UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF GELATIN ADDITION AND HOT-AIR TEMPERATURE ON THE DRYING BEHAVIOUR AND QUALITY ATTRIBUTES OF SHEA (*Vitellaria paradoxa)* FRUIT LEATHER

YVONNE NYAME

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BY

YVONNE NYAME
(B.Sc. Agricultural Technology)
(UDS/MPHT/0003/21)

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MARCH, 2025

DECLARATION

Student

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

Candidate:

Signature: Date: 25th March, 2025

Name: **Yvonne Nyame**

Supervisor

I hereby declare that the preparation and presentation of the dissertation was supervised following the guidelines on supervision of dissertation laid down by the University for Development Studies.

Signature: Date: 25th March, 2025

Name: **Prof. Joseph Kudadam Korese**

ABSTRACT

Shea (*Vitellaria paradoxa)* fruit is a widely available wild fruit known for its nutritional and health benefits. However, its seasonal nature and high perishability limit its consumption. This study explored the effects of adding gelatin and using different drying air temperatures (50 °C and 60 °C) on the drying process, energy use, colour, bioactive and sensory properties of shea fruit leather. The findings indicated that gelatin had a positive influence on drying efficiency, while drying air temperature significantly ($p<0.05$) influenced the drying time. The Midilli et al. model was the best fit in describing the drying process of the shea fruit leather. Moisture diffusivity increased from $3.91 \times 10^{-12} – 2.76 \times 10^{-11}$ m^2/s for both 50 and 60 °C, while activation energy varied between 13.20 and 87.71 kJ/mol. The energy consumption also decreased as the drying air temperature was increased from 50 °C to 60 °C. The different drying air temperatures and gelatin additions significantly ($p < 0.05$) influenced the colour parameters of the shea fruit leather. The overall colour change (ΔE^*) significantly ($p < 0.05$) increased as drying air temperature increased and decreased as gelatin levels increased. Drying the shea fruit leather at a lower temperature (50 °C) was found to reduce total carotenoid contents, while the highest retention of total flavonoid, total phenolics and total antioxidant contents was observed at 60 °C. Overall liking scores ranged from 5.77 to 6.27 at 50 °C and from 5.80 to 6.27 at 60 °C, with mid-range gelatin levels being generally preferred.

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DEDICATION

I dedicate this work to my late mother Mrs Mercy Achiaa Nyame.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The lives of rural inhabitants are significantly dependent on native fruit trees from both semi-wild and wild. In Ghana, the shea (*Vitellaria paradoxa,* C.F. Gaertn) is one of these fruit trees belonging to the Sapotaceae family. It occupies nearly 1 million km^2 across 21 African countries, mostly in marginally dry and slightly humid savannas of sub-Saharan regions (Naughton *et al.*, 2015). According to Ojo *et al*. (2021), shea is a slow-growing tree that starts bearing fruit after about 10 to 15 years, reaching its peak fruit production at 20 to 30 years of age. A single tree may live for 200–300 years (Karambiri *et al*., 2017). The shea fruit has an oval shape and consists of a soft delicate outer skin (epicarp), a flesh (mesocarp), and a nut-like inner layer (endocarp) (Honfo *et al*., 2014; Korese and Chikpah, 2023). Both humans and animals eat the outer skin and flesh of the shea fruit, which account for approximately 60-80% of the fruit's entire weight (Akoma *et al.*, 2018; Donkor *et al*., 2021; Gyedu-Akoto *et al*., 2017; Iddrisu *et al*., 2020).

Shea fruits are typically gathered and processed mainly for its nuts or kernels, leading to the production of large volumes of pulp (outer skin and flesh) that are often discarded as waste or, at best, used as animal feed with minimal additional benefit (Gyedu-Akoto *et al*., 2017). The pulp of the fruit is an excellent source of phenolic compounds, flavonoids, amino acids, and vitamins B and C, as well as a few carbohydrates (sucrose, glucose, and fructose) and minerals (Akoma *et al.*, 2018; Gyedu-Akoto *et al*., 2017; Maranz *et al*., 2004). Studies have shown that these phytochemical substances may be used to make nutraceutical goods and functional foods by adding them to food as food additives, excipients for pharmaceutical products, or parts of pharmaceutical formulations or food matrices (Jiménez-Moreno *et al*., 2020; Ueda *et al*., 2022; Uleria *et al*., 2020).

