UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF PRETREATMENT AND DRYING AIR TEMPERATURE ON DRYING KINETICS AND QUALITY CHARACTERISTICS OF FRAFRA POTATO (*Solenostemon rotundifolius*) SLICES

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BY

ALBERT ABUGRI

(BSc. Agricultural Engineering)

(UDS/MPHT/0003/18)

[THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL MECHANIZATION AND IRRIGATION TECHNOLOGY, FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN POSTHARVEST TECHNOLOGY]

APRIL, 2022

DECLARATION

Student

I hereby declare that this thesis is the result of my original work and that no part of it has been presented for another degree in this University or elsewhere:

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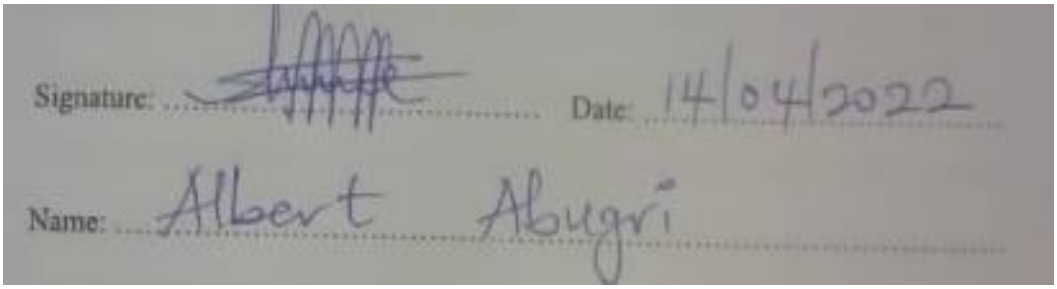

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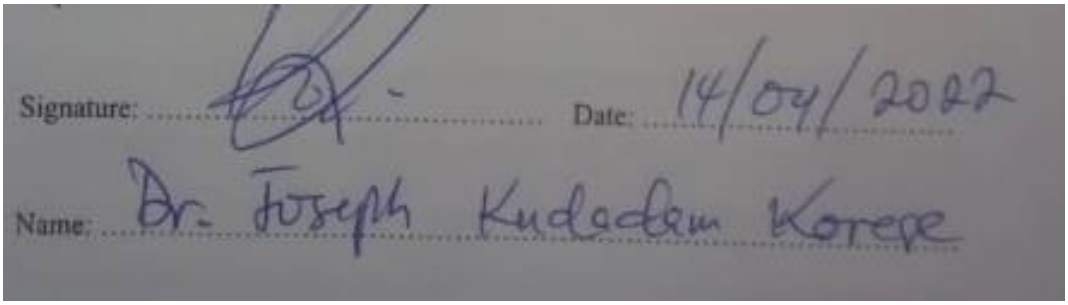

ABSTRACT

Frafra potato (FP) is an underutilized root tuber crop with great potential to improve food security, but the tubers are prone to discolouration and rot after harvest. This study investigated the effect of different pretreatment and drying air temperature on the drying kinetics, surface temperature uniformity, and quality characteristics of hot-air dried FP slices. Four pretreatment methods (dipping in 5 % w/v potassium metabisulfite solution for 5 minutes, blanching at 100 °C for 3 minutes, a combination of dipping in potassium metabisulfite solution plus blanching, and no pretreatment) and four drying temperatures (40, 50, 60, and 70 °C) were used. Drying of FP slices occurred in the falling rate period, and drying time was affected significantly ($p < 0.05$) by pretreatment and drying air temperature. The Page model and logarithmic model fitted best with the drying kinetics of FP slices. Blanched samples had higher final water activity and moisture content (0.46 – 0.63 and 6.42 – 9.89 % wb respectively), compared to samples pretreated with dipping in potassium metabisulfite (0.34 – 0.53 and 6.19 – 9.39 % wb), dipping potassium metabisulfite plus blanching (0.46 – 0.49 and 5.22 – 9.01 % wb) and no pretreatment (0.23 – 0.53 and 5.59 – 7.64 % wb). Samples pretreated by dipping in potassium metabisulfite were more desirable in lightness and whiteness index (56.57 – 64.52 and 51.92 – 59.49 respectively) compared to the other pretreated samples at all levels of drying temperature (40 – 70 °C). Pretreatment and drying air temperature significantly ($p < 0.05$) affected surface temperature uniformity of dried FP slices and the degree of non-uniformity generally decreased with a decrease in drying temperature. Pretreatment and drying of samples also resulted in 9 – 30 % and 27 –

71 % reduction in beta-carotene and total phenolic content, respectively, and an increase of 6 – 177 % in antioxidant activity compared to no treatement samples (fresh FP samples). Vitamin C content in blanched samples increased with increase in drying temperature. Samples pretreated with potassium metabisulfite solution had higher phenolic content at all drying temperatures, and phenolic content in these samples increased as drying temperature increased from 40 – 70 °C. The results in this study demonstrate that pretreatment and drying air temperature had different effects on the quality characteristics of dried FP slices. However, for optimum retention of quality, pretreatment by dipping in $K_2S_2O_5$ combined with drying at 70 °C is recommended. But where $K_2S_2O_5$ is unavailable, it is better to dry FP without pretreatment.

ACKNOWLEDGEMENT

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DEDICATION

To my dear wife Selina Nlok-ion Wurineya, my parents Mr. Moses Abugri and Mrs. Rebecca Abugri, all of High Powered Ministries International – Bolgatanga.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Frafra Potato (FP) is a small herbaceous root tuber, belonging to the family *Labiatae*. Although the exact origin of FP is not documented, it is believed to have originated from the Eastern part of Africa. From there, it spread into the rest of Africa and South-East Asia (Tindall, 1983). Across Africa, some of the local names associated with FP include Sudan potato (Sudan); *Saluga* (Nigeria); *Kembili* (Mali); Hausa potato (Ghana). Production of FP is largely by traditional practices, and it is cultivated for its small tubers which cluster at the base of the stem (Opoku-Agyemang et al., 2004). Tubers are generally dark-brown with white flesh and just a little above the size of an average thumb if well cultivated. FP produces many small-sized tubers up to 70 per plant. According to Kwarteng et al. (2017), the tubers are 3.78 cm and 1.53 cm in length and width, respectively, and with yield potential of 7 to 15 tonnes per hectare.

Although FP has the potential of improving food security, it is still one of the neglected and under-utilized food crops in Ghana. FP tubers have high marketing potential even compared with sweet potatoes (Sugri et al., 2013). The taste of its tubers is close to that of trifoliate yam (*Dioscorea dumetorum*) and Irish potato (*Solanum tuberosum*) and are eaten as a staple food combined with rice, legumes, and vegetables (Schippers, 2000). When FP tubers are eaten immediately after harvest vitamins content can be higher than apples (Kwarteng et al., 2017). FP

tubers also contain good amounts of calories and essential micronutrients (Alleman & Coertze, 1997), and its tubers serve as a good source of food for people especially during periods when food is scarce (Nanbol et al., 2020). Furthermore, its tubers can be used to produce local alcoholic flavored beverages (Schippers, 2000; Phungpanya et al., 2013).

In Ghana, FP is associated with the Upper East and West regions where the crop has gained popularity, hence the name Frafra potato. Among the indigenous people of the Upper East and Upper West regions, the crop is identified with names similar to *Persa* and *Pia ha* respectively. FP tubers are commonly eaten boiled, served with pounded pepper and salt. However, in some localities in the Upper East region, it is also sometimes combined with soup made from millet and groundnut and eaten as a whole meal. After harvest, the most common storage practice is by spreading tubers on the floor under ambient conditions or by storing in local earthen-ware pots stuffed with straw. This practice often leads to the sprouting of tubers and some also begin to rot. Some FP growers, in an effort to extend the shelf life of its tubers also parboil and dry the tubers in the open sun. Albeit a cheap method of drying, sunshine is unpredictable even during the dry season and traditional open sun drying exposes the product been dried to marauding animals and dust, resulting in quality loss and physical contamination (Sankat & Mujaffar, 2004).

Drying presents a good avenue to process tubers into stable products in order to minimize postharvest loss (Sugri et al., 2013) as well as promote the use of tubers

for different purposes. Hot air drying of FP tubers to produce chips and flour will widen its usage as a food crop. For instance, flour obtained from its tubers could be incorporated in various food products or even used separately for novel food products development.

Research has proven that pretreatment and drying temperature is an important factor in drying, and interferes with the quality of dried products (Diamante et al., 2010; Heras-Ramirez et al., 2012; Guine, 2018). Drying air temperature influences final product moisture content and consequently its microbiological stability during storage. It also affects product colour and heat-sensitive bioactive compounds (Demirel & Thuran, 2003). Discolouration (enzymatic browning) is a common phenomenon that affects the quality of tuber food products during drying, and dipping tubers in sulphite solution or blanching prior to drying has proven to be effective in reducing enzymatic browning in tubers (Utomo et al., 2008). Although sulphiting and blanching can reduce the negative effect of browning, it also affects the drying characteristics of the product (Kingsly et al., 2007).

1.2 Problem statement and Justification

The availability of food resources for the constantly growing population of the world is becoming difficult by the day. For the UNDP's Sustainable Development Goals 2 and 3 to be achieved by 2030, every country has to optimize its already-available food resources. According to a United Nations report (2016), one person in every four still goes hungry in Africa, and about 30

percent of children under five are stunted due to hunger and malnutrition in Northern Ghana. The situation has prevailed partly because of failure to make maximum use of food crops such as FP, and huge dependence on a few selected crops as food (FAO, 2018).

Albeit formerly a staple among the people of the Upper East and West regions, FP has suffered research neglect and as a result not much is known about how to develop stable products from its tubers. FP has been largely replaced by other food crops like sweet potato, and production is focused on domestic consumption only (Dittoh et al., 1998). This therefore calls for increase awareness on how to conserve, document, and promote the diversified use of FP tubers (Olojede et al., 2005). Among others, high postharvest losses coupled with inappropriate postharvest preservation techniques have been enumerated as major constraints facing FP farmers in Ghana (Tetteh & Guo, 1997). Furthermore, apart from a moisture content of between 70 – 80 % which makes it easily prone to deterioration, FP tubers become fibrous, begin to sprout, and some rot away after harvest (Sugri et al., 2013). Tubers have been reported to be difficult to store in hot tropical sub-Saharan Africa because of their susceptibility to decay (Okigbo et al., 2009). To deal with the high moisture content in fresh tubers which make them perishable, tubers can be peeled, sliced, pretreated, dried, and subsequently processed into flour (Akissoe et al., 2001). According to Sugri et al. (2013), one of the crop improvement targets requiring research interventions includes

processing tubers into stable products using different processing methods such as blanching, drying, parboiling, and frying.

A considerable amount of food materials such as yam (Falade et al.,2007), apple (Heras-Ramirez et al., 2012), mango (Russo et al., 2019), and sweet potato (Chikpah et al., 2020) have been dried artificially using mechanical hot air dryers, and the temperature of the air used for drying has also been reported to affect the quality of the dried product (Mphahlele et al., 2016). Enzymatic browning caused by polyphenol oxidase (PPO) is generally associated with tubers during drying, and pretreatments such as sulphiting and blanching have shown to be effective in controlling browning (Falade et al., 2007). Nonetheless, these pretreatments influence the quality characteristics of the dried product.

Therefore, the purpose of this study was to investigate the effect of pretreatment and drying temperature on FP tubers during drying, in order to find out which pretreatment method and/or drying temperature yields desirable products. The outcome of this study will provide the needed knowledge required for pretreatment and drying of FP tubers into high-quality flour in order to minimize postharvest deterioration. The outcome of this study will also promote the production and consumption of FP.

1.3 Research objectives

The main purpose of the study is to investigate the effect of postharvest pretreatment and drying air temperature on drying kinetics and quality

characteristics of FP slices using convective hot air drying. Specifically, the study seeks to:

1. investigate the effect of pretreatment and drying air temperature on drying kinetics, such as moisture ratio and drying rate of FP slices.
2. assess the effect of pretreatment and drying air temperature on water activity, colour, and surface temperature distribution of FP slices.
3. evaluate the effect of pretreatment and drying air temperature on total antioxidant, total phenols, total flavonoid, vitamin C, and beta-carotene contents.

1.4 Significance of the study

FP is an under-utilized and under-exploited food crop in the Upper East and Upper West regions of Ghana (Dittoh et al., 1998). The outcome of this study will aid unearth the potentials of FP as a food crop. This study will help increase the production and utilization of FP tubers as it lays emphasis on its bioactive compounds composition such as vitamin C, beta-carotene, and antioxidant content. This study will also draw the attention of food processors to consider integrating FP as ingredient in food product formulations. The study provides useful information for researchers, food processors, and students who may be interested in carrying out research work on the crop. Finally, the study provides knowledge to FP growers on how to deal with the postharvest loss of FP tubers by drying it.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Underutilized food crops: the case of Frafra potato

A major part of the Sustainable Development Goals 2 (SDG 2) is centered on the eradication of hunger and malnutrition. Finding ways to make hunger and poverty less severe in developing countries does not always rely on developing new crop varieties with higher yields. However, reigniting the interest and consumption of indigenous, traditional, neglected, endangered, and underutilized foods can help alleviate malnutrition, provide income for homes, promote agricultural biodiversity, and preserve local cultures (Stone et al., 2011).

As defined by Padulosi et al. (2013), Neglected and Underutilized Species (NUS) are those crop species that have received little attention or those which have been completely ignored by agricultural researchers, plant breeders, as well as policymakers. NUS is often associated with terms such as orphan, lost, abandoned, minor, traditional, niche, or underdeveloped crops. They are believed to be food for the 'poor man'. Nonetheless, NUS can play a key role in the fight against poverty, hunger, and malnutrition in Ghana; by extension in Africa.

To deal with the negative stigma associated with the name Neglected and Underutilized, NUS is now known as Future Smart Food (FSF) (Li & Siddique, 2020). FAO (2018), reports that NUS that are locally available, nutrient

endowed, economically viable and climate-resilient are now also considered as FSF. Such is the case of Frafra Potato (*Solenostemon rotundifolius*).

Frafra Potato (FP) is an under-utilized food crop found in the Upper East and Upper West Regions of Ghana (Abbiw, 1990; Bennett-Lartey et al., 2008). In these regions of Ghana, where hunger and malnutrition remain persistent, FP can be a player in the fight against food insecurity. The crop, which has the ability to thrive in soils from low to average nutrient content, has a good market value after harvest. Tubers that cluster at the base of the stem require minimal traditional processing prior to marketing (Ukpabi et al., 2011). As staple crops are predicted to present major challenges in the future, diversification of agricultural food resources will reduce over-reliance on staples and promote the fight towards achieving food security (Mayes et al., 2011).

2.2 Origin, description, and production of Frafra potato

Frafra potato (*Solenostemon rotundifolius*) is a root tuber that belongs to the family *Lamiaceae* (Kwarteng et al., 2017). The origin of the crop can be traced to Kenya or Ethiopia in East Africa, where it then spread into other African countries like Togo, Guinea, Nigeria, Mali, Sudan, and Ghana (Harlan et al., 1976). It was formerly known as *Coleus dysentericus*, because of its ability to treat dysentery (Tindall, 1983) or *Coleus rotundifolius* (Bejoy et al., 1990) or *Coleus parviflorus* (Abbiw, 1990). It is a small herbaceous annual crop that has ascending succulent stems and branches. FP can grow up to a height of between 15 to 30 cm and has a characteristic odor because of volatile oils present in its

leaves (Phungpanya et al., 2013). According to Opoku-Agyeman et al. (2007), the leaves have an aromatic mint smell and are predominantly green (over 90%) with variations such as green, light green, and olive green. Its flowers are small and with slender false spikes which measure 15 cm long (Enyiukwu et al., 2014). FP tubers can be brown or black with a smooth surface, and with a strong aromatic odor. Regardless of the type of variety, tuber flesh is generally white (Opoku-Agyeman et al., 2007) but peel differ in colour.

In Africa, FP is commonly found in the Savannah regions in countries such as Senegal, Sudan, Mali, Nigeria, Ghana, and South Africa (Nkansah, 2004). In Ghana, FP is grown mainly in the Sudan Savannah and Guinea Savannah agro-ecological zones (Tortoe et al., 2020), with production primarily planned for domestic consumption. The crop is propagated using tubers that are intentionally left to sprout as shown in Figure 1A. Sprouted tubers are cultivated on raised beds as shown in Figure 1B. However, stem propagation is now also promoted.

Figure 1: (A) Sprouted FP tubers ready for planting; (**B**) FP cultivated on raised beds. Source: (Sugri et al., 2013).

