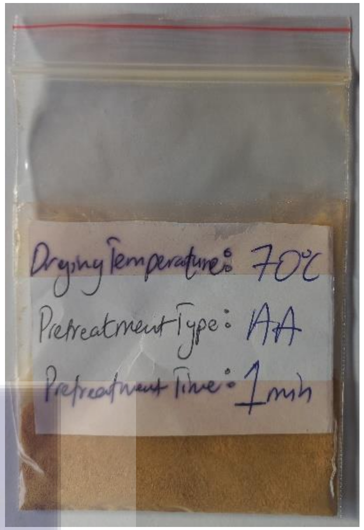

Illustration 16: Milled Sample Pretreated with AA and dried at 70^{o}C for 1min

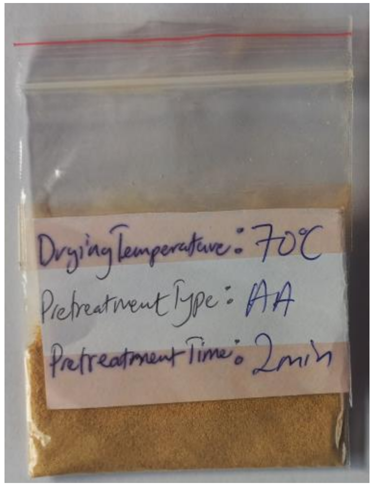

Illustration 17:Milled Sample Pretreated with AA and dried at 70°C for 2min

Illustration 18: Milled Sample Pretreated with AA and dried at 70°C for 3min

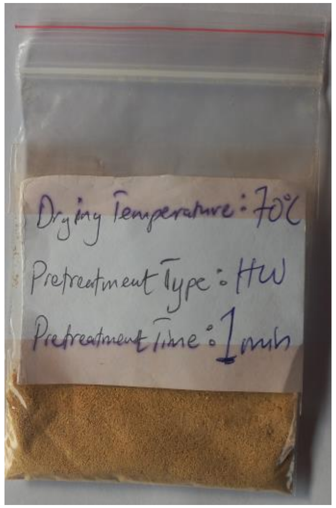

Illustration 19: Milled Sample Pretreated with HW and dried at 70°C for 1min

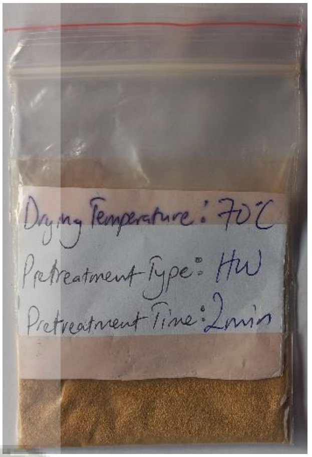

Illustration 20: Milled Sample Pretreated with HW and dried at 70°C for 2min

Illustration 21: Milled Sample Pretreated with HW and dried at 70ºC for 3min