Today's consumer preference is shifting towards wholesome snacks made from fresh fruits (Gujral *et al*., 2013). One frequent fruit product produced all throughout the world, including North America, South America, Africa, and Asia, is fruit leather (Juthong *et al*., 2019; Offia-Olua and Ekwunife, 2015). Due to its richness in vitamins, antioxidants, and fruit fiber, fruit leather is typically considered to be nutritious and a healthy choice (Concha-Meyer *et al*., 2016; Huang and Hsieh, 2005). Fruit leathers are fruit rolls which are chewy and dehydrated constructions resembling sheets that are eaten as fruit snacks (Diamante *et al*., 2013; Diamante *et al*., 2014). It is often an ingredient of pastries, morning cereal, and biscuits (Offia-Olua and Ekwunife, 2015). Fruit leather preservation relies on moisture content, which should be between 15% and 25% (Ndlovu, 2016), after drying to reduce moisture and prevent bacterial and enzyme activity thus, extending the product's shelf life (Addai *et al*., 2016).

Fruit leather's physical and nutritional qualities are greatly influenced by the preparation method (Diamante *et al*., 2014). The procedure of making fruit leather typically consists of two steps: puree preparation and drying. The edible parts of the shea fruit are separated from the nut. The peel and pulp are then blended to obtain a puree. In order to deactivate the enzymes and lower the amount of microbial contamination, purees often need to be cooked (Fulchand *et al*., 2015; Kumar *et al*., 2005). The second and most important stage in the process of making leather is drying the fruit puree. Fruit leathers are created by taking the moisture out of a flat tray of wet puree until the texture becomes cohesive and leathery. In several procedures, insufficient drying might result in permanent damage to the product's quality, making it unacceptable for sale. Fruit leathers however, have extended shelf life and are inexpensive to ship since they are light and low in moisture

(Diamante *et al.*, 2014). Also, they are pleasant to chew and tasty, hence, becoming an attractive way of incorporating fruits in our daily diet, especially, for children and adolescents (Ruiz *et al.*, 2012). As a result, creating fruit leather from fresh fruit is a useful method of fruit preservation (Maskan *et al.*, 2002).

1.2 Problem Statement and Justification

Vitellaria paradoxa, is an economically significant tree that thrives in sub-Saharan Africa's savannah areas and yields the edible and nutritious shea fruit (Chakravarty *et al.*, 2016; Donkor *et al.*, 2021; Hatskevich *et al.*, 2011; Honfo *et al.*, 2014; Maranz *et al*., 2004). Anthraquinones, alkaloid compounds, saponins, glycosides, carotenoids, polyphenols (Korese and Chikpah, 2023) and dietary fibre (Donkor *et al.*, 2021) are all found in significant amounts in shea fruit (Akoma *et al*., 2018). Total phenolic and flavonoid levels of the shea fruit varied from 231.33 - 381.67 mg GAE/100 g and 20.70 - 30.95 mg QE/100 g, respectively (Lamien-Meda *et al.*, 2008). In addition, Honfo *et al.* (2014), reported that shea fruit included 191.1 mg/100 g d.b. of vitamin C and 7.0 mg/100 g d.b. of vitamin B. Also, the shea fruit pulp possesses the required macro and microminerals (Akoma *et al*., 2018; Donkor *et al*., 2021; Korese and Chikpah, 2023; Maranz *et al*., 2004) and a significant sugar content of 74.60 ± 4.22 mg/g (Gyedu-Akoto *et al*., 2017).