2.3 Harvesting of FP tubers

After planting sprouted FP tubers, it takes approximately 120 – 150 days to mature. Under relatively favourable environmental conditions, the crop has a high yield potential up to about 5 – 15 MT/ha (Kwarteng et al., 2017). There is no known mechanical equipment for harvesting FP, hence tubers that cluster at the base of the stem are harvested manually. Harvesting is done by digging with the local hoe to uproot the crop to have access to the small tubers underneath the soil. Harvested plants, as shown in Figure 2, are heaped in the field and tubers are later detached from the stem of the plant by plucking with the hand.

Figure 2: Harvested FP showing tubers attached to the plant. Source: (Kwarteng et al., 2017).

2.4 Postharvest handling of FP tubers

FP tubers are traditionally stored on the ground under shade like other tuber crops such as potatoes. Storing under shade can help maintain freshness of tubers for approximately four weeks, and after this period tubers start to lose their taste and flavor (Tortoe et al., 2020). Large FP tubers are usually desirable for immediate consumption or sale in the market. They are sometimes also parboiled and dried to prolong shelf life (Sugri et al., 2013). According to Alagumpola (2007), FP tubers meant for consumption are also stored in pits, baskets, or on the floor in a cool room. On the other hand, small FP tubers are often selected and stored as tuber setts for the next growing season. To preserve FP tuber setts for the next season, they are stored in earth pots stuffed with ash or millet husk and sealed with cow dung (Sugri et al., 2013).

Curing also helps to reduce the high moisture content in FP tubers. Curing is the process where injured tuber surfaces undergo natural wound healing, with new tissue forming beneath the injured surface. It helps to reduce water loss, increase the resistance of tubers to decay and extend storage life (Damtew, 2021). According to Sugri et al. (2013), after harvest, FP tubers are sorted according to size and cured for 2 – 3 weeks by spreading under well-ventilated dry shade. Ravi et al. (1996) and Eshel (2011) report that warm temperatures of between 30 – 40 °C and high relative humidity greater than 85 % coupled with proper ventilation is ideal for curing tubers. FP tubers should be cured as soon as possible after harvest, preferably not later than 12 hours after harvest (Eshel, 2011). Tubers meant for storage do not necessarily require washing prior to curing since it increases the incidence of decay, however, tubers prepared for the market can be washed (Edmunds et al., 2008).

2.5 Postharvest control of FP tuber rot and sprouting

According to Tindall (1983), tuber rot and sprouting are the major problems of FP tuber loss after harvest. In most root and tuber crops, tuber rot is caused by pathogens that penetrate the skin of damaged tubers or holes made by nematodes (Knoth, 1993). Several measures have been adopted by FP growers for the management of tuber rot and sprouting. Minimizing the risk of injuries to tubers especially at the time of harvest, during transport and storage is key to the prevention of tuber rot. Tubers found to be exhibiting signs of rot prior to storage should be discarded or used for another purpose. Knoth (1993) recommends

regular inspection of tubers in the store so that tubers that are infested can be identified and removed from the store. The commencement of sprouting in roots and tubers is an indication that the dormancy period has come to an end (Ellis et al., 2007). High temperatures during storage generally promote sprouting of tubers (Suhag et al., 2006), and this was confirmed by Apuri et al. (2018) when a significantly high percentage of FP tubers were observed to have sprouted as a result of increased temperature during storage. Apuri et al. (2018) further reported that the application of plant extracts such as ginger rhizome, neem bark, and pawpaw leaf prior to storage was effective in suppressing the sprouting of FP tubers.

2.6 Nutritional and medicinal importance of FP

FP contains both major and minor nutrients which are necessary for the proper functioning of the body (Kana et al., 2012). Earlier research by Leung (1968) reports that sample tubers of *S. rotundifolius* contained carbohydrates (9 %), crude protein (5 %), fibre (45 %), and fat (1 %). Raw FP tubers are high in dietary energy, which provides between 392 – 394 kJ of energy per every 100 g (Schoeninger et al., 2000).

According to the Plant Resources of Tropical Africa (PROTA, 2013), every 100 g of raw FP tubers is estimated to contain 76 % water, 21 % carbohydrate, 1.4 % protein, 0.7 % fibre, and 0.2 % fat, as well as other significant nutrients. In a study conducted by Nkansah (2004), FP tubers were reported to contain appreciable quantities of iron, calcium, and beta-carotene, and 100 g of raw FP

tubers was reported to contain 1.3 g protein, 21.9 g carbohydrate, 1.1 g fibre, 17 mg calcium, 6.0 mg iron, 0.02 mg riboflavin, 1.0 mg ascorbic acid, 1.0 mg niacin, 0.05 mg thiamin, and 75.6 g water. The amount of protein in FP is reported to be approximately equivalent to the content of protein in Irish potato and sweet potato on a dry matter basis (Alleman, 2002). It also contains principal amino acids such as arginine, aspartic and glutamic acids which are present in its protein (Enyiukwu et al., 2014).

FP is also believed to possess some significant medicinal benefits. The tubers contain saponins and anthraquinones which have been reported to be effective in reducing blood cholesterol levels in humans and are also able to control fungal and viral infections (Kana et al., 2012). Studies conducted by Enyiukwu et al. (2014) also revealed the presence of certain biologically active ingredients like epi-α-cardinol (15.52 %), epi-α-bisabolol (3.0 %), sesquiceneole (9.36 %), cyperene (4.88 %), and α-santalene (2.25 %). These compounds play an antibacterial role against *Pseudomonas aeroginosa*, *Escherichia coli*, and *Staphylococcus aereus* (Phungamngoen et al., 2013).

2.7 Drying of agricultural products

There are many food preservation methods such as salting, drying, canning, freezing, and vacuum packaging. For most agricultural products, like fruits, vegetables, spices, herbs, roots, and tubers, drying remains the most common postharvest operation because of its economic benefits (Grabowski et al., 2003; Jangam, 2011). According to Vijayan et al. (2017), drying is an energy-intensive

process that involves the removal of excess moisture from a food product to its desired level of moisture content to extend storage life. It makes the product convenient for transportation, slows down microbial activity, and prevents microbial multiplication (Sabarez et al., 2012).

Drying of food materials is a complex process and involves heat, mass, and momentum transfer. In most cases (except for freeze-drying), drying is achieved by exposing the product to thermal energy to cause moisture to evapourate from the product. The thermal energy obtained during drying is transferred to the product, which increases the temperature of the product, hence causing moisture to evapourate. High product moisture content after harvest is the major factor responsible for the deterioration of food products. Nonetheless, there is no known universal safe moisture value because it varies from one product to the other. The safe moisture content of any product, if not strictly adhered to will not yield the expected length of storage before deterioration commences.

Reports suggest that in very industrialized countries, drying accounts for 10 – 25 % of the total energy consumption (Erbay & Hepbasli, 2013). With the development of the drying industry, novel drying technologies and processes have been developed recently, all in an attempt to make the process efficient and to lower the amount of energy consumed during drying. There are about 500 types of dryers, of which 100 types are used in commercial drying (Mujumdar & Law 2010). These dryers, according to Grabowski et al. (2003), range from simple sun-drying to more sophisticated methods like vacuum freeze-drying and

infrared drying. There are several designs of dryers available in the market with different modes of heat supply to meet the drying needs of specific products and operating conditions (Vijayan et al., 2017), as well as the scale of production. The final selection of a dryer type is therefore influenced by certain key factors like the drying characteristics of the material, the cost associated with drying, and the quality requirements (Augustus-Leon et al., 2002).

Hot-air drying is one of the common methods used to extend the shelf-life of agricultural food products. It involves removing excess moisture from a product by subjecting the product to continuously flowing heated air (Onwude et al., 2016). This method of drying poses less harm to the environment, is non-toxic, and the final products are more hygienic and uniform. According to Zhang et al. (2006), food products dried using hot air can stay safe for up to about a year. However, evidence suggests that the quality of food products dried using hot air can be seriously affected by the drying process if not properly handled (Lechtanska et al., 2015). Prolonged drying at high temperatures could cause a reduction of heat-sensitive nutrients in the product.

2.8 Properties of agricultural products been dried

The rate of drying of any food product can be affected by the drying air properties and the wet product properties. This part of literature review is focused on some properties of the wet product such as moisture content, equilibrium moisture content and water activity that must be carefully considered to ensure quality during drying.

2.8.1 Product moisture content (MC)

Nearly all agricultural products contain moisture, and the amount of moisture content varies from one product type to the other. The amount of moisture in a product can affect its size, texture, shelf-life, and ease of processing. Products with high moisture are susceptible to quick deterioration, whereas products that lack moisture or are excessively dry tend to be brittle or too hard to be eaten (Ranowsky, 2018). Thus, determining the amount of moisture to remove is a very important decision that must be taken to extend storage life, facilitate handling, and retention of quality (Das & Chakraverty, 2003). Moisture content in agricultural products exists in three forms – bound moisture, unbound moisture, and free moisture or water. Free moisture refers to that which can be easily removed when the product is exposed to heat. It is the moisture content of the product which is more than its equilibrium moisture content. The moisture content of the product which exerts a lower vapour pressure than that of pure liquid at the same temperature is called bound moisture, and this moisture is chemically or physically bound to the solid contents of the product. Food products such as roots and tubers contain both bound and unbound moisture.

The moisture content of a product can be expressed either as dry basis (db) or wet basis (wb), and expressed as a decimal ratio or a percent. According to Belessiotis and Delyannis (2011), dry basis and wet basis moisture content are respectively calculated using Equations (1) and (2), respectively.

$$M = \frac{m_w}{m_{dm}} \text{ (Kg water/Kg dry material)} \quad (1)$$

$$m = \frac{m_w}{m_w + m_{dm}} = \frac{m_w}{m_T} \text{ (Kg water/Kg material)} \quad (2)$$

where:

M = dry basis moisture content

m = wet basis moisture content

m_w = mass of water in product

m_{dm} = mass of dry material in product

m_T = total mass of product

There are different methods of determining the moisture content of agricultural food materials. However, one method which is very commonly used in the drying industry and scientific research is the oven-dry method.

2.8.2 Product equilibrium moisture content (EMC)

When a food product is surrounded by air with constant temperature and relative humidity, with time the product will attain a moisture content equal to that of the air surrounding it. When this happens, moisture loss from the product (desorption) is equivalent to moisture gained by the surrounding air (adsorption). At this point, there is no more interaction of moisture between the product and the surrounding air, and the moisture content of the product at this stage is called equilibrium moisture content (Belessiotis & Delyannis, 2011). It is one of the very important factors to consider when drying food materials because it helps

to determine the stability of the food at a given moisture content in a given environment. This EMC also determines the maximum amount of moisture that dehydrated food can absorb during storage (Vijayan et al., 2017). The EMC is affected by temperature, and for most agricultural products EMC is expected to decrease by nearly 0.5 % for every 10 °C rise in temperature (Gunathilake et al. 2018). For instance, it was found that the EMC of cassava pulp increased as relative humidity increased, but decreased as drying temperature increased (Luampon & Charmongkolpradit, 2019). Hence, it is clear that EMC is dependent mainly on air temperature and relative humidity. However, a change in chemical composition and the adsorption-desorption history of the food product can also affect EMC values (Chiachung, 2003).

2.8.3 Water activity (a_w) of agricultural products

In the food preservation industry, water activity is of critical importance, because it determines how well microorganisms will thrive. The amount of water available in the product for use by microorganisms and participation in chemical reactions in food products is defined by water activity. The ratio of vapour pressure of water in a product to the vapour pressure of pure water at the same temperature is called water activity (Barbosa-Canovas et al., 2007). The water activity of food products can be determined using hygrometers, the hygroscopicity of salts, and colligative properties (Sahin & Sumnu, 2006).

The water activity of any food product range from 0 (no water) to 1 (pure water). A product with a water activity value of 1 means that 100 % of the water in the

product is available for microbial growth. On the other hand, 0 water activity value means that none of the water in the product is available for chemical reaction and microbial growth (Bhandari & Adhikari, 2008). Water activity values are used to predict the stability of foodstuffs during storage, especially in relation to microbial growth, chemical and physical changes that can cause food degradation during storage (Christian, 2000). Moisture content alone cannot be used to judge the shelf life of a product. But the product's moisture content and water activity will present a fair idea of its longevity in storage. The relationship between moisture content and water activity is not straightforward, and hence it will be wrong to conclude that products with higher water content will necessarily have higher water activity than products that are dried (Chiachung, 2019). Products with the same water content can have water activity values different from each other.

The majority of bacteria will grow at a water activity of around 0.85, while yeast and mold at water activity around 0.61 and fungi at water activity less than 0.70 (Beuchat, 1981). Some microorganisms can thrive slowly at or above water activity of approximately 0.6. However, no microbial growth is expected below a water activity of 0.6. Although temperature and pH can influence how well microorganisms will thrive in a product, water activity may be the key factor in reducing deterioration.

2.9 Drying rate curves

During drying of agricultural food products, changes in the product moisture content over a period of time can be recorded and presented as a curve. This curve is called the drying rate curve. Drying rate curves are obtained using reduction in moisture content with respect to drying time, changes in drying rate with drying time, or changes in drying rate versus moisture content. The resulting curve explains the behavior of moisture content in the product from the commencement of the drying process up to the point where the process is terminated at equilibrium moisture content or pre-determined moisture content. The drying characteristics of agricultural products can be better understood using drying rate curves. The drying rate is calculated for each time interval using equation (3) (Ali, 2008):

$$Drying\ rate = \frac{Initial\ weight - Final\ weight}{Time\ interval} \quad (3)$$

In simple terms, the weight of water removed from the product per unit time divided by the weight of the dry product is termed drying rate (Vijayan, et al., 2017). Drying-rate curves can be used to explain the drying characteristics of a given product under a given condition (s). Ali (2008) reports that the rate of drying also has an important effect on the quality of the dried product, as well as the fuel consumption. A typical drying rate curve is divided into three distinct

periods; Constant-rate period (1 – 2), First falling-rate period (2 – 3), and Second falling-rate period (3 – 4) as shown in Figure 3 (Ekechukwu, 1999).

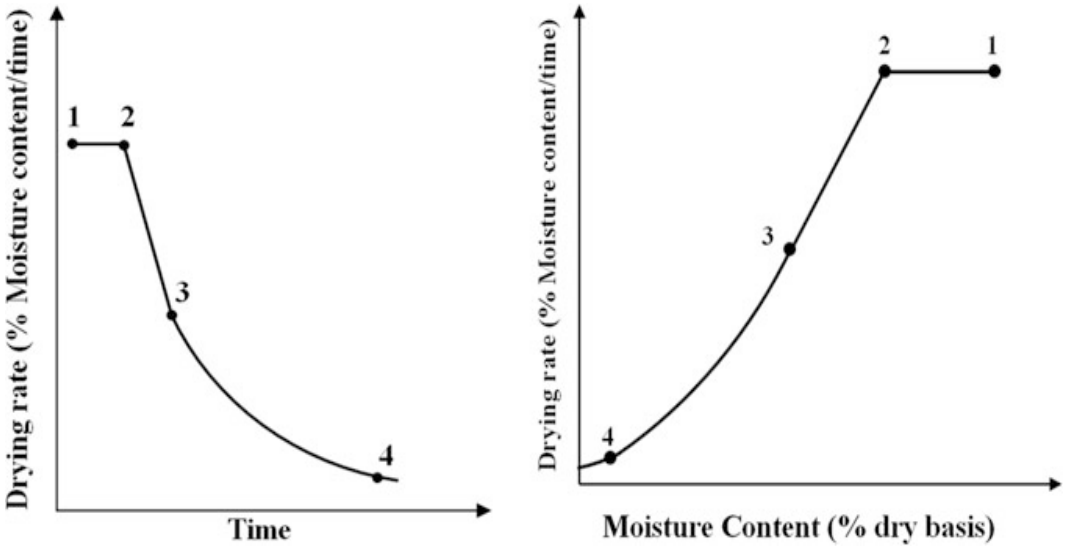


Figure 3: Drying rate curves showing the different periods (1 - 2; 2 - 3; and 3 - 4)

2.9.1 Constant drying-rate period

During the constant rate period, moisture that exists freely on the surface of the product (also called free water) is the first to evapourate. During this period, the external resistance to water vapour evapouration is much greater than the internal resistance to moisture transfer offered by the product. In stage 1, as shown in Fig. 3, the rate at which evapouration of moisture occurs is nearly constant, and the product surface temperature is maintained constant and almost the same as the wet-bulb temperature of the air that surrounds it. In stage 2, the movement of moisture is governed by diffusion as a result of the saturation of moisture on the

surface of the product. The drying rate of the product at this point is largely affected by the vapour pressure gradient between the drying air and the product surface. It is also affected by the amount of product surface area that is available to the drying air, the mass transfer coefficient, and the flow rate of the drying air (Ekechukwu, 1999). The constant drying rate period is terminated when the product reaches its critical moisture content, and then the falling-rate period immediately follows (Belessiotis & Delyannis, 2011).