Shea fruits, despite their potential, are exceedingly perishable and require postharvest preservation techniques. Drying is one of the preservation strategies (Dinrifo, 2012; Doymaz, 2007; Korese and Achaglinkame, 2024; Raponi *et al*., 2017). The process of drying entails reducing biologically effective moisture content to a concentration that hinders microbial activity and deteriorative chemical processes, hence extending the dried product's shelf life (Amit *et al*., 2017). Drying, not only drastically lowers weight and volume but also lowers packaging, preservation and distribution expenses (Doymaz, 2007). Convective hot-air cabinet dryer is a popular, common and validated drying apparatus with extensive temperature ranges that are essential to maintaining product quality. Convective hot air drying process has been shown to offer several advantages, including improved removal of surface water, minimal operating costs, and the production of hygienic dried products with a prolonged shelf life (El-Mesery *et al*., 2023; Korese and Achaglinkame, 2024; Miraei Ashtiani *et al*., 2018).

Hydrocolloids such as gelatin are generally used in food formulations to improve quality attributes and shelf life (Patil *et al*., 2017). Hydrocolloids are commonly employed as thickening or gelling agents (Al-Hinai *et al*., 2013). As thickening agents, they find uses in a variety of dishes, including soups, gravies, salad dressings, sauces, and toppings. Additionally, they serve as gelling agents in products such as jam, jelly, marmalade, restructured meals, and gels with reduced sugar or calories (Patil *et al*., 2017). Hydrocolloids have been used as thickening agents that can bind water molecules thereby enhancing the desired textural properties of food products (Rascón-Díaz *et al*., 2012). The incorporation of hydrocolloids into fruit leathers helps to maintain the desirable texture of the fruit leathers.

A thorough review of literature found that shea fruit has not been utilized in the development of fruit leather. Given this research gap, this study aims to develop shea fruit leather using gelatin which is a hydrocolloid as a binding agent and explore the effect of different gelatin levels and drying air temperature on the drying kinetics, colour, water activity, final moisture content, energy consumption, antioxidant, bioactive components, and sensory aspects of the shea fruit leather. It is anticipated that if the pulp of shea fruit is collected and processed into food products such as fruit leather, processors and rural women who usually pick the fruits in the wild can earn additional revenue and decrease the amount of bio waste discarded. This will also offer a viable alternative to fresh fruits, ensuring the availability of shea fruits even when they are out of season.

1.3 Main Objective

The main objective of this work is to study the effect of different gelatin levels and drying air temperatures on the drying kinetics, energy consumption and the quality of shea fruit leather.

1.3.1 Specific Objectives

The specific objectives of the proposed study are:

1. To investigate the effect of different gelatin levels and drying air temperatures on the drying behaviour and corresponding energy consumption of shea fruit leather.
2. To evaluate the effect of different gelatin levels and drying air temperatures on quality attributes of shea fruit leather.
3. To assess sensory characteristics of shea fruit leather produced at different gelatin levels and drying air temperatures.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution of the Shea Tree

The shea tree (Figure 2.1), is a fruit tree belonging to the Sapotaceae family. Its scientific name is *Vitellaria paradoxa* C.F.Gaertn. Currently, two subspecies have been classified (Gwali *et al.*, 2014). While *V. paradoxa* subsp. nilotica is commonly found in East Africa (Byakagaba *et al.*, 2011; Okiror *et al.*, 2012; Okullo *et al.*, 2004), *V. paradoxa* subsp. paradoxa is located in West and Central Africa (Fontaine *et al.*, 2004; Kelly *et al.*, 2004; Nyarko *et al.*, 2012; Sanou *et al.*, 2005), in a band of Sudanic vegetation that extends south of the Sahel (Aremu *et al.*, 2019; Byakagaba *et al.*, 2011; Okullo *et al.*, 2004). Shea trees are distributed from Senegal to Uganda, occurring at latitudes of 2° to 8° north in East Africa, 7° to 12° north in Central Africa, and 9° to 14° north in West Africa (Naughton *et al.*, 2015). It can live for over 200 years, grow up to 20 meters tall, and have a diameter at breast height (DBH) of 1 meter (Cardi *et al.*, 2005; Kelly *et al.*, 2004).

Figure 2. 1: Shea Tree

2.2 Nutritional Composition of Shea Fruit

Shea fruits (Figure 2.2) have significant nutritional and dietary value across its range (Di Vincenzo *et al*., 2005; Maranz *et al.*, 2004; Maranz and Weisman, 2003). Shea fruit pulp's varying nutritional content has been reported by many researchers using various estimate techniques. The fruit is high in protein building blocks and inorganic nutrients (Akoma *et al.*, 2018; Gyedu-Akoto *et al.*, 2017; Maranz *et al*., 2004). In line with Maanikuu and Peker (2017) and Ugese *et al.(*2008) reports, the moisture level in the dried shea fruit pulp can range from 8.8% to 72.4%. Seasonality, storage techniques, and processing all contribute to variations in moisture content.

The shea tree fruit contains additional nutrients, such as calcium and iron (Maranz *et al.*, 2004; Okullo *et al.*, 2010). As a result, it is a necessary local fruit to raise the standard of living for people in its growing areas (Kalinganire *et al.*, 2008). Reports have indicated that the crude protein content varies between 15.2 g/100 g dw (Alu and Randa, 2019) and 3.5 g/100 g dw (Aguzue *et al*., 2013). The crude fiber content is 42.2 g/100 g dw and the crude lipid content is 4.2 g/100 g dw (Maanikuu and Peker, 2017; Ugese *et al.*, 2008).

Figure 2. 2: Shea fruits

2.3 Fruits and the Production of Fruit Leathers

Fruit leathers are fruit-flavoured treats made by blending acid, sugar, and high methoxyl pectin to create a gel-like texture. They are available in pliable sheets and can be enjoyed as either candies or snacks. Fruit leathers are chewy, delectable, lightweight, and easy to carry around, making them attractive to customers (Ruiz *et al*., 2012). It is also a convenient and economical substitute for fresh fruit, providing a range of vital nutrients, including fiber, carbohydrates, and minerals. Fruit leathers are a practical method for boosting fruit solids intake.

Valenzuela and Aguilera (2015) developed apple fruit leather and explored various factors influencing stickiness. Various studies also focused on the production of leathers from apple (Demarchi *et al*., 2013; Ruiz *et al*., 2012; Torres *et al.*, 2015; Valenzuela and Aguilera, 2013) while da Silva Simão *et al.* (2019) and Gujral *et al.* (2013) conducted a study on mango leather. Durian leather (Wandi and Man, 1996), Grape leather (Maskan *et al*., 2002), Guava leather (Kumar *et al*., 2005), Pumpkin leather (Karabacak *et al*., 2021), Mulberry leather (Suna and Özkan-Karabacak, 2019), Hawthorn leather (Eyiz *et al*., 2020), and Strawberry leather (Cichella Frabetti *et al*., 2021) are all researches which have been conducted. Apple is the preferred choice for fruit leather production due to its high pectin levels (0.15-0.25 kg/kg of dry matter). Similarly, mango is a well-researched and popular fruit worldwide, appreciated for its vibrant colour, delicious taste, and nutritional value (da Silva Simão *et al*., 2019; Moreira *et al*., 2006).

In addition to expanding the types of fruits that can be consumed, the creation of fruit leathers offers an alternate method for fruit preservation and value addition (Concha-Meyer *et al*., 2016). Fruit leather is valuable because it transforms fruit waste, which would otherwise be thrown away and contribute to help curb environmental issues and turning them into useful products. Producing fruit leather also increases the value of fruits for use in food and other industrial uses and lessens waste disposal problems (Ravani and Joshi, 2013).

Heat treatment which is a requirement in the first step of fruit leather production is essential to inactivate enzymes and also reduce enzymatic browning (Villamiel *et al*., 2006). Additionally, as the heat treatment breaks down the cellular substance in the fruit, it often softens its texture and lowers microbial contamination, which includes moulds, yeasts, and harmful microbes (Heaton and Jones, 2008). Basumatary et al. (2020), reported on the effect of heat treatment on both sensory and textural attributes of fruit leathers made from wild olive. The study revealed that, heat treatment generally softens the peel of the fruit, limits microbial contamination while compromising on the nutrients of the fruit.