2.9.2 Falling-rate period

This period is divided into two parts, namely; the first falling-rate period and the second falling-rate period. Stage 2 – 3, is described as the first falling-rate period, and at this stage, the product has attained its critical moisture content. As a result, there is no more enough moisture on the surface of the product to allow for easy evapouration. This leads to a continuous decrease in the drying rate of the product as shown in Figure 3. The critical moisture content is the moisture content at which the least migration of free water from the interior surface of the product becomes equal to the maximum evapouration of moisture from the surface. (Vijayan et al., 2017). In stage (3 – 4) described as the second falling-rate period, the drying process is largely by desorption, and the partial pressure of water vapour at this stage is lower than the saturated vapour pressure. The product at this stage becomes nearly dry, and movement of moisture from the inner part of the product to the surface occurs slowly (Doymaz & Karasu, 2018). According to Gunathilake et al. (2018), hygroscopic food products have multiple

falling-rate periods, but products non-hygroscopic in nature have a single falling-rate period. During the falling-rate period, movement of moisture from the inner part of the product to the surface is dependent on a number of factors including capillary force, diffusion of liquids, and vapour diffusion. In most agricultural products, the falling rate period lasts longer than the constant drying-rate period, and heat damage to food is more likely to happen in the falling-rate period (Gunathilake et al., 2018).

2.10 Thin-layer drying models

The type of drying involving just a single layer of the wet product or slices is described as thin-layer drying. Distribution of temperature in thin layer drying can be assumed to be uniform because the wet product been dried is usually broken into smaller slices. The use of thin-layer drying models to predict drying characteristics has been applied to a wide range of agricultural food products. According to Erbay and Icier (2010), these models are grouped into empirical, theoretical, and semi-theoretical. The theoretical models were formulated using many assumptions while taking into account the internal resistance of the product to moisture transfer, and they can be used to explain the drying behavior of the product under all conditions. However, because these models are formulated using assumptions, they may result in considerable errors which can affect the results obtained. Models formulated using Fick's second law of diffusion and Newton's law of cooling are the most widely used theoretical models (Ertekin &

Firat, 2015). The following section of literature review is focused on some of the common theoretical models used in thin-layer drying.

2.10.1 Lewis model

Some authors refer to this model as Newton's model because it is formulated out of Newton's law of cooling. This model explains that in the falling rate period, change in moisture content is proportional to the difference between the product moisture content and the expected moisture content of the product at equilibrium with the surrounding drying air (Lewis, 1921). The Lewis model is regarded as one of the simplest models used to describe the drying behavior of agricultural products. It is represented by equation (4).

$$MR = \exp(-kt) \quad (4)$$

where *k* and *MR* represent the drying constant and moisture ratio respectively at any time *t*. The above model has been used to describe the drying behavior of many agricultural products like black tea (Panchariya et al., 2002), red chili (Hossain et al., 2007), and grape seeds (Roberts et al., 2008).

2.10.2 Page model

Page (1949) modified the Lewis model by introducing a constant *n*, to minimize the flaws common with the Lewis model. Hence the Page model is also known as the Modified Lewis model. The constant introduced is meant to moderate the time term in the model to ensure that the prediction of moisture loss is accurate

(Kahveci & Cihan, 2008; Doymaz & Ismail, 2011). The Page model has two constants (*k* and *n*), and is represented by the equation (5).

$$MR = \exp(-kt^n) \quad (5)$$

k and *n* represent model constants, and *MR* is moisture ratio at any time *t*. This model has been reported to be most appropriate in describing the thin-layer drying behavior of kiwifruit (Mohammadi et al., 2008), banana slices (Doymaz, 2010), pumpkin (Guine et al., 2011), onion slices (El-mesery & Mwithiga, 2012), and plantain (Oforkansi & Oduola, 2016). Because of its wide application, it has been accepted as a standard model that can be used in thin-layer modeling of agricultural as well as other biological products (ANSI/ASAE, 2014).

2.10.3 Modified Page model

As the name suggests, it is a modified form of the Page model, and comes in different forms as reported in literature by Ertekin and Firat (2015). These models are represented equations (6) to (9).

Modified Page I: $MR = \exp(-kt)^n$ (6)

Modified Page IV: $MR = a\ exp[-(kt^n)]$ (7)

Modified Page V: $MR = exp(-kt^n)$ (8)

Modified Page VI: $MR = exp(kt^n)$ (9)

Modified Page I and V have been reported to be best for thin-layer drying of sesame hull (Al-Mahasneh et al., 2007) and sweet potato slices (Falade &

Soldemi, 2010) respectively. Modified Page IV and VI have also been tested for thin-layer drying of figs (Babalis et al., 2006) and mushrooms (Kurozawa et al., 2012) respectively

2.10.4 Henderson and Pabis model

This model was developed by Henderson and Pabis (1961) using Fick's second law of diffusion. The model was initially tested in the drying of corn and millet. Henderson and Pabis model has two constants and has been used to effectively model the drying of onion (Sawhney et al., 1999), cassava (Koua et al., 2009), and African breadfruit seed (Shittu & Raji, 2011). Henderson and Pabis' model is expressed by equation (10).

$$MR = a \exp(-kt) \tag{10}$$

Where a is a dimensionless constant and represents the shape of the material used.

2.10.5 Logarithmic model

Another name for the Logarithmic model is an asymptotic model. It is the logarithmic form of the Henderson and Pabis model. This model has three constants and is expressed by equation (11).

$$MR = a \exp(-kt) + c \tag{11}$$

where c is a dimensionless empirical constant.

The Logarithmic model is reported to be suitable in describing the drying characteristics of pumpkin slices (Doymaz, 2007) and apple slices (Kaleta & Gornicki, 2010).

2.11 Pretreatment methods and their effects on agricultural products

Pretreatment before drying has received considerable attention in the food processing industry because it is a cost-effective method of preservation. There are many pretreatment methods that can be used to maintain or enhance the quality of processed foods. These methods include immersion in chemical solutions, hot-water blanching, and physical pretreatments. Pretreatment is a pre-drying operation that is used to enhance the drying process, maintain quality, and inactivate enzymes. Drying as a postharvest operation has a huge demand for time and energy, however, pretreatment has been shown to effectively enhance the drying process (Deng et al., 2017). Studies show that it can greatly decrease the drying time, as well as improve water diffusion, and quality of final products (Wang et al., 2017). It can also enhance retention of antioxidant compounds, modify product tissue properties thereby increasing drying rate, and improving product quality (Liu et al., 2015; Deng et al., 2017). This part of the review focuses on some advances in pretreatment technology reported in literature, and their effects on the drying process and the quality of the final dried product.

2.11.1 Thermal blanching

Thermal blanching is a common pre-drying operation. The main reasons for subjecting agro-products to thermal blanching are to reduce the activities of

enzymes that cause deterioration, decrease the microbial load, and enhance the drying process. Blanching in hot water is a widely used thermal blanching technique in agricultural food products prior to drying (Filho et al., 2016; Ando et al., 2016). It involves immersing the products to be dried into hot water (70 – 100 °C) for several minutes (Guida et al., 2013). Thermal blanching involving the use of hot water or steam or microwave blanching can be applied to destroy enzymes that cause undesirable darkening of food products during the process, hence helping to preserve the colour of the product (Bai et al., 2013). In a study involving carrots, the amount of alpha-carotene and beta-carotene in samples of blanched carrots were 51 % and 76 % respectively, which was more than that of the unblanched samples (Lavelli et al., 2007). This was attributed to the effectiveness of blanching in stopping the activities of enzymes such as peroxidase and lipoxidase. Meanwhile, it has also been reported that there is a considerable loss of soluble nutrient substances such as sugars, carbohydrates, minerals, and vitamins due to leaching into blanching water (Garba et al., 2015; Mukherjee & Chattopadhyay, 2007). The loss of soluble nutrient substances is further worsened by the negative effect of blanching on the texture and microstructure of samples (Badwaik et al., 2015). To reduce the effect of nutrients and solid content dissolving into hot water, food processors now rely on steam blanching. Steam blanching is believed to be more effective in retaining most of the minerals and water-soluble substances than hot water blanching. This is because the leaching effect is reduced to negligible amounts when steam blanching is used. As reported in a study by Gamboa-Santos et al. (2013), steam-

blanched carrots retained more amounts of vitamin C (81.2 %) than carrots samples that were blanched in hot water (vitamin C 1.3 %) at 60 ^{o}C. In a similar study, steam-blanched peas retained more ascorbic acid content (22 mg/100 g) than peas blanched in water (14 mg/100 g) (Lin & Brewer, 2005). Nonetheless, steam blanching is not without any shortcomings. Steam blanching results in tissues of the product becoming softer, and may also lead to undesirable alterations in quality as a result of prolonged heating time (Deng et al., 2017).

2.11.2 Freezing pretreatment

Freezing can be used as a pre-drying treatment to accelerate the drying process and maintain product quality (Albertos et al., 2016). Usually, freezing pretreatment is performed by exposing the food product to a very low temperature (−20 ^{o}C) for several minutes, after which it is then allowed to thaw at room conditions (20 ^{o}C, 30 % to 50 % RH). Large ice crystals formed during freezing lead to a breakdown of cellular structure which facilitates both water migration and mass transfer. As observed by Pimpaporn et al. (2007), freezing pretreatment resulted in enhancing the lightness of dried potato chips, as well as its crispness and toughness. Kowalska et al. (2008) also observed that freezing pretreatment performed prior to drying of pumpkin samples resulted in more water loss as compared to samples that received no pretreatment. Freezing pretreatment can improve the quality and drying rate of the product. Nonetheless, freezing pretreatment has been reported to be less effective in inactivating enzymes responsible for causing browning reactions. In addition, apart from the

high operation cost involved in freezing pretreatment, there is also a possible loss of considerable amounts of food nutrients during the thawing period (Deng et al., 2017).

2.11.3 High hydrostatic pressure pretreatment

High hydrostatic pressure (HHP) involves the application of a high-pressure shockwave (100 to 800 MPa) transmitted through water to food products. When food products are subjected to HHP prior to drying, the high pressure makes cells permeable, resulting in higher diffusion and drying rates. HHP pretreatment, though an emerging technology, is reported to lower drying time and minimize deterioration of product quality (Yucel et al., 2010). By using HHP pretreatment, the drying time could be reduced by nearly 32 % while at the same time improving the rehydration capacity of the product by close to 32 % (Hulle & Rao, 2015). Apart from its ability to modify the texture and microstructure of the food product, an increase in antioxidant activity and water diffusion coefficient was reported when HHP pretreatment was applied to aloe vera (Vega-Galvez et al., 2011). In a separate study by Tedjo et al. (2002), mango samples subjected to HHP were also reported to give higher lightness values than the untreated samples. However, the application of advanced technologies such as HHP has always been a huge challenge, especially for small and medium-scale food processors considering the initial equipment cost involved in acquiring these advanced systems. Besides the high equipment cost, processing plant materials

using high pressure can greatly destroy their shape and structure (Jermann et al., 2015).

2.11.4 Sulfuring pretreatment

Sulfuring refers to the use of sulfite compounds like sodium metabisulfite ($Na_2S_2O_5$), potassium metabisulfite ($K_2S_2O_5$), or sodium hydrogen sulfite ($NaHSO_3$). The process, also known as sulfitation, is a common practice in the food industry and can alternatively be performed using sulfur dioxide gas. Sulfitation when performed before drying, is capable of preventing quality loss as well as reducing darkening in foods during processing and storage (Miranda et al., 2009). It improves drying by improving the permeability of cell membranes in the food product (Lewicki, 1998). In a study conducted by Kingsly et al. (2007), peaches pretreated with 1% potassium metabisulfite showed increased effective diffusivity and drying rate relative to untreated peaches. The use of sulfites in low concentration solutions can prevent both enzymatic and non-enzymatic browning because sulfite ions react with quinines to stop the activity of polyphenol oxidase activity and reduce the amount of oxygen present (Van Hal, 2000). Where drying is likely to cause considerable loss of ascorbic acid and carotenoids, sulfuring acts as an antioxidant against oxidative deterioration during processing, thus preventing ascorbic acid and carotenoid loss (Mujumdar, 2006). According to Mir et al. (2009), apricots pretreated in a solution of $K_2S_2O_5$ were able to retain more carotenoids and ascorbic acid.

When performing sulfitation or sulfuring, factors such as processing time, the concentration of the solution, and pH of the soaking liquor are critical to its efficacy. For instance, there was reduced non-enzymatic browning of apricots when dipping time, and the concentration of potassium metabisulfite solution was increased (Mir et al., 2009). Sulfitation before drying has proven to have enormous benefits but also has its downside. One of the major disadvantages of sulfuring reported in literature is leaching. Sulfite pretreatment may cause loss of water-soluble nutrients as a result of leaching, and may also give the processed food an undesirable flavor. For instance, there was a total loss of ascorbic acid in apricots dipped in metabisulfite solution as a result of leaching from the fruit into the sulfite solution (Garcia-Martinez et al., 2013). The presence of chemical residue in food is another prominent problem associated with sulfite pretreatment. With the increasing demand for organic foods, sulfuring is been discouraged. Foods containing more than 10 ppm sulfating agents are discouraged by legislation in some countries because of their alleged hazard to asthmatic patients (Kamiloglu et al., 2016).

2.11.5 Carbonic maceration pretreatment

Carbon dioxide pretreatment is generally applied through a technique known as carbonic maceration (CM). The samples to be treated are placed in a closed tank with an atmosphere saturated with carbon dioxide. Food products such as tomato, sweet potato, and chili have been pretreated with CM and found to be successful in enhancing the quality of dried products. CM pretreatment, as observed by

Zhao et al. (2016) was found to reduce drying time and the retention of phytochemicals namely, total phenols, β-carotene contents, vitamin C, flavonoids, and anthocyanin in dried sweet potato. Liu et al. (2012) used CM pretreatment on grapes and found that there was an increase of 44.6 % in drying rate, while the total phenolic content of fermented grapes also increased by 48.3 % relative to untreated grapes.

However, CM pretreatment may trigger anaerobic respiration leading to undesirable changes in product texture and aroma. According to Chen et al. (2017), CM pretreatment of jujube products increased acetaldehyde and ethanol and consequently altered the aroma of dried jujube. It is very difficult to avoid alteration in product texture and flavor when using CM pretreatment.

2.11.6 Alkaline pretreatment

Dipping agro-products into an alkaline solution such as sodium hydroxide or potassium carbonate is an effective chemical pretreatment method. Dipping of grapes in alkali solutions at 60 ^{o}C for 2 and 3 minutes was found to improve lightness by 37 – 55 % (Bingol et al., 2012). Dipping in alkaline solution is capable of inhibiting polyphenol oxidase (PPO) activity and further slowing down browning reactions in grape berries during drying. However, leaching is a prominent problem associated with alkali dipping pretreatment. Also, the residue of alkaline agents in processed food may cause health problems to humans.

2.11.7 Acid pretreatment

Acid pretreatment when used before drying can improve product quality and pigment stability by slowing down enzymatic activities. Pigments such as anthocyanins are stable in acid environments. PPO activity thrives well within a pH region of 6.0 – 7.0, hence PPO activity can be slowed in a solution with a low pH (Ngamwonglumlert et al., 2015). Citric acid and ascorbic acid are the most common organic acids used in food processing. Citric acid, when used as a pretreatment agent can accelerate drying rate and also serve as an anti-darkening agent. A combination of citric acid and ascorbic acid used for the pretreatment of apple cubes was reported to be effective in slowing down enzymatic browning (Zhu et al., 2007), and improved the colour of sweet potato slices (Doymaz, 2010). Nonetheless, dipping in acid solution may cause loss of water-soluble nutritional compounds as a result of leaching into the solution.

2.12 Quality changes during drying of agricultural products

It is very difficult to find any food product that does not change in quality or characteristics after drying. Many people equate the success of a drying operation to how much water or moisture is removed from the product. Hence, to speed up the drying process, most food processors choose to subject the product to high air temperatures and volumetric flow rates. Though this will hasten the drying process, the resultant effect on the final product can be dire, and therefore there is the need to pay attention to the effects on the quality of the product. Literature has shown that drying is necessary to increase shelf life, but can also lead to

changes in quality characteristics such as colour and nutrients (Diamante et al., 2010; Deng et al., 2017; Guine, 2018). This part of the review is focused on changes in bioactive compounds and colour that occur in food products as a result of drying.