Including ingredients in the process of developing fruit leather is necessary as it plays a huge role on the quality of the fruit leather produced as reported by Patil et al. (2017). Fruit pulp contains organic acids, sugars, and other compounds with tiny molecular weights. As a result, fruit peels have a tendency to stick to a variety of surfaces (Valenzuela and Aguilera, 2015).

2.4 Effect of Hydrocolloid Inclusion on Fruit Leather Quality

Hydrocolloids consist of complex carbohydrates which form gel when mixed with water. They are extensively used in producing fruit leather to promote its consistency and prolong the product's longevity. A variety of hydrocolloids, including gelatin, agar, pectin, and carrageenan, can be used in the process of making fruit leather. It has been discovered that adding hydrocolloids such as carboxymethyl cellulose, pectin, guar gum, gum acacia, and sodium alginate enhances the extensibility and texture of fruit leather (Gujral and Brar, 2003). Including hydrocolloids in the process of developing fruit leather is necessary as it plays a huge role on the quality of the fruit leather produced as reported by Patil et al. (2017). As noted by Gómez-Pérez *et al*. (2020), the addition of hydrocolloids can also have an effect on the fruit leather's drying kinetics, affecting its mass diffusion coefficient and drying time. The kind and quantity of hydrocolloids used can have an enormous effect on the fruit leather's colour and texture. Overall, as noted by Mphaphuli *et al*. (2020), hydrocolloids are essential for enhancing the feel and durability of fruit leather, making it a more wholesome and practical substitute for sweets and confections.

Fruit leathers also undergo the Maillard reaction and ascorbic acid oxidation, which can be detrimental to the fruit leathers nutritional value and sensory qualities. As a result, introducing browning inhibitors may be a beneficial step. Fruit leather browning during production and storage may be lessened by adding citric acid, sulfite, and maqui berry extract. In papaya (Addai *et al*., 2016), apple (Ruiz *et al*., 2012; Torres *et al*., 2015) and quince (Torres *et al*., 2015) leathers, this additive has been successful in reducing the browning kinetics.

2.5 Processing Methods of Fruit Leather

Fruit pulp dehydration preserves the natural flavour of fruit generally as well as reducing expenses in packing, reduce weight and prolong durability (Gujral and Khanna, 2002). Due to chemical and biological properties, variations in the product's colour, feel and taste may arise throughout the drying process. To achieve a final moisture content of 12 – 20%, fruit leathers are typically dried at temperatures between 30-80 °C for 24 hours (Demarchi *et al.*, 2013). However, the amount of water in dried foods can still range from 2 - 30%, depending on the kind of food product.

2.5.1 Hot Air Drying Technique

Despite the fact that it necessitates high temperatures and lengthy drying times, convective hot air drying, is an easy, affordable, and frequently utilized drying method in the food processing industry (Karam *et al.,* 2016). Drying times of fruit leathers are influenced by leather's thickness (0.2–13 mm), air temperature (45–121 °C), relative humidity (3.5–50%), and air velocity (0.55–

7.4 m/s). Karam *et al*. (2016) states that one of the essential parameters influencing the end product's quality is the drying air temperature. Elevated temperatures cause drying rates to rise, but they also lower fruit leather quality (Quintero Ruiz *et al*., 2014; Tontul and Topuz, 2017; Yılmaz *et al*., 2017).

2.6 Quality Evaluation of Fruit Leathers

2.6.1 Physicochemical Features

Fruit leather often has a low pH, low moisture content, and moderate water activity, which leads to strong microbiological stability over time (Torres *et al.*, 2015). The key ingredient that affects how long food items last on the shelf is water activity. According to Barbosa-Cánovas *et al*. (2007), it symbolizes the energy status of water in food and its suitability as a solvent for microbiological, enzymatic, nonenzymatic, and chemical processes. The water activity of various fruit leathers reported in literature varies between 0.31 and 0.71, depending on the formulations and drying methods (da Silva Simão *et al*., 2020). Pathogenic bacteria are prevented from growing within this range because they are unable to do so below water activity of 0.85–0.86 (Rahman, 2007).

2.6.2 Bioactive Compounds

Fruit colour, taste, and aromatic qualities are all influenced by bioactive chemicals, which are abundant in fruits and have positive impact on the health of humans (Septembre-Malaterre *et al*., 2018). The phytochemicals found in fruit leathers that have been studied the most are phenolic compounds (Addai *et al*., 2016; Chen and Martynenko, 2018; Concha-Meyer *et al*., 2016; Quintero Ruiz *et al*., 2014; Sharma *et al*., 2016; Tontul and Topuz, 2017; Torres *et al*., 2015; Yılmaz *et al*., 2017). The bioactive ingredients in fruit leather, however, could deteriorate during production and storage. The rate at which phenolic compounds degrade (from 10.9 to 83.3%) is often greatly influenced by the drying process conditions (Tontul and Topuz, 2017). It was shown that the breakdown of bioactive components were less in these methods.

The antioxidant activity is used to determine if fruit leather may be called a functional food. Fruit leathers have been found to have lower antioxidant activity than fruit purees, according to several studies (Concha-Meyer *et al.*, 2016; Quintero Ruiz *et al.*, 2014; Torres *et al.*, 2015). Pregelatinized starch in pomegranate leather (Tontul and Topuz, 2018) and maqui berry extract in apple and quince leather (Torres *et al*., 2015) are two substances that have been shown to boost the antioxidant activity of fruit leathers**.**

2.7 Colour Changes in Fruit Leather during Drying

Food colour is a crucial qualitative characteristic that affects consumer preferences and decisions. Due to perceived benefits, some customers have a preference for certain food products because of their colour. It is possible to evaluate sensory qualities like flavour and nutritional (pigmented) substances indirectly by using food colour, since it has been demonstrated to have a strong association with certain quality criteria including sensory and nutritional attributes (Pathare *et al.*, 2013). Nonetheless, fruits and food items in general are subject to colour changes when exposed to various elements, including light, air, chemicals, and heat (Swain *et al*., 2014).Often measurable colour factors include a* (-a*=green, +a*=red), b* (-b*=blue, +b*=yellow), and L* (0=dark and 100=light). They are frequently measured directly with colourimetric apparatus. Nonetheless, additional derived colour parameters can be acquired by means of computational techniques that employ the main colour attributes (L*, a*, and b*). These include hue angle, h* (h*=0^{o} or 360^{o} implies red, 90^{o} =yellow, 180^{o} =green, and 270^{o} =blue), colour intensity or saturation (chroma, C*), and total colour change (ΔE*). Hue is the angular representation of 14 visual appearance, whereas chroma is related to the colour's intensity.

When a food material is heated or chemically treated, all the characteristics of the substance alter, either little or considerably. Food product's colour characteristics are primarily determined by the amount or presence of pigmented chemicals (Swain *et al*., 2014). For example, the colour characteristics of an unripe banana are different from those of its ripe counterpart because of variations in the pigment components. Research has shown that food reduces brightness or lightness when temperature rises owing to burning or charring caused by the corresponding increase in heat (Ali *et al*., 2016; Stępień *et al*., 2019). Due to the presence of amino acids and sugars, higher temperatures at the other end of the temperature range stimulate non-enzymatic browning processes such caramelization and the Maillard reaction.

Previous research (Argyropoulos and Müller, 2014; Swain *et al*., 2014; Korese and Achaglinkame, 2024; Korese and Chikpah, 2023) have tracked how changes in colour attributes occur over time during processing, such as drying. The majority of literature have concentrated on the colour changes in fruits and vegetables before and after different processing procedures. The latter is the goal of the current investigation.