2.12.1 Changes in bioactive compounds during drying

Human beings consume food to make good use of the nutrients in them to nourish the body. Some of these nutritional compounds found in agricultural food products are sensitive to heat, and therefore their amounts in the food product can change as a result of drying. When subjected to drying, some of the nutritional contents in the food can be substantially reduced or may be completely destroyed. One of the common heat-sensitive nutrients in food products is vitamins. In food processing, Vitamin C is often used to judge nutritional quality because it is sensitive to thermal treatments (Di Scala & Crapiste, 2008). Because vitamin C is extremely heat-sensitive, its availability indicates the retention of other nutrients in dried food items. If vitamin C is well maintained during the drying process, the possibility of maintaining other nutrients is also high (Lin et al., 1998). Drying blueberries at a temperature range of 50 – 90 °C resulted in nearly the same magnitude of degradation in vitamin C. Drying at air temperatures of 50 – 70 °C also produced a decline in the total phenolic content of berries, but at 90 °C drying air temperature a significant increase in polyphenol content was observed. High temperatures (80 – 90 °C) increased the antioxidant activity of berries. Previous studies on the effect of hot

air drying on the ascorbic acid concentration of apricot, kiwi, and potato concluded that the degradation of ascorbic acid was heat and time-dependent (Khraisheh et al., 2000; Diamante et al., 2010). Moursy et al. (2014) has also confirmed that vitamin C is affected by drying temperature. Vitamin C content of lemon fruits increased with increasing temperature, and after a certain temperature, it begins to decrease. There was little change in ascorbic acid contents of fresh and hot-air dried green and gold kiwifruits when dried at 60 and 80 °C. However, about 19 % decrease in the ascorbic acid content was observed after drying at 100 °C (Diamante et al., 2010). Jayarman and Das Gupta (1992) recommend that fast drying can preserve maximum ascorbic acid contents than slow drying.

Carotenoids are orange and yellow pigments and they are categorized into carotenes and xanthophylls. Alpha and beta-carotene are the major carotenes found in agricultural materials. Beta-carotene is predominant in foods like carrots, while in tomatoes the major pigment is lycopene. Studies have shown that pretreatment helps in stabilizing carotenoids, but subsequent drying can cause degradation of carotenoids depending on the drying conditions (Soria et al., 2009). Carotenoids are sensitive to heat treatment and enzymatic degradation by lipoxygenase (Sogi et al., 2015). Drying temperature affects lycopene content in food products. In a study conducted by Muratore et al. (2008) using hot air drying, it was observed that cherry tomatoes dried at 80 °C contained higher contents of lycopene when compared to those samples dried at 60 °C and 40 °C.

Samples dried at 80 °C took 4 hours to complete drying whiles samples dried at 60 °C and 40 °C took 9 hours and 29 hours respectively. The study revealed that lycopene content in cherry tomatoes is destroyed by the length of drying.

2.12.2 Colour changes during hot air drying of agricultural products

Colour is an important physical attribute when it comes to the quality of dried foods; since it is the first criteria consumers consider when choosing a new product. Chemical and biochemical reactions which occur during drying may cause colour changes in food products. Enzymatic and non-enzymatic reactions cause degradation of natural food pigments such as carotenoids, anthocyanins, and chlorophylls induced by drying (Marty-Audouin et al., 1992). The colour characteristics of agricultural materials are complex and depend on both the chemical composition and physical properties of the material. Therefore, the perception of colour in a raw food material is highly likely to differ from its dried product (Lewicki & Duszczyk, 1998). During hot air drying, several deteriorative reactions that affect the colour of food products occur. The change in colour of dried food materials emanate chemical changes, such as pigment degradation, browning reactions, and oxidation of ascorbic acid (Bonazzi & Dumoulin, 2011). For example, carotenoids when exposed to oxygen are subjected to rapid decomposition. In food materials like carrots, the principal components that determine colour are α- and β-carotene. Hence, during hot air drying of carrots, loss of colour is largely attributed to the destruction of these two major carotenoids (Mangels et al., 1993).

Colour quality is widely measured using tri-stimulus colour coordinates. In modern-day food processing and research, colour quality is measured using CIE colour parameter (L^*, a^*, b^*) values from a colourimeter. L^* value represents the degree of lightness to darkness, a^* value indicates the degree of redness (+) to greenness (-), b^* value is the degree of yellowness (+) to blueness (-) and ΔE^* is a measure of total colour change (Chen et al., 2015). According to Zielinska and Markowski (2012), there was a decrease in redness and yellowness of carrot samples after spout-fluidized bed drying. This was attributed to internal structure alterations, moisture reduction, the concentration of dry matter, and changes in surface texture as a result of drying. In a separate study by Chen et al., 2017, hot air drying resulted in increased lightness and redness of jujube slices. There was an increase in b^* values with increasing drying temperature, causing dried slices to appear yellower than the fresh samples. Karabulut et al. (2007a) also found that the L^* and b^* values of dried apricots decreased when the drying temperature was increased from 60 to 80 °C, and the total colour change of dried apricot increased with temperature. This was expected because the higher the drying temperature the more colour deterioration will take place in the dried apricots.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Raw material and sample preparation

Fresh Frafra potato (FP) tubers (Dark brown skin variety) were purchased from a farmer in Pelungu, a farming community in Nabdam District of the Upper East Region of Ghana. The samples were transported to the UPGRADE Plus Project laboratory at the University for Development Students, Nyankpala Campus. Upon arrival, samples were sorted, and defective tubers were removed and discarded. Samples were washed thoroughly with water to remove earth particles on the tubers. After samples have been well washed, they were then peeled manually to remove the thin black skin using a stainless knife, and sliced into a thickness of 3 mm using a laboratory slicing device (Ritter E16, Ritterwerk GmbH, Gröbenzell, Germany).

3.2 Experimental design

The experimental design was a 4 × 4 factorial design. The study was conducted using four different pretreatment methods combined with four levels of drying temperature.

3.2.1 Pretreatment methods

Pretreatments such as blanching, dipping in potassium metabisulfite ($K_2S_2O_5$), combination of dipping in potassium metabisulfite plus blanching ($K_2S_2O_5$+Blanching), and no pretreatment (Control) of sliced FP samples was done before drying.

Blanching: Sliced FP tubers were subjected to blanching treatment in steam as described by Bakare et al. (2016). This was done by subjecting the sliced samples to steam (100 °C) for 3 min. The blanched slices were allowed to cool before drying commenced.

Dipping in Potassium metabisulfite ($K_2S_2O_5$): FP samples were immersed in potassium metabisulfite solution (5 % *w/v*) for 5 min as described by Bakare et al. (2016).

Combined treatment ($K_2S_2O_5$+Blanching): Samples were treated using a combination of $K_2S_2O_5$ and blanching as described by Tunde-Akintunde (2010). The sliced samples were first immersed in $K_2S_2O_5$ solution (5 % w/v) for 5 min. Immediately after immersing in $K_2S_2O_5$ solution, samples were removed from the solution and subjected to steam (100 °C) under boiling water for 3 min. The samples were then removed from the steam and allowed to cool before drying commenced.

Control treatment: FP samples dried directly without any pretreatment were used as the control treatment.

3.2.2 Hot-air drying process

Drying experiments were conducted in the laboratory using Hohenheim HT Mini temperature control dryer (*Innotech-ingenieursgesellschaft* mbH, Altdorf, Germany) as shown in Figure 4. Before drying commenced, the dryer was set to the desired temperature (40, 50, 60, and 70 °C) and allowed to operate empty for a minimum period of 30 min before samples were inserted. This was done to

ensure steady-state conditions in the drying cabinet. Sliced FP samples after pretreatment were spread in single layer on a drying tray (300 g/tray) for drying. The drying tray containing sliced samples was inserted into the dryer for drying to commence. Weight loss was monitored and recorded every 30 min as drying progressed by immediately removing the samples and reweighing using a balance (Kern PCB, 10000 – 1, Kern & Sohn, GmbH Ziegeler, Balingen, Germany). After recording the weight loss, the samples were immediately returned to the drying chamber to avoid moisture absorption. Sliced samples were dried until a constant weight was obtained (Abano & Amoah, 2015). Drying experiments were replicated twice for each drying temperature and pretreatment. Dried FP slices (Figure 5A) were allowed to cool, milled into flour (Figure 5B), and sieved with 250 µm sieve aperture size, and then stored in high-density polyethylene (HDPE) bags for future use. The entire experimental procedure has been illustrated in a flow chart in Figure 6.

Figure 4: Hohenheim HT Mini temperature control dryer

Figure 5: (A) Dried Frafra potato slices; (**B**) milled Frafra potato flour in HDPE bags

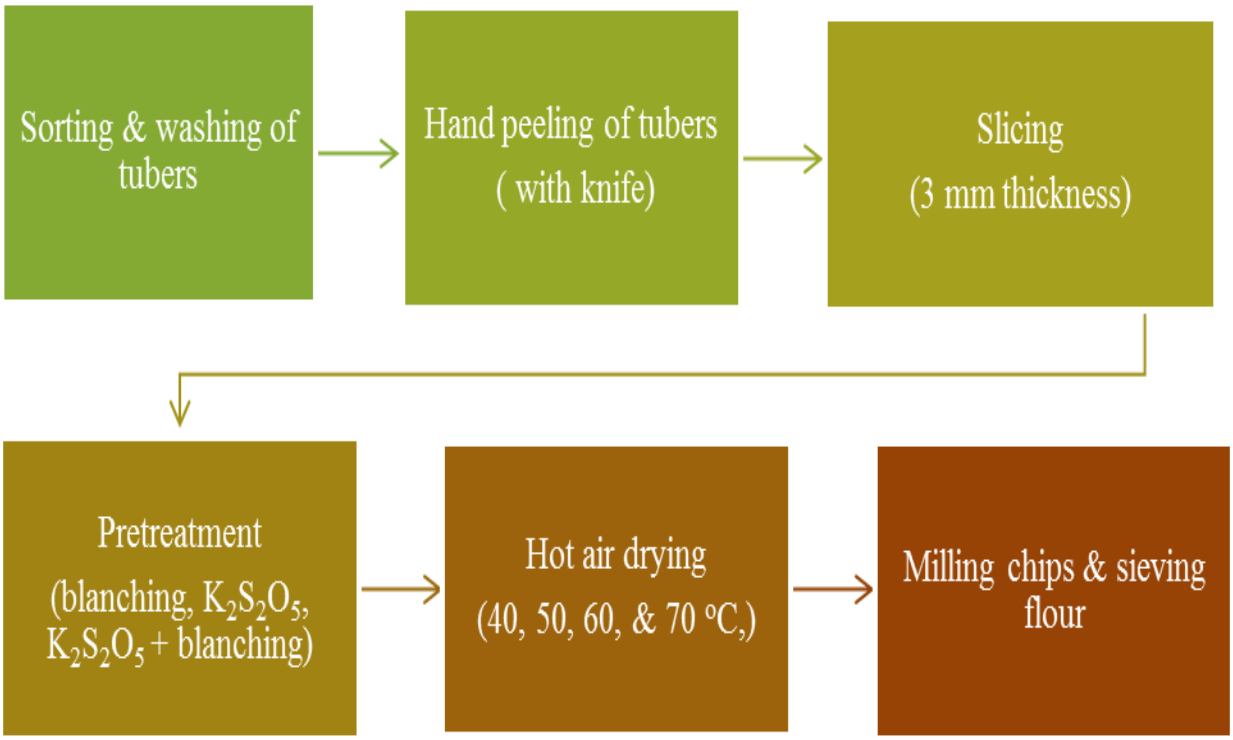


Figure 6: Flow chart describing the experimental procedure

3.3 Drying kinetics

Moisture ratio (MR) of FP samples during the drying experiments was obtained using Equation (12) (Ju et al., 2016; Deng et al., 2017):

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (12)$$

Where M_t is the moisture content at drying time of t (g water/g dry mass), M_o represent initial moisture content and M_e is the equilibrium moisture content (g water/g dry mass).

The drying rate (DR) of FP slices was calculated using Equation (13) (Doymaz, 2015; Doymaz & Karasu, 2018):

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad (13)$$

where $M_{t+\Delta t}$ represents moisture content at $t + \Delta t$ (g water/g dry solid) and t represents the drying time (min).

3.4 Modelling of thin-layer drying of FP slices

Drying curves obtained using the experimental data were fitted into five commonly used thin-layer drying models: Lewis model (Eq. 4), Page model (Eq. 5), Modified page model (Eq. 6), Henderson and Pabis model (Eq. 10), and Logarithmic model (Eq. 11) (Doymaz & Ismail, 2011; Ertekin & Firat, 2015). The models were tested with the experimental data to determine which model best described the drying process of FP slices. The empirical model constants (*k, n, a, c*) were evaluated using Excel Solver in Microsoft Office Excel 2016. To determine the model goodness of fit, statistical parameters such as coefficient of determination (R^2), root mean square error (*RMSE*), and reduced Chi-square (X^2) were evaluated using Equation (14), (15), and (16) respectively (Kumar et al., 2013; Karabulut et al., 2007b):

$$R^2 = 1 - \sum \frac{\left(MR_{exp.} - MR_{pre.}\right)^2}{\left(MR_{exp.} - MR_{exp.mean}\right)^2} \quad (14)$$

$$RMSE = \left\{\frac{1}{N}\sum\left(MR_{exp.} - MR_{pre.}\right)^2\right\}^{\frac{1}{2}} \quad (15)$$

$$X^2 = \frac{\sum\left(MR_{exp.} - MR_{pre.}\right)^2}{N - n} \quad (16)$$

where: *N* represents the number of observations; *n* is the number of constants in the model; $MR_{exp.}$ represents experimental moisture ratio; $MR_{pre.}$ represents the predicted moisture ratio.

3.5 Determination of moisture content

The oven-dry method of moisture content determination was used to determine the initial and final moisture content of FP slices and expressed on a dry basis. FP samples were dried for 8 hours to a constant weight in an oven set to 105 ^{o}C (AOAC, 1980). Mass values of each sample before and after drying were determined gravimetrically, and moisture content on a dry weight basis (MC) was calculated using Equation (17) (Wei et al., 2018).

$$MC = \frac{M_t - M_d}{M_d} \quad (17)$$

Where M_t and M_d represent the actual sample mass and drier mass (in grams) respectively.

3.6 Water activity (a_w) determination

Water activity (a_w) was determined using a portable water activity meter (LabSwift-aw, Novasina AG, CH – 8853 Lachen, Switzerland) measured at a room temperature (25±1 °C). Water activity data was taken on the final dried slices and in triplicates.

3.7 Colour measurement

Colour parameters of both fresh and dried FP samples were measured with the aid of a Chroma Meter (CR – 400, Konica Minolta, Inc., Japan). Before measurements were taken, the Chroma Meter was calibrated using a standard white tile plate with D65 illumination (Y = 80.1, x = 0.3219, and y = 0.3394). Colour parameters measured were based on the Commission Internationale de l'Éclairage (CIE) colour coordinates (L^*, a^* and b^*). L^*represent lightness or darkness (black, for L^*= 0; white, for L^*= 100), $+a^*$ is redness, $-a^*$ is greenness, $+b^*$ is yellowness and $-b^*$ is blueness. Colour measurements were taken after every 30 minutes of drying and in triplicates.

In addition, hue angle (h^o), chroma (C^*), browning index (BI), and whiteness index (WI) were calculated using the equation (18), (19), (20), (21) and (22) (Diamante et al., 2010; Wei et al., 2018):

$$h^o = \tan^{-1}\left[\frac{b^*}{a^*}\right] \quad (18)$$

$$C^* = \left(a^{*2} + b^{*2}\right)^{0.5} \quad (19)$$

$$BI = \left[\frac{100(x-0.31)}{0.17}\right] \quad (20)$$

Where x in the above equation is calculated as:

$$x = \frac{(a^*+1.75L^*)}{(5.645L^*+a^*-3.012b^*)} \quad (21)$$

$$WI = 100 - \sqrt{(100-L^*)^2 + a^{*2} + b^{*2}} \quad (22)$$

Where L^* , a^* , and b^* represent colour parameters of dried FP slices and L_0^* , a_0^* , and b_0^* represent colour parameters of fresh FP slices.

3.8 Surface temperature distribution

The surface temperature distribution of FP slices was also measured using a handheld infrared thermal imaging camera (FLIR – E5, FLIR Systems, Inc., USA) (Figure 7). Samples were removed from the drying chamber at regular intervals of 30 minutes and thermal images of FP slices on the drying tray were captured within 20 seconds and in replicates of five (Wei et al., 2018). The thermal imaging camera was held at approximately 0.4 m above the samples in all the experiments as suggested by Wei et al. (2018). FLIR Tools software (Version 5.13) was used to analyze the temperature distribution of images captured.

Figure 7: FLIR - E5 handheld infrared thermal imaging camera

3.9 Determination of total antioxidant activity, total phenolic content, and flavonoid

Extraction of the sample

The extraction of flour samples from FP was done using the method suggested by Li et al. (2015). FP flour of about 2 g was poured into 80 % methanol of volume 16 ml and mixed with 1 % HCl. The mixture was incubated in a dark room (25 ± 2 °C) for 24 h and then centrifuged using Rotofix 32A (Andreas Hettich GmbH & Co. KG, Tuttlingen, Germany) for 30 min at a speed of 4000 rpm. The liquid suspension was collected and stored at 4 ± 1 °C for further analyses.