2.8 Sensory Properties of Fruit Leathers

A sensory analysis is a step in the creation of new products. It allows connections to be made between the formulation, storage, and processing factors of a product and the responses of consumers. This information can then be used to determine a product's potential for marketing (Giacalone, 2018). The standard method used to assess fruit leather's sensory qualities is acceptability testing, in which customers rate how much they like or dislike the product (Addai *et al*., 2016; Azeredo *et al*., 2006; Concha-Meyer *et al*., 2016; Gujral and Khanna, 2002; Huang and Hsieh, 2005; Torres *et al*., 2015).The acceptability of the product is affected by the fruit employed to make fruit leather. Due to the intense sourness of quince leather, Torres *et al*. (2015) the quince leather's overall acceptability was lower than that of apple leather. Conversely, Concha-Meyer *et al*. (2016) found that while the acceptance of strawberry and kiwi leather was generally excellent, untrained panelists favoured the strawberry leather because of its colour, strong scent, and sweet flavour. The acceptance of the product is also influenced by the inclusion of components. According to Torres *et al*. (2015), the hue of apple leather was the primary factor resulting in the lower acceptance of the product when untrained judges were used.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Location

This study was conducted at the Postharvest Technology Laboratory located at the Engineering and Mechanization Workshop, University for Development Studies (UDS), Nyankpala (9° 25' 0''N, 0° 59' 0'' W). All laboratory analysis were done in the laboratory mentioned above.

3.2 Source of Sample and Preparation

Freshly ripped shea fruits utilized in this research were collected from the wild in Daboya, situated in the North Gonja District of the Savanna region in Ghana. The fruits were transported to the laboratory in jute sacks in the early hours of the day of collection to avoid deterioration caused by high temperatures. Fresh and healthy shea fruits were selected based on visual evaluation ensuring homogeneity, and absence of mechanical damage or diseases and washed in tap water. The epicarp and mesocarp of the shea fruits were then removed manually from the nuts using a stainless knife. The pulp and peel were then blended using Kenwood blender (BL400A, Kenwood Ltd, India) to obtain a puree. The total soluble solid of the shea fruit puree was 4.952 ± 0.0061 °Brix with a pH of 2.1. The puree of the fruits were stored in a refrigerator at 4 °C in sealed low-density polyethylene (LDPE) bags until utilisation for the experiments.

3.3 Shea Fruit Leather Preparation

Prior to the experiments, the puree was retrieved from the refrigerator and thawed at room temperature (25±1 °C) for 2 hours and sieved with a 500-micron sieve (SO3310-1, Controls, Milano- Italy). The puree was then cooked with a Master Chef Rice Cooker (MC – RC – 32, Master Chef, UK) for about 15 minutes (Suna, 2019) with continuous stirring. On cooling, gelatin was added to the shea fruit puree at levels of 0, 1, 2, 3, and 4% respectively. The levels of gelatin used were based on pre-trials. Each percentage of gelatin measured was first mixed with a small amount of the puree to form a paste to avoid formation of lumps and disperse uniformly the gelatin (Gujral and Brar, 2003; Raj and Dash, 2022). The paste was then added to the puree and thoroughly mixed. Each formulation was prepared by mixing the puree and gelatin for 2 min using a Kenwood hand mixer (HM330, Kenwood Ltd, China) (Cichella Frabetti *et al*., 2021).