Determination of total antioxidant activity

The total antioxidant activity of FP flour extracts was determined using the phosphomolydenum complex method proposed by (Prieto et al., 1999). About 0.1 ml of flour extract was mixed with 1 ml of reagent solution (0.6 M, H_2SO_4, 28 mM sodium phosphate, and 4 mM ammonium molybdate) and incubated in a water bath (JP Selecta S.A., Barcelona, Spain) at 95 °C for 90 min. The absorbance was measured at 695 nm against the blank (0.1 ml extraction solvent and 1 ml reagent solution) using UV/Vis spectrophotometer (Model: C-7000UV, Peak Instruments, Huston, TX, USA). Ascorbic acid was used as standard and total antioxidant activity was measured and expressed as mg ascorbic acid equivalence/100 g.

Determination of total phenolic content

The Folin-Ciocalteu test (Li et al., 2015) was used to determine the total phenolic content of flour extract. Briefly, about 0.5 ml of extract was mixed with 5 ml of Folin-Ciocalteu reagent (1 mol), after which 4 ml of sodium carbonate (7.5 %, w/v) was added. The reaction mixture was incubated for 2 h at room temperature (25 ± 2 °C) after which absorbance was taken at 765 nm using a spectrophotometer (Model: C-7000UV, Peak Instruments, Huston, TX, USA). Gallic acid was used to establish a standard calibration curve from which total phenolic content was measured.

Determination of flavonoid content

Total flavonoid content was determined using the method described by (Li et al., 2015). About 0.5 ml of the extract was added to about 2 ml of distilled water containing 0.15 ml sodium nitrite (50 g/l). After 5 min, 0.15 ml of 10 % $AlCl_3$ solution was added and the mixture was kept at room temperature (25 ± 2 °C) for 5 min, followed by the addition of 1 ml of 1 M NaOH. The solution was then mixed thoroughly and incubated at room temperature for 15 min, after which absorbance was measured at 415 nm with a spectrophotometer (Model: C-7000UV, Peak Instruments, Huston, TX, USA). Catechin was used as a standard for the calibration curve, from which total flavonoid content was measured.

3.10 Determination of β-carotene and vitamin C contents

β-carotene content was determined using petroleum ether to extract and partition the amount of β-carotene contained in the samples as described in literature by Rodriguez-Amaya and Kimura (2004). At 450 nm, absorbance was measured with a Spectrophotometer (C-7000UV, Peak Instruments, Houston, TX, USA). To determine the amount of Vitamin C in the flour samples, about 5 g of flour was extracted in 5 % metaphosphoric acid and titrated against 0.21 % of 2,6-dichlorophenolindophenol (DIP) dye as described by Mohammed et al. (2012). The amount of Vitamin C was measured and expressed in mg/100 g.

3.11 Statistical analyses

The experimental data obtained from this study were expressed as means ± standard deviations of three replicate measurements. Data analyses were

performed using XLSTAT 2016.02.2845. Differences among means were analyzed using Tukey (HSD) test and with a significance level set at 5 % ($p \leq 0.05$).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Drying characteristics of FP slices

The variation of moisture ratio versus drying time for FP samples dried using different pretreatment methods (control, blanching, $K_2S_2O_5$, and a combination of blanching and $K_2S_2O_5$) and drying temperatures (40, 50, 60, and 70 °C) are shown in Figure 8A–D. The moisture content of fresh FP samples measured before drying was 3.72 g water/g dry matter (g_w/g_{DM}). Sugri et al. (2013) also reported the moisture content of FP to be 3.10 g_w/g_{DM}, which is close to the value reported in this study. From Figure 8A–D, there was a decreasing trend in moisture content as drying progressed, showing moisture reduction throughout the drying process. It was also observed that, regardless of the pretreatment method used, an increase in drying air temperature resulted in a shorter drying time. The longest drying time (600 min) was observed on samples pretreated with a combination of $K_2S_2O_5$ plus blanching and dried at 40 ^oC (Fig. 8D), followed by samples dried at 40 ^oC without any pretreatment (Fig. 8A). The shortest drying time (330 min) was recorded on samples pretreated with $K_2S_2O_5$ and dried at 70 ^oC (Fig. 8B), as well as $K_2S_2O_5$ plus blanching dried at 70 ^oC (Fig. 8D). Drying time decreased by 32 % when the temperature of the drying air was increased from 40 ^oC to 70 ^oC in the control samples. In samples that were pretreated by dipping in $K_2S_2O_5$, drying time was found to reduce by 35 % when the temperature of the drying air was increased from 40 ^oC to 70 ^oC (Fig. 8B). A reduction of 18 % and 45 % in drying time was observed when the

temperature was increased from 40 ^{o}C to 70 ^{o}C in blanched samples (Fig. 8C) and samples pretreated by dipping in $K_2S_2O_5$ plus blanching (Fig. 8D), respectively. Higher drying air temperatures generally resulted in a shorter drying time. This is because at higher drying temperatures samples received more heat, resulting in faster moisture evapouration. Similar findings were reported by Torres et al. (2012) for yam, Oyewole and Olaoye (2013) for "Poundo" yam, and Pornpraipech et al. (2017) for Cassava. The results in this study suggest that both pretreatment and drying temperature influenced the drying characteristics of FP tubers.

The drying rate as a function of time for the various treatments is shown in Figure 9A–D. The drying rate was generally rapid at the early stages of drying and then began to decrease continuously with drying time as drying progressed. Similar observations have been reported in literature during drying of pineapple (Ponkham et al., 2012), bamboo slices (Kumar et al., 2013), and sage leaves (Doymaz and Karasu, 2018). The continuous decrease in drying rate with drying time could be attributed to shrinkage of FP slices during drying, thus reducing the porosity of the samples. Singh et al. (2006), explained that this phenomenon prevents the movement of water towards the outer surface of the samples, thereby causing a decrease in drying rate. There was no constant drying rate period observed for all treatments studied, and drying largely occurred in the falling rate period. Similar results were also reported by Chen et al. (2015) for hot air drying of jujube slices, Niamnuy et al. (2012) for soybean, and Fang et

al. (2009) for whole Chinese jujube. This suggests that the movement of water from the inner part of the sample to the outer surface is largely controlled by diffusion (Arepally et al., 2017; Doymaz, 2004).

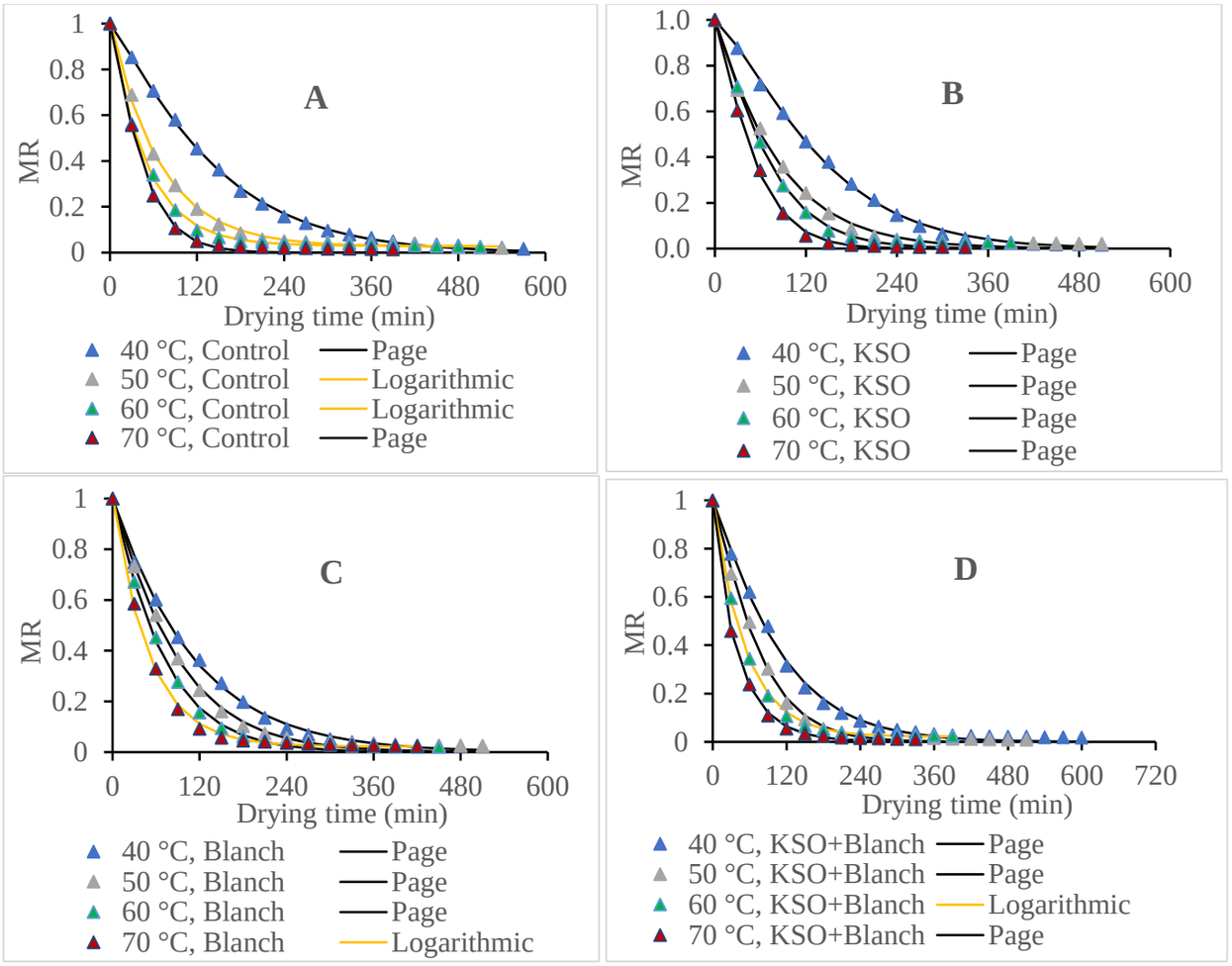


Figure 8(A-D): Drying kinetics and model fitting of FP slices. **A** = Control; **B** = KSO pretreatment; **C** = Blanching pretreatment; **D** = KSO+Blanching pretreatment. Solid line represents Page model and Logarithmic model.

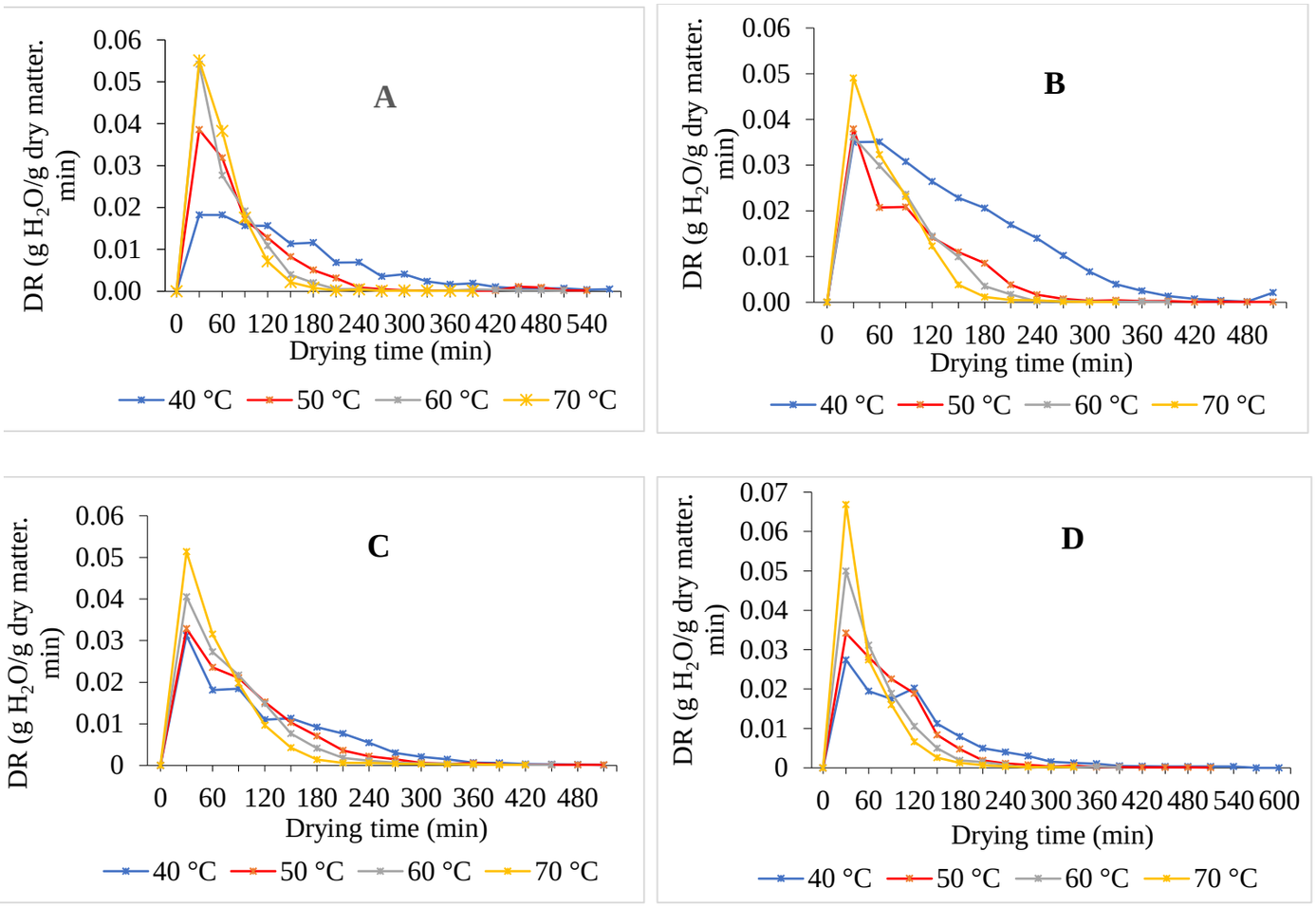


Figure 9(A–D): Variation of drying rate (DR) as a function of drying time for different drying temperatures
A = Control **B** = KSO pretreatment **C** = Blanching pretreatment **D** = KSO+Blanching pretreatment

4.2 Mathematical modelling of drying curves

Moisture content data obtained from the experimental drying of FP slices using different pretreatments and drying air temperatures were converted into *MR* and fitted in five widely used thin-layer drying models, as presented in Fig. 8A–D and Tables 1 – 4. All drying models used in this study gave high values of R^2 ranging from 0.794537 to 0.999436. Except for the Logarithmic model at drying air temperature of 70 °C with $K_2S_2O_5$+Blanch pretreatment, R^2 values for all the models were greater than 0.970000. This result suggests that, apart from the Logarithmic model at drying temperature of 70 °C and $K_2S_2O_5$+Blanch pretreatment, the rest of the other drying models used in this study can describe the drying characteristics of FP slices.

For control samples dried at 40 °C and 70 °C, the Page model had the highest R^2 (0.999436) and lowest *RMSE* (0.007657) and X^2 (0.000229), making it the best fit model for both drying conditions as shown in Table 1 and Fig. 8A. However, for the same control samples dried at 50 °C and 60 °C, the Logarithmic model was the most appropriate model. R^2, *RMSE* and X^2 values under both conditions were 0.998390, 0.010343 and 0.000621 respectively for control dried at 50 °C and 0.998975, 0.007907 and 0.000420 respectively for control dried at 60 °C.

In Table 2, the Page model showed the highest R^2 and lowest *RMSE* and X^2 values at all temperature levels from 40 °C to 70 °C for FP slices pretreated

with $K_2S_2O_5$. The Page model therefore best described the drying behavior of FP slices under the said drying conditions as shown in Fig. 8B.

For FP samples treated with blanching pretreatment (as shown in Table 3 and Fig. 8C), the Page model was most appropriate in predicting the drying behavior of FP slices at all the drying temperatures, except at 70 °C. In a similar study (Fudholi et al., 2013), the Page model was also reported as the best model for describing the drying characteristics of turmeric at temperatures ranging from 45 °C to 55 °C. However, this finding contradicts the report that the Logarithmic model showed higher R^2 values when drying temperatures are low (50 °C and 60 °C) while the Page model yielded higher R^2 values at temperatures 70 °C and 80 °C (Turan & Firatligil, 2019). This contradiction could be attributed to a varietal difference in the samples.

For samples pretreated with $K_2S_2O_5$+Blanch (as shown in Table 4 and Fig. 8D), the Page model was the most appropriate model at drying temperatures 40 °C, 50 °C, and 70 °C. However, the Logarithmic model was found to be the best model at 60 °C drying temperature with R^2, *RMSE*, and X^2 values of 0.999046, 0.008516, and 0.000396 respectively.

Table 1: Model fitting results for FP treated with control and dried at different temperatures

Temperature °C	Model	Model constants				Statistical parameters		
		k	***n***	***a***	***c***	***R²***	***RMSE***	***X²***
40	Lewis	0.006993				0.996501	0.023216	0.002071
	Page	0.002988	1.165080			0.999436	0.007657	0.000229
	Modified Page	0.062656	0.111616			0.996501	0.023216	0.002071
	Henderson & Pabis	0.007286		1.044221		0.996073	0.019119	0.001392
	Logarithmic	0.007286		1.044220	0.000000	0.996073	0.019119	0.001392
50	Lewis	0.013367				0.996489	0.021398	0.002875
	Page	0.015896	0.961399			0.995717	0.021063	0.002760
	Modified Page	0.013582	0.984216			0.996489	0.021398	0.002876
	Henderson & Pabis	0.013390		1.001733		0.996558	0.021394	0.002873
	Logarithmic	0.014676		0.987045	0.026428	0.998390	0.010343	0.000621
60	Lewis	0.018267				0.997032	0.024342	0.004500
	Page	0.028627	0.893309			0.995143	0.022788	0.003833
	Modified Page	0.030222	0.604441			0.997032	0.024342	0.004500
	Henderson & Pabis	0.018144		0.992986		0.996743	0.024280	0.004486
	Logarithmic	0.020081		0.973553	0.029478	0.998975	0.007907	0.000420
70	Lewis	0.022297				0.995844	0.018830	0.002421
	Page	0.011070	1.174446			0.999117	0.013918	0.001359
	Modified Page	0.033389	0.667780			0.995844	0.018830	0.002421
	Henderson & Pabis	0.022533		1.012616		0.996001	0.018500	0.002325
	Logarithmic	0.023194		1.005098	0.009518	0.996183	0.017013	0.001895

Table 2: Model fitting results for FP pretreated with $K_2S_2O_5$ and dried at different drying temperatures

Temperature °C	Model	Model constants				Statistical parameters		
		k	***n***	***a***	***c***	***R^2***	***RMSE***	***X^2***
40	Lewis	0.007104				0.991709	0.041344	0.006036
	Page	0.001450	1.309132			0.999028	0.009859	0.000348
	Modified Page	0.018846	0.376929			0.991709	0.041344	0.006036
	Henderson & Pabis	0.007549		1.069277		0.989351	0.035125	0.004282
	Logarithmic	0.007549		1.069280	0.000000	0.989351	0.035125	0.004282
50	Lewis	0.011908				0.995911	0.017853	0.001726
	Page	0.008992	1.060452			0.996964	0.016604	0.001508
	Modified Page	0.024401	0.488025			0.995911	0.017853	0.001726
	Henderson & Pabis	0.011995		1.007752		0.996002	0.017728	0.001699
	Logarithmic	0.012307		1.003154	0.007889	0.996144	0.016991	0.001534
60	Lewis	0.014063				0.992786	0.026033	0.003275
	Page	0.005842	1.197629			0.998110	0.016598	0.001369
	Modified Page	0.026517	0.530344			0.992786	0.026033	0.003275
	Henderson & Pabis	0.014418		1.028059		0.993039	0.024654	0.002913
	Logarithmic	0.014589		1.025399	0.003935	0.993069	0.024535	0.002865
70	Lewis	0.019271				0.995274	0.022768	0.002734
	Page	0.007655	1.220376			0.999120	0.009123	0.000450
	Modified Page	0.031041	0.620829			0.995274	0.022768	0.002734
	Henderson & Pabis	0.019582		1.019385		0.995102	0.021976	0.002528
	Logarithmic	0.019581		1.019385	0.000000	0.995102	0.021976	0.002528

Table 3: Model fitting results for FP pretreated with blanching and dried at different temperatures

Temperature °C	Model	Model constants				Statistical parameters		
		k	***n***	***a***	***c***	***R^2***	***RMSE***	***X^2***
40	Lewis	0.009001				0.997682	0.013746	0.000811
	Page	0.007455	1.038168			0.998011	0.012777	0.000704
	Modified Page	0.021215	0.424301			0.997682	0.013746	0.000811
	Henderson & Pabis	0.009031		1.003372		0.997670	0.013712	0.000806
	Logarithmic	0.009031		1.003372	0.000000	0.997670	0.013711	0.000806
50	Lewis	0.011343				0.996162	0.017920	0.001671
	Page	0.007797	1.080319			0.997898	0.015660	0.001294
	Modified Page	0.023815	0.476295			0.996162	0.017920	0.001671
	Henderson & Pabis	0.011522		1.016594		0.996463	0.017336	0.001558
	Logarithmic	0.011965		1.009948	0.011659	0.996767	0.015715	0.001251
60	Lewis	0.014223				0.996771	0.016663	0.001545
	Page	0.010174	1.075272			0.998209	0.014839	0.001241
	Modified Page	0.026667	0.533348			0.996771	0.016663	0.001545
	Henderson & Pabis	0.014383		1.012085		0.996970	0.016324	0.001478
	Logarithmic	0.014908		1.005029	0.011159	0.997247	0.014531	0.001140
70	Lewis	0.018581				0.997279	0.019219	0.002368
	Page	0.018652	0.999086			0.997263	0.019219	0.002368
	Modified Page	0.030481	0.609613			0.997279	0.019219	0.002368
	Henderson & Pabis	0.018631		1.002896		0.997364	0.019203	0.002362
	Logarithmic	0.020023		0.987656	0.021956	0.998479	1.20E-08	0.000652

Table 4: Model fitting results for FP pretreated with $K_2S_2O_5$+Blaching and dried at different temperatures

Temperature °C	Model	Model constants				Statistical parameters		
		k	***n***	***a***	***c***	***R^2***	***RMSE***	***X^2***
40	Lewis	0.009282				0.995081	0.020362	0.002122
	Page	0.004974	1.128123			0.997911	0.014583	0.001110
	Modified Page	0.021542	0.430849			0.995081	0.020362	0.002122
	Henderson & Pabis	0.009521		1.027317		0.995323	0.019007	0.001839
	Logarithmic	0.009615		1.025666	0.003097	0.995343	0.018914	0.001811
50	Lewis	0.013576				0.994300	0.021591	0.002809
	Page	0.006044	1.179676			0.998195	0.013326	0.001097
	Modified Page	0.026054	0.521081			0.994300	0.021591	0.002809
	Henderson & Pabis	0.013874		1.024512		0.994403	0.020590	0.002537
	Logarithmic	0.013874		1.024512	0.000000	0.994403	0.020590	0.002537
60	Lewis	0.017707				0.997982	0.017031	0.001675
	Page	0.018947	0.984037			0.997743	0.016964	0.001656
	Modified Page	0.029755	0.595100			0.997982	0.017031	0.001675
	Henderson & Pabis	0.017728		1.001264		0.998017	0.017028	0.001673
	Logarithmic	0.019019		0.986937	0.021254	0.999046	0.008516	0.000396
70	Lewis	0.024662				0.999395	0.010832	0.000736
	Page	0.034456	0.916202			0.999427	0.008053	0.000400
	Modified Page	0.024661	1.000021			0.999395	0.010832	0.000736
	Henderson & Pabis	0.024549		0.994850		0.999326	0.010725	0.000723
	Logarithmic	0.834266		0.909945	0.090055	0.794537	0.127891	0.098600

4.3 Moisture content and water activity characteristics of dried FP slices

As shown in Table 5, FP samples pretreated with $K_2S_2O_5$+Blanching and dried at 70 °C had the lowest moisture content of 5.22 ± 0.26 (w.b) and were significantly different ($p < 0.05$) from the other treatments. However, samples pretreated with $K_2S_2O_5$+Blanching was not the lowest in terms of water activity. The highest moisture content value of 9.89 ± 0.43 (w.b) was recorded in samples pretreated with blanching and dried at 40 °C, and these samples varied significantly ($p < 0.05$) from the other treatments. Blanched FP samples also recorded high moisture content at all the temperature levels, except at 60 °C. The high moisture content observed in the blanched samples could be due to gelatinization of starch (Dandamrongrak et al., 2003). This restricts the rate of moisture movement from inside the material to the surface during drying. It was also observed that samples pretreated with $K_2S_2O_5$ and $K_2S_2O_5$+Blanching were not significantly different ($p > 0.05$) in moisture content at 40, 50, and 60 °C.

Water activity (a_w) values of dried FP samples ranged from 0.23±0.01 to 0.63 ± 0.01 (Table 5). The range of values reported in this study is slightly lower than a_w values reported in a study by Apuri et al. (2018) for different varieties of dried FP. The lowest a_w value of 0.23 ± 0.01 was observed on control samples dried at 70 °C, and was significantly different ($p < 0.05$) from all the other treatments. According to Rahman (2010), these samples with a_w value of 0.23 are more likely to be less susceptible to destruction by yeast, and molds,

and more likely to have reduced enzymatic activity in storage than all the other treatments. A reduced enzymatic activity contributes significantly to a longer shelf-life since enzymatic activities lead to changes in nutritional value, colour, and flavor of produce (Molnar, 2009). Samples treated with blanching and dried at 40 °C recorded the highest a_w value, and differred significantly ($p < 0.05$) from all other treatments. These samples with a_w value of 0.63 are more likely to be susceptible to yeast and molds (Rahman, 2010). The high a_w in samples treated with blanching and dried at 40 °C may be attributed to the low drying air temperature used. The formation of a sticky surface on FP slices as a result of blanching and drying at 40 °C, which created a hard surface during drying, could also be attributed to the high a_w in samples.

Table 5: Effect of pretreatment and drying air temperature on final moisture content and water activity of dried FP slices

Temperature (ºC)	Pretreatment	Final Moisture content (% w.b)	Final water activity (aw)
40	Control	5.63 ± 0.43^{ab}	0.53 ± 0.01^{c}
	$K_2S_2O_5$	9.39 ± 0.05^{fg}	0.53 ± 0.01^{c}
	Blanching	9.89 ± 0.43^{g}	0.63 ± 0.01^{b}
	$K_2S_2O_5$+Blanching	9.01 ± 0.31^{fg}	0.49 ± 0.01^{cde}
50	Control	7.64 ± 0.10^{de}	0.43 ± 0.01^{g}
	$K_2S_2O_5$	7.11 ± 0.58^{cd}	0.43 ± 0.01^{g}
	Blanching	8.33 ± 0.33^{ef}	0.52 ± 0.01^{cd}
	$K_2S_2O_5$+Blanching	6.84 ± 0.24^{cd}	0.48 ± 0.01^{def}
60	Control	6.71 ± 0.20^{bcd}	0.34 ± 0.03^{i}
	$K_2S_2O_5$	6.19 ± 0.95^{abc}	0.38 ± 0.01^{h}
	Blanching	6.42 ± 0.24^{bc}	0.47 ± 0.01^{ef}
	$K_2S_2O_5$+Blanching	6.29 ± 0.08^{abc}	0.46 ± 0.01^{fg}
70	Control	5.59 ± 0.14^{ab}	0.23 ± 0.01^{j}
	$K_2S_2O_5$	6.27 ± 0.37^{abc}	0.34 ± 0.00^{i}
	Blanching	6.58 ± 0.31^{bcd}	0.46 ± 0.01^{fg}
	$K_2S_2O_5$+Blanching	5.22 ± 0.26^{a}	0.46 ± 0.01^{fg}

Values are expressed as means ± standard deviation. Values that have different superscripts are significantly different at ($p < 0.05$).

4.3 Effect on colour characteristics

Table 6 shows the effect of pretreatment and drying air temperature on colour characteristics of FP slices. Colour attribute (L^*, a^*, and b^*) values for fresh untreated FP samples were 54.10±0.29, 2.99±0.11 and 17.24±0.04,

respectively. *L** values ranged from 40.65±0.22 to 53.81±0.23 for control, 56.57±0.21 to 64.52±0.12 for samples treated with $K_2S_2O_5$, 38.18±0.29 to 50.36±0.36 for samples treated with blanching, and 43.41±0.18 to 56.93±0.25 for samples treated with $K_2S_2O_5$+Blanching at the temperature range of 40 to 70 °C. It was observed that samples treated with $K_2S_2O_5$ produced higher *L** values than samples treated with blanching, $K_2S_2O_5$+Blanching, and control samples at all temperature levels (from 40 to 70 °C). The highest *L** value was recorded in samples treated with $K_2S_2O_5$ and dried at 60 °C, and this varied significantly ($p < 0.05$) from all the other treatments, except for samples treated with $K_2S_2O_5$ and dried at 70 °C. The high values of *L** recorded in samples treated with $K_2S_2O_5$ could be attributed to the effectiveness of $K_2S_2O_5$ in preventing both enzymatic and non-enzymatic browning (Deng et al., 2017). The *a** range was 2.84±0.15 to 4.06±0.03 for control samples, 0.75±0.09 to 2.55±0.09 for samples treated with $K_2S_2O_5$, 0.63±0.12 to 1.91±0.07 for samples treated with blanching, and 0.74±0.10 to 1.68±0.05 for samples treated with $K_2S_2O_5$+Blanching at the temperature range of 40 – 70 °C. Generally, *a** values were higher in the control samples across temperature levels, and this may be due to the browning of the fresh FP tubers after peeling and slicing without any pretreatment. On the other hand, samples treated with blanching generally recorded lower values of *a**, and this may be due to the effectiveness of blanching pretreatment at reducing the browning of FP tubers after peeling and slicing. The *b** range was 12.08±0.09 to 15.34±0.06 for control, 19.04±0.21 to 23.93±0.12 for $K_2S_2O_5$, 17.94±0.17 to 21.01±0.25 for blanching and

20.64±0.08 to 27.67±0.08 for $K_2S_2O_5$+Blanching at a temperature range of 40 – 70 °C. Comparatively, *b** values were higher in samples pretreated with $K_2S_2O_5$+Blanching than the other pretreatments for all the temperature levels except for 60 °C. The results revealed that both pretreatment and drying temperature affected *L**, *a**, and *b** values of dried FP slices significantly ($p < 0.05$). The findings of this study are similar to those reported by Junqueira et al. (2017) in cape gooseberry colour behaviour.

Hue values for dried FP samples ranged from 72.68±0.84 to 78.76±0.64 for control, 83.82±0.12 to 87.93±0.25 for $K_2S_2O_5$, 84.62±0.21 to 88.00±0.32 for blanching, and 85.36±0.11 to 88.48±0.21 for $K_2S_2O_5$+Blanching. Hue angle (*h**) which can be interpreted as 0 ° = red and 90 ° = yellow, was greatest in samples treated with $K_2S_2O_5$+Blanching and dried at 70 °C, and varied significantly ($p < 0.05$) from all the other samples. Comparatively, at all temperature levels, except for 60 °C, samples treated with $K_2S_2O_5$+Blanching gave higher hue values compared to other pretreatments. The high hue values in samples treated with $K_2S_2O_5$+Blanching and dried at 70 °C means that these samples were much yellow compared to other treatments, which may be attributed to FP slices turning yellow after blanching. Chroma (*C**) is the saturation or vividness of colour. Samples treated with $K_2S_2O_5$+Blanching and dried at 70 °C recorded higher *C** value of 27.68±0.08 and varied significantly ($p < 0.05$) from all the other treated samples. Also, there was an increase in *C** values when drying temperature increased from 40 °C to 60 °C for all control

samples (Table 6). This pattern of results disagree with findings reported by Karabulut et al. (2007b) for dried apricots.

Browning index (*BI*) was highest in samples treated with blanching and dried at 50 °C, while the least *BI* was observed in samples treated with $K_2S_2O_5$ and dried at 70 °C. *BI* which describes the pure nature of brown colour, and for products known to undergo enzymatic and non-enzymatic browning during processing, it is an important colour parameter (Maskan, 2001; Lu et al., 2007). This means that samples treated with blanching and dried at 50 °C changed from 41.18 to 77.21 when compared to the fresh sample and hence produced more brown compounds. This was however not statistically different ($p > 0.05$) in *BI* from samples treated with $K_2S_2O_5$+Blanching and dried at 40 °C.

Whiteness index (*WI*) is used to measure how close a surface matches the properties of a white surface that neither absorbs nor transmits light. There was generally an increase in *WI* in samples treated with $K_2S_2O_5$ at all temperature levels when compared to the fresh FP sample, and *WI* was highest in samples treated with $K_2S_2O_5$ and dried at 70 °C. This means that samples treated with $K_2S_2O_5$ and dried at 70 °C were whiter than all the other samples. This is due to the effectiveness of $K_2S_2O_5$ in suppressing enzymatic browning of the sliced samples (Koffi et al. 1991), hence helping improve the whiteness of slices. Apart from samples pretreated with $K_2S_2O_5$, drying temperature (40 to 70 °C) caused a decrease in *WI* in all treated samples, except for control samples that were dried at 70 °C when compared to the fresh untreated samples. The results

suggest that pretreatment by dipping in $K_2S_2O_5$ is most effective in retaining the whiteness of FP tubers when compared to the other pretreatment methods studied.

Table 6: Effect of pretreatment and drying air temperature on colour characteristics of dried FP slices

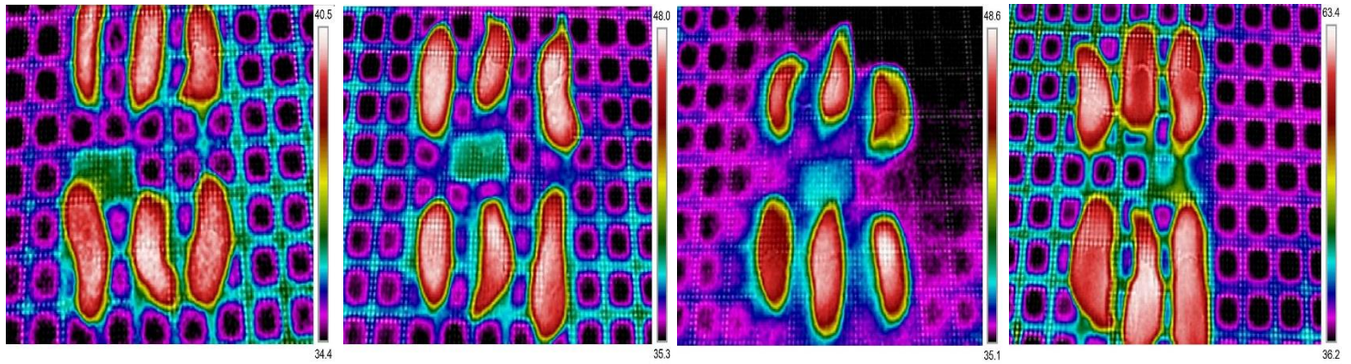
		*L**	*a**	*b**	*h**	*C**	*BI*	*WI*
Fresh FP		54.10 ± 0.29^{d}	2.99 ± 0.11^{b}	17.24 ± 0.04^{i}	80.15 ± 0.35^{g}	17.50 ± 0.04^{h}	41.18 ± 0.45^{g}	50.88 ± 0.28^{d}
Dried FP								
Drying Temperature (oC)	**Pretreatment**							
40	Control	40.65 ± 0.22^{k}	3.77 ± 0.17^{a}	12.08 ± 0.09^{m}	72.68 ± 0.84^{k}	12.66 ± 0.04^{k}	40.99 ± 0.25^{g}	39.32 ± 0.22^{j}
	$K_2S_2O_5$	56.57 ± 0.21^{c}	0.75 ± 0.09^{gh}	20.63 ± 0.24^{ef}	87.93 ± 0.25^{ab}	20.65 ± 0.24^{ef}	42.52 ± 0.86^{fg}	51.92 ± 0.29^{c}
	Blanching	41.87 ± 0.11^{j}	0.63 ± 0.12^{h}	17.94 ± 0.17^{h}	88.00 ± 0.38^{ab}	17.95 ± 0.17^{h}	52.22 ± 0.54^{d}	39.16 ± 0.14^{j}
	$K_2S_2O_5$+Blanching	47.37 ± 0.05^{h}	0.90 ± 0.18^{gh}	26.80 ± 0.28^{b}	88.09 ± 0.37^{ab}	26.81 ± 0.29^{b}	76.37 ± 0.96^{a}	40.93 ± 0.18^{i}
50	Control	49.18 ± 0.30^{f}	2.97 ± 0.07^{b}	12.71 ± 0.09^{l}	76.85 ± 0.25^{i}	13.05 ± 0.09^{k}	33.39 ± 0.39^{i}	47.53 ± 0.28^{f}
	$K_2S_2O_5$	62.95 ± 0.16^{b}	2.34 ± 0.07^{d}	21.59 ± 0.22^{d}	83.82 ± 0.12^{f}	21.72 ± 0.22^{d}	37.45 ± 0.46^{h}	57.05 ± 0.21^{b}
	Blanching	38.18 ± 0.29^{l}	1.06 ± 0.16^{fg}	21.01 ± 0.25^{e}	87.10 ± 0.47^{bc}	21.04 ± 0.24^{e}	77.21 ± 1.75^{a}	34.70 ± 0.34^{k}
	$K_2S_2O_5$+Blanching	50.61 ± 0.24^{e}	1.06 ± 0.15^{fg}	21.98 ± 0.24^{d}	87.24 ± 0.35^{bc}	22.00 ± 0.25^{d}	52.68 ± 0.77^{d}	45.93 ± 0.27^{gh}
60	Control	48.14 ± 0.08^{g}	4.06 ± 0.03^{a}	15.34 ± 0.06^{j}	75.16 ± 0.17^{j}	15.87 ± 0.05^{i}	43.38 ± 0.09^{ef}	45.76 ± 0.66^{h}
	$K_2S_2O_5$	64.52 ± 0.12^{a}	2.55 ± 0.09^{cd}	23.93 ± 0.12^{c}	83.93 ± 0.18^{f}	24.06 ± 0.13^{c}	41.33 ± 0.25^{g}	57.13 ± 0.17^{b}
	Blanching	50.36 ± 0.36^{e}	0.98 ± 0.09^{fg}	19.41 ± 0.06^{g}	87.11 ± 0.25^{bc}	19.44 ± 0.06^{g}	45.14 ± 0.44^{e}	46.69 ± 0.32^{g}
	$K_2S_2O_5$+Blanching	43.41 ± 0.18^{i}	1.68 ± 0.05^{e}	20.64 ± 0.08^{ef}	85.36 ± 0.11^{de}	20.71 ± 0.08^{ef}	58.12 ± 0.40^{c}	39.74 ± 0.17^{j}
70	Control	53.81 ± 0.23^{d}	2.84 ± 0.15^{bc}	14.29 ± 0.10^{k}	78.76 ± 0.64^{h}	14.57 ± 0.07^{j}	33.76 ± 0.15^{i}	51.57 ± 0.19^{cd}
	$K_2S_2O_5$	64.26 ± 0.37^{a}	1.28 ± 0.06^{f}	19.04 ± 0.21^{g}	86.14 ± 0.23^{cd}	19.08 ± 0.21^{g}	32.30 ± 0.74^{i}	59.49 ± 0.43^{a}
	Blanching	43.22 ± 0.25^{i}	1.91 ± 0.07^{e}	20.23 ± 0.07^{f}	84.62 ± 0.21^{ef}	20.32 ± 0.07^{f}	56.42 ± 0.47^{c}	39.70 ± 0.24^{j}
	$K_2S_2O_5$+Blanching	56.93 ± 0.25^{c}	0.74 ± 0.10^{gh}	27.67 ± 0.08^{a}	88.48 ± 0.21^{a}	27.68 ± 0.08^{a}	62.06 ± 0.27^{b}	48.80 ± 0.18^{e}

Values are means of three replicates. Values in the same column which have different superscript letters are significantly different at ($p < 0.05$). *BI* = Browning index; *WI* = Whiteness index

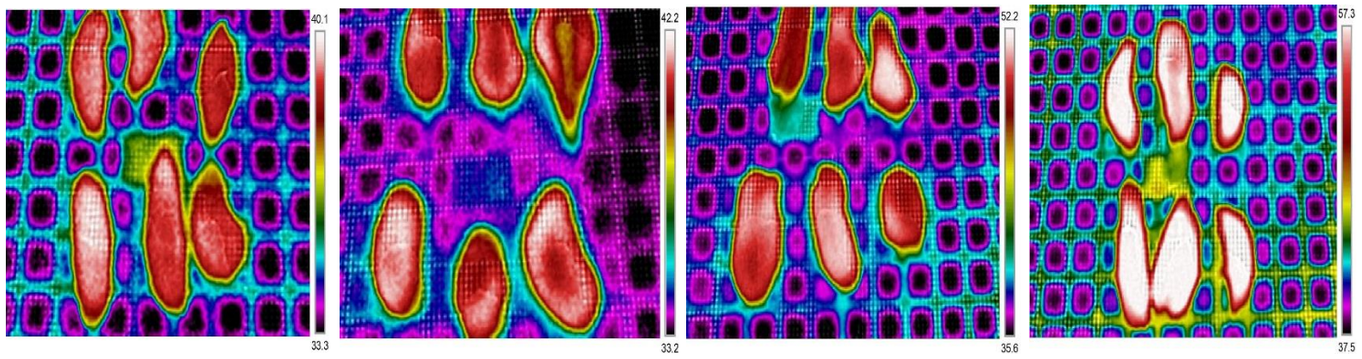
4.4 Effect on surface temperature distribution

Thermal images showing the surface temperature distribution of FP slices are presented in Figure 10A–P. Pretreatment, drying air temperature and the interaction of both factors significantly ($p < 0.05$) influenced the degree of non-uniformity of dried FP slices. The degree of non-uniformity was calculated as the difference between the maximal and minimal surface temperature captured with the aid of a thermal camera shown in Figure 7. The degree of non-uniformity for all treatments ranged from 2.28±0.6 °C to 15.32±4.13 °C as shown in Table 7. For samples pretreated with $K_2S_2O_5$ and dried at 70 °C, the average maximal and minimal surface temperature was 58.46 °C and 43.14 °C, respectively and resulted in the highest non-uniformity value of 15.32 °C among all the treatments. This was significantly ($p < 0.05$) different from the other treatments. According to Wei et al. (2018), high non-uniformity values could be caused by high drying air temperature, leading to overheating and charring. Control samples dried at 40 °C had the least non-uniformity value of 2.28±0.6 °C, with average maximal and minimal surface temperature of 39.84 °C and 37.56 °C respectively. A low non-uniformity value of 2.28 °C means that there was no overheating, and heating was relatively uniform during drying compared to the other treatments. The low non-uniformity value observed in control samples dried at 40 °C could be because of the low drying air temperature used. Generally, non-uniformity values in this study are relatively lower than non-uniformity values reported in a previous study by Wei et al.

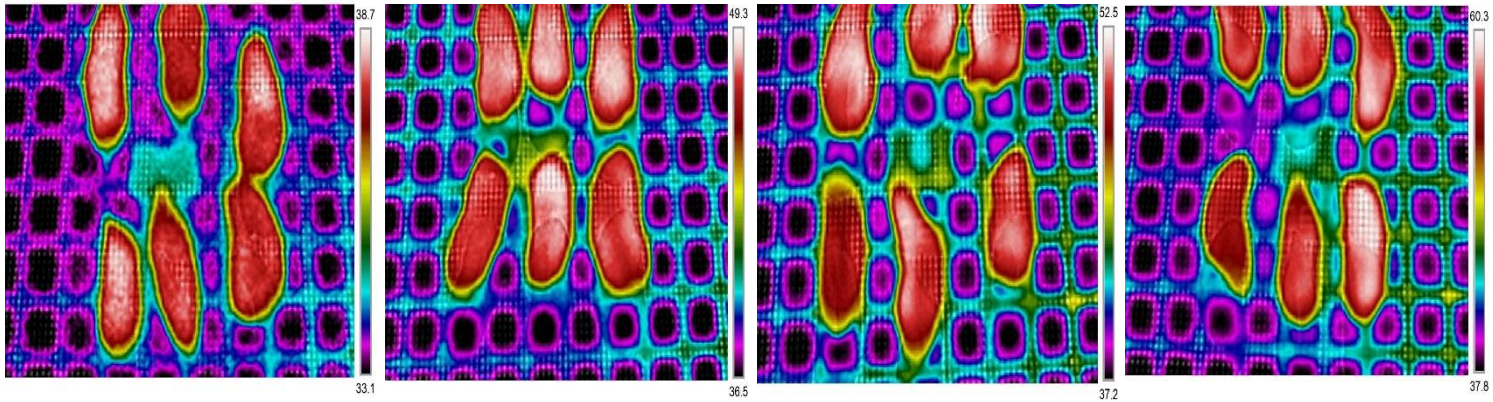
(2018), and therefore suggest that the hot-air drying temperatures used in this study are not likely to result in charring of FP slices.



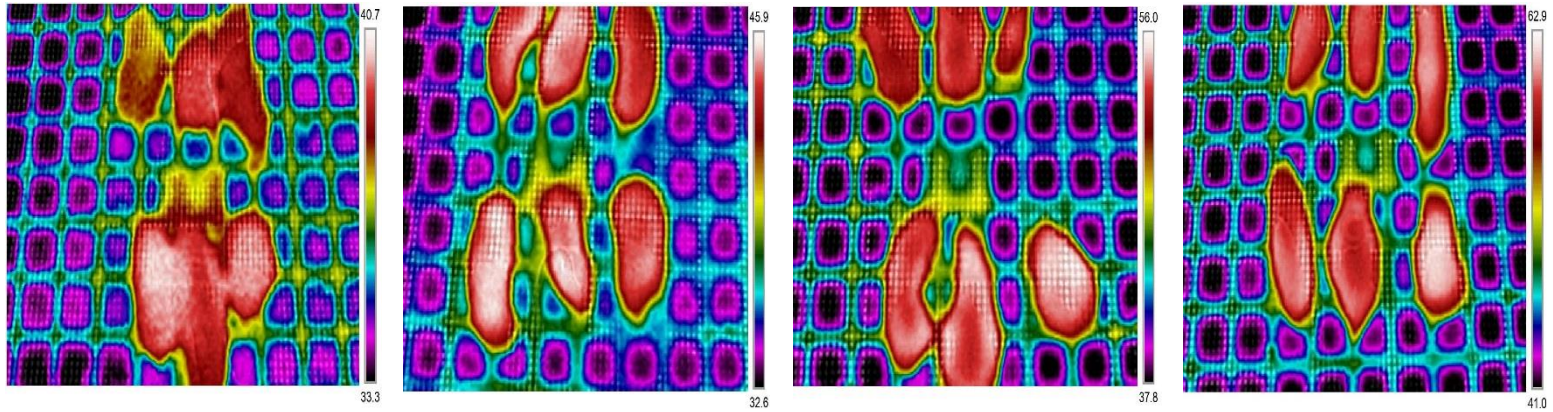
A: 40 °C_Control **B**: 50 °C_Control **C**: 60 °C_Control **D**: 70 °C_Control



E: 40 °C_Blanching **F**: 50 °C_Blanching **G**: 60 °C_Blanching **H**: 70 °C_Blanching



I: 40 °C_$K_2S_2O_5$ **J**: 50 °C_$K_2S_2O_5$ **K**: 60 °C_$K_2S_2O_5$ **L**: 70 °C_$K_2S_2O_5$



M: 40 °C_$K_2S_2O_5$+Blanching **N**: 50 °C_$K_2S_2O_5$+Blanching **O**: 60 °C_$K_2S_2O_5$+Blanching **P**: 70 °C_K_2SO_5+Blanching

Figure 10A–P: Thermal images of FP slices at end of drying for different pretreatments and drying air temperatures.

Table 7: Effect of pretreatment and drying temperature on surface temperature distribution of dried FP slices.

Treatment	Surface Temp (°C)	R_1	R_2	R_3	R_4	R_5	Mean	Deg. of non-uniformity (°C)
40 °C _ Control	Max	40.0	40.2	39.8	39.6	39.6	39.84	2.28 ± 0.67^{g}
	Min	37.1	39.0	37.7	37.1	36.9	37.56	
	Average	39.5	40.0	39.3	39.1	39.1	39.40	
50 °C _ Control	Max	47.4	46.8	48.4	47.0	46.3	47.18	6.26 ± 0.65^{bcdefg}
	Min	40.9	41.3	42.7	40.5	39.2	40.92	
	Average	36.3	46.3	47.8	45.1	44.6	44.02	
60 °C _ Control	Max	48.5	49.2	52.1	47.5	48.5	49.16	9.48 ± 0.83^{bc}
	Min	39.8	38.5	42.5	38.8	38.8	39.68	
	Average	46.4	45.4	48.1	46.3	43.6	45.96	
70 °C _ Control	Max	61.6	58.8	63.5	57.1	60.7	60.34	8.04 ± 1.62^{bcde}
	Min	52.8	48.5	57.5	49.8	52.9	52.30	
	Average	59.6	55.7	62.1	55.2	59.1	58.34	
40 °C _ Blanching	Max	39.9	39.8	39.0	39.3	38.4	39.28	2.64 ± 1.28^{fg}
	Min	35.7	37.1	38.3	36.1	36.0	36.64	
	Average	39.1	39.2	38.7	38.6	38.1	38.74	
50 °C _ Blanching	Max	41.8	42.8	43.4	41.9	40.4	42.06	5.20 ± 1.23^{cdefg}
	Min	35.5	39.0	36.9	36.6	36.3	36.86	
	Average	40.9	41.6	41.9	41.1	39.9	41.08	
60 °C _ Blanching	Max	51.3	51.0	52.8	49.7	50.4	51.04	7.74 ± 2.16^{bcdef}
	Min	40.9	45.0	47.7	41.3	41.6	43.30	
	Average	50.1	50.0	51.6	47.2	49.0	49.58	
70 °C _ Blanching	Max	59.0	58.8	62.5	54.7	58.3	58.66	9.08 ± 0.73^{bcd}
	Min	48.8	50.5	53.4	46.1	49.1	49.58	
	Average	57.9	57.8	61.0	52.8	56.7	57.24	
40 °C _ $K_2S_2O_5$	Max	38.4	38.5	38.4	38.2	38.0	38.30	3.70 ± 1.19^{efg}
	Min	35.5	34.0	33.7	36.2	33.6	34.60	
	Average	38.0	36.6	36.4	37.3	35.6	36.78	
50 °C _ $K_2S_2O_5$	Max	48.6	48.0	48.9	46.6	46.9	47.80	9.88 ± 2.44^{bc}
	Min	39.1	41.8	36.6	37.1	35.0	37.92	
	Average	46.2	45.9	43.9	43.6	41.7	44.26	
60 °C _ $K_2S_2O_5$	Max	51.6	51.0	54.1	49.9	52.3	51.78	11.22 ± 2.79^{ab}
	Min	39.0	38.6	39.8	42.6	42.8	40.56	
	Average	47.6	46.0	48.9	47.5	48.2	47.64	
70 °C _ $K_2S_2O_5$	Max	58.9	57.9	62.3	56.0	57.2	58.46	15.32 ± 4.13^{a}
	Min	43.3	39.4	42.2	45.6	45.2	43.14	
	Average	53.7	51.1	55.4	51.3	52.6	52.82	

40°C_$K_2S_2O_5$+Blanching	Max	39.6	39.4	39.9	39.9	39.1	39.58	3.76±1.35^{defg}
	Min	34.8	37.7	36.1	34.8	35.7	35.82	
	Average	37.7	39.0	38.5	38.1	37.5	38.16	
50°C_$K_2S_2O_5$+Blanching	Max	43.9	43.2	44.8	45.3	45.8	44.60	9.70±1.51^{bc}
	Min	34.3	35.4	33.0	34.9	36.9	34.90	
	Average	38.6	39.6	39.2	42.7	41.9	40.40	
60°C_$K_2S_2O_5$+Blanching	Max	60.2	60.8	62.0	57.1	55.3	59.08	10.98±5.31^{ab}
	Min	42.1	53.7	54.8	49.9	40.0	48.10	
	Average	53.4	59.4	60.5	55.1	48.8	55.44	
70°C_$K_2S_2O_5$+Blanching	Max	50.6	53.5	54.9	52.4	51.4	52.56	11.20±3.58^{ab}
	Min	43.8	40.8	46.7	37.0	38.5	41.36	
	Average	49.3	51.2	53.7	46.3	48.5	49.80	

Values are expressed as means ± standard deviation (n = 5). Values that have different superscripts are significantly different (at $p < 0.05$). R_1 to R_5 represent five replicates.

4.5 Effect on bioactive compounds content

Table 8 shows the effect of pretreatment and drying air temperature on total antioxidant activity, total phenolic content, flavonoid content, vitamin C, and beta-carotene contents of FP samples. The total antioxidant activity (TAA) of fresh samples was 67.82 mg/100 g. Generally, dried samples had higher TAA than fresh samples (Table 8). This suggests that, regardless of the pretreatment method, drying of FP slices from 40 °C – 70 °C will trigger an increase in antioxidant activity. According to Madrau et al. (2009), this increase in TAA could be due to increased antioxidant power of polyphenols as a result of drying. Similar results of increased antioxidant activity in dried products have been reported for coffee (Sanchez-Gonzalez et al., 2005), dried plums (Piga et al., 2003), apricots (Ihns et al., 2011) and for mango seed kernel (Soong and Barlow, 2004). The highest value of

antioxidant activity was observed in samples pretreated with $K_2S_2O_5$ and dried at 40 °C (40 °C_$K_2S_2O_5$), and this varied significantly ($p < 0.05$) from all the other treatments. The least antioxidant activity was observed in samples dried at 60 °C without any pretreatment (60 °C_Control), but this was not statistically different ($p > 0.05$) from samples dried at 40 °C without any pretreatment (40 °C_Control). The results in Table 8 further show that both pretreatment and drying air temperature significantly ($p < 0.05$) influenced antioxidant activity of dried FP, but not in any particular order.

Table 8: Effect of drying temperature and pretreatment on bioactive compounds content of dried FP slices

		TAA (mg/100g)	TPC (mg/100g)	Flavonoid (mg/100g)	Vitamin C (mg/100g)	β-carotene (µg/100g)
Fresh FP		67.82 ± 1.38^{j}	104.64±5.18^{a}	28.50±1.32^{b}	36.88±1.54^{d}	990.00±55.68^{a}
Dried FP						
Temp. (ºC)	**Pretreatment**					
40	Control	77.33±5.81^{ij}	32.52±1.39^{gh}	17.82±1.20^{c}	139.38±0.90^{a}	173.33±11.55^{fgh}
	$K_2S_2O_5$	188.27±3.52^{a}	62.82±3.18^{c}	39.64±2.40^{a}	59.71±7.75^{c}	686.67±32.15^{b}
	Blanching	100.16±7.21^{fg}	29.64±2.40^{h}	4.79±0.70^{d}	120.46±1.46^{b}	213.33±5.77^{def}
	$K_2S_2O_5$+Blanching	96.96±3.39^{gh}	43.58±1.72^{e}	1.91±0.79^{d}	17.05±2.04^{e}	190.00±10.00^{fgh}
50	Control	85.01±3.52^{hi}	34.49±1.15^{fgh}	20.55±3.55^{c}	113.71±1.23^{b}	380.00±10.00^{c}
	$K_2S_2O_5$	115.09±1.33^{de}	63.88±2.50^{c}	19.18±2.76^{c}	23.13±1.52^{e}	246.67±15.28^{de}
	Blanching	131.95±1.96^{c}	40.39±3.03^{ef}	6.45±0.91^{d}	134.80±2.02^{a}	203.33±5.77^{defg}
	$K_2S_2O_5$+Blanching	111.68 ±5.00^{def}	34.79±0.70^{fgh}	1.00±0.45^{d}	21.21±2.47^{e}	153.33±5.77^{gh}
60	Control	72.43±4.26^{ij}	32.82±1.98^{fgh}	16.00±0.91^{c}	141.71±4.14^{a}	136.67±5.77^{hi}
	$K_2S_2O_5$	120.21±5.81^{cd}	73.88±3.87^{b}	30.09±5.91^{b}	63.21±4.38^{c}	200.00±10.00^{efg}
	Blanching	105.71±6.41^{efg}	32.21±1.39^{gh}	1.91±1.36^{d}	141.88±1.15^{a}	173.33±5.77^{fgh}
	$K_2S_2O_5$+Blanching	81.60±5.08^{i}	44.18±1.37^{e}	4.79±3.78^{d}	24.30±1.38^{e}	160.00±10.00^{fgh}
70	Control	101.65±2.89^{fg}	38.12±2.50^{efg}	32.36±4.38^{ab}	23.55±1.51^{e}	256.67±15.28^{d}
	$K_2S_2O_5$	166.29±2.25^{b}	76.00±2.36^{b}	19.79±1.60^{c}	35.46±1.66^{d}	433.33±15.28^{c}
	Blanching	94.83±2.96^{gh}	34.49±1.60^{fgh}	6.76±1.60^{d}	121.55±4.45^{b}	383.33±15.28^{c}
	$K_2S_2O_5$+Blanching	102.93±3.91^{efg}	52.52±1.89^{d}	2.52±0.53^{d}	25.55±1.04^{e}	96.67±5.77^{i}

Values are expressed as means ± standard deviation (n = 3). Values in the same column that have different superscripts are significantly different at ($p < 0.05$). Note: TAA and TPC represent Total antioxidant activity and Total phenolic content respectively.

The TPC of fresh FP samples was 104.64 mg/100 g. After drying at temperatures of 40 – 70 °C, the TPC of FP samples ranged from 29.64 – 76.00 mg/100 g. Comparing the dried FP samples to the fresh FP samples, it was observed that drying at 40 – 70 °C led to a reduction of 27.4 % – 71.7 % in TPC. Similar results of reduced levels of TPC have been reported in potato and sweet potato flour (Ahmed et al., 2010; Hesam et al., 2012; Koala et al., 2013). According to Rajha et al. (2014), the reduction in TPC levels in the dried samples could be attributed to excess drying after the product has reached a constant weight, and further suggest that drying should be halted immediately when it is observed that the product has reached a constant weight to avoid degradation of polyphenols. This suggestion however contradicts reports that drying leads to an increase in total phenolic content as reported by Ruenroengklin et al. (2008) for Litchi Fruit; Madrau et al. (2009) for apricots; and Candrawinata et al. (2014) for apple pomace. This contradiction could be due to differences in genetic composition, sample treatment, processing method, and extraction condition (Huang et al., 2006; Hamouz et al., 2007). The results in Table 8 further showed that both pretreatment and drying air temperature significantly influenced ($p < 0.05$) TPC of dried FP samples. It was also observed that samples pretreated with $K_2S_2O_5$ were higher ($p < 0.05$) in TPC at all drying temperature levels (40 – 70 °C) than samples pretreated with blanching, $K_2S_2O_5$+blanching, and control. This suggests that pretreatment by dipping in $K_2S_2O_5$ for temperatures ranging from 40 °C – 70 °C is more effective in retaining TPC in FP samples. At all drying air temperature levels,

except 50 °C, pretreatment by blanching produced the least desirable TPC. This generally suggests that pretreatment by blanching may not be ideal in retaining TPC in FP during processing.

The flavonoid content of fresh FP samples was 28.50 mg/100 g. After subjecting FP samples to various pretreatment and drying temperature, flavonoid content ranged from 1.00 – 39.64 mg/100 g. Generally, dried samples had lower flavonoid content when compared to the fresh samples. Among all treated samples, the most desirable flavonoid content was observed in samples pretreated by dipping in $K_2S_2O_5$ and dried at 40 °C, and the least desirable flavonoid content was recorded in $K_2S_2O_5$+Blanching and dried at 50 °C. Flavonoid content reported in this study is generally lower than what has been reported by Chikpah et al. (2020), indicating that dried FP may contain lower flavonoid content when compared to orange flesh sweet potato flour. The level of flavonoids recorded in this study is also lower than what has been previously reported by Garba et al. (2015) for black carrot pretreated with hot water blanching, citric acid, $K_2S_2O_5$, and calcium chloride. However, the results in Table 8 also show that samples pretreated with blanching and a combination of $K_2S_2O_5$+blanching did not differ significantly ($p > 0.05$) from each other in flavonoid content at all the temperature levels studied.

The concentration of Vitamin C was affected ($p < 0.05$) by both pretreatment and drying temperature (Table 8). Vitamin C content of fresh samples was 36.88 mg/100g. However, after subjecting samples to varied pretreatment and

drying temperature, the concentration of Vitamin C ranged from 17.05 – 141.88 mg/100g. Pretreatment caused either an increase or degradation of Vitamin C when compared to the fresh samples. Vitamin C is reported to be heat sensitive, water-soluble, and susceptible to degradation under the influence of factors including temperature and enzymes (Garba & Kaur, 2014). From the results in Table 8, it was observed that drying at 60 °C generally produced higher Vitamin C relative to the other temperature levels, and this can be attributed to short exposure of samples to heat. Drying at 70 °C yielded lower levels of Vitamin C, and this could be because drying at a higher temperature will degrade the vitamin C even though its exposure time to the heat was shorter (Tajudin et al., 2019). Higher drying air temperatures lead to quick oxidation of Vitamin C, hence resulting in its loss (Gregory, 1996). Similar results of Vitamin C degradation at higher temperatures have been reported by Ashaye (2013) for dried roselle calyces, Latiff et al. (2020) for *Cosmos caudatus*, and Lin et al. (1998) for carrot slices. FP samples pretreated with blanching yielded the most desirable Vitamin C content at all temperature levels, except at 40 °C. Similar findings of higher Vitamin C content in blanched samples were reported by Garba and Kaur (2014) during pretreatment and drying of black carrots. FP samples pretreated with blanching and dried at 60 °C recorded the highest content of Vitamin C, but was not significantly different ($p > 0.05$) from samples that were pretreated using blanching and dried at 50 °C, and control samples dried at 40 °C and 60 °C. Samples pretreated with $K_2S_2O_5$+Blanching and dried at 40 ^oC recorded the least content of Vitamin C. Nindo et al. (2003)

reported that low drying temperature might led to more Vitamin C degradation. This is because low-temperature drying will take a longer time to inhibit the activities of enzymes causing degradation of Vitamin C (Sehrawat et al., 2018).

Beta-carotene content of dried FP samples was affected ($p < 0.05$) by both pretreatment and drying temperature (Table 8). Beta-carotene content of the fresh samples was 990.00±5.68 µg/100 g and varied significantly ($p < 0.05$) from all treated samples. The results reveal that pretreatment and drying air temperature caused degradation of beta-carotene content when compared to the fresh FP sample (Table 8). Pretreatment and drying air temperature resulted in a 90.24 % to 69.36 % reduction in beta-carotene content when compared to the fresh samples. Similar results of loss in beta-carotene have been reported by Chen et al. (2007) during hot air drying of Taiwanese mango. Samples treated with $K_2S_2O_5$ and dried at 40 °C yielded the most desirable beta-carotene content and differed significantly ($p < 0.05$) from all the other treated samples. Pretreatment using sulfite has been reported to enhance retention of beta-carotene in potato and apricot (Krokida et al., 2000; Mir et al., 2009). The least beta-carotene content was observed in samples treated with $K_2S_2O_5$+Blanching and dried at 70 °C, and this varied significantly ($p < 0.05$) from the other treatments.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The effect of different pretreatments (Blanching, dipping in $K_2S_2O_5$, dipping in $K_2S_2O_5$+Blanching) and drying air temperatures (40, 50, 60, and 70 °C) on the drying uniformity, drying kinetics and quality attributes of FP slices was investigated. Drying of FP slices occured in the falling rate period, and this indicates that drying was governed by diffusion. Generally, the best drying model that fits the drying behavior of FP slices was the Page model and Logarithmic model, and there was a decrease in moisture ratio with an increase in drying air temperature. Pretreatment and drying air temperature significantly ($p < 0.05$) affected the final water activity and moisture content of FP samples, and drying caused a reduction in water activity. FP samples pretreated with blanching were generally higher in final moisture content and water activity. Pretreatment by dipping in $K_2S_2O_5$ produced higher L^* values and higher *WI* values in dried FP samples at all temperature levels than pretreatment by blanching, dipping in $K_2S_2O_5$+blanching, and control. Hence where colour of the final product is of paramount interest, pretreatment by dipping in $K_2S_2O_5$ solution can be considered. The surface uniformity of FP slices during drying was affected significantly ($p < 0.05$) by pretreatment and drying air temperature, and the degree of non-uniformity generally increased as drying temperature was increased. Hence to decrease non-uniformity during drying of FP slices, drying should be done at a low temperature close to 40 °C. Bioactive

compounds content of FP was affected significantly ($p < 0.05$) by pretreatment and drying temperature. Dried samples were higher in antioxidant activity than fresh samples, and pretreatment by dipping in $K_2S_2O_5$ generally produced desirable antioxidant values at all temperature levels. Fresh samples were higher in phenols and beta-carotene than dried FP samples, and pretreatment by dipping in $K_2S_2O_5$ and drying at 60 °C is recommended for best retention of beta-carotene in dried samples. Where vitamin C is of paramount interest to the processor, pretreatment with blanching and drying at 60 °C is recommended. The findings show that pretreatment and drying air temperature used in this study had mixed effect on the quality of dried FP slices, and therefore a compromise has to be made on which processing condition is suitable depending on the quality attribute(s) of major interest to the processor.

5.2 Recommendations

- For optimum retention of quality of dried FP, pretreatment by dipping in potassium metabisulfite ($K_2S_2O_5$) combined with drying at 70 °C is recommended.
- Where beta-carotene is of paramount interest to the processor, pretreatment by dipping in $K_2S_2O_5$ combined with drying at 40 °C is recommended.
- Where $K_2S_2O_5$ as a pretreatment substance is unavailable, FP should be dried without pretreatment.

- Further research should be conducted to assess the potential of using FP flour as ingredient for food processing.

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