3.5. Drying Procedure

3.5.1 Convective Hot Air Drying

Hot air drying experiments were conducted using a table top Hohenheim HT mini" cabinet dryer (Innotech-ingenieursgesellschaft mbH, Altdorf, Germany) (Figure 3.1), containing six perforated trays. The dryer has a fan for air circulation and an exhaust flap at the back of the dryer that opens and closes to release exhaust air and attain maximum heating, respectively. Heating power is provided by a 1.5-3 kW heater that is connected to a thermostat for automatic switching on and off. Drying was performed at drying air temperatures of 50 and 60 °C. Prior to the start of the experiment, the dryer was allowed to run for 30 minutes to obtain steady-state conditions. Then about 100 g of shea fruit puree mixed with each level of gelatin was placed in stainless steel drying tray (0.154 m x 0.124 m) covered with mesh and adjusted to 3 mm thickness (Moradi *et al*., 2019). The aluminum tray was lined with baking paper to avoid the sticking of the shea fruit leather after drying. The drying tray and shea puree were weighed at 30 minutes intervals for the first 2 hours of drying and then after every 1 hour (Gujral *et al*., 2013) till the moisture content of the puree was about 18 - 22% wet basis (w.b.)(Fulchand *et al*., 2015). The shea fruit leather obtained was allowed to cool under room temperature (25±1 °C) and then packaged in low-density polyethylene (LDPE) bags for further quality analysis.

Figure 3. 1: Table top Hohenheim HT mini" cabinet dryer

3.6 Drying Kinetics for Shea Fruit Leather

The moisture ratio (MR) and drying rate (DR) of the shea fruit leather were calculated using Eq. 1 and Eq. 2. (Akgun and Doymaz, 2005; Perez and Schmalko, 2009).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad \text{(Eq. 1)}$$

$$DR = \frac{M_{t+dt} - M_t}{dt} \qquad \text{(Eq. 2)}$$

Where M_t is the dry basis moisture content (g water/ g dry mass) at time t, M_0 is the initial moisture content (g water/ g dry mass), M_e is the equilibrium moisture content (g water/ g dry mass), M_{t+dt} is moisture content at time t + dt (d.b.), dt is the small increase in time t (min). According to Wang et al. (2007) the value of M_e is relatively small compared to M_t or M_0. Therefore, M_e was set to zero.

Six thin-layer drying models (Table 3.1) were fitted using the experimental drying data. Nonlinear regression analysis was utilized to ascertain the model coefficients, while regression statistics, namely the coefficient of determination (R^2), reduced Chi-square (χ^2), absolute percentage error (PE) and root mean square error (RMSE), were employed to assess the models' goodness of fit (Sadeghi *et al.*, 2019).

Table 3. 1: Selected thin-layer drying models

No.	Model name	Model	Reference
1	Lewis	MR = exp (-kt)	(Doymaz *et al.*, 2016)
2	Page	MR = exp ($-kt^n$)	(Sadeghi *et al.*, 2019b)
3	Henderson & Pabis	MR = a exp (-kt)	(Henderson & Pabis, 1961)
4	Midilli et al.	$MR = a\ exp(-kt^{\ n}) + bt$	(Midilli *et al.*, 2002)
5	Logarithmic	MR = a exp (-kt) + c	(Chayjan *et al.*, 2014)
6	Diffusion approach	MR = a exp(-kt) + (1-a) exp(-kbt)	(Yaldiz & Ertekin, 2001)

a, b, c, k, and n are drying model constants and t is the drying time in min.

3.6.1 Determination of Effective Moisture Diffusivity and Activation Energy

When drying occurs at a decreasing rate and diffusion becomes the primary physical mechanism controlling moisture movement, the term "effective moisture diffusivity" (D_{eff}) is employed to determine the movement of water internally in food materials (Delfya *et al.*, 2022; Sadeghi *et al.*, 2019). The D_{eff} value of the shea fruit leather was calculated using Fick's second law of diffusion, which is represented in Eq. 3 (Aidani *et al.*, 2017). This calculation was predicated on the assumptions of uniform initial moisture distribution, minimal shrinkage, and constant temperature and moisture diffusivity.

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \quad \text{(Eq. 3)}$$

Where n, D_{eff}, t and L stand for the integer value n, effective moisture diffusivity (m^2/s), drying time in seconds (s), and sample's half-thickness measured in meters (m) respectively.

According to Doymaz *et al*. (2016), Eq. 3 can be reduced to Eq. 4 for extended drying.

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad \text{(Eq. 4)}$$

Additionally, Eq. 4 can be further modified into a linear natural logarithmic expression, as shown in Eq. 5. A plot of the natural logarithm of the experimental MR data (lnMR) as a function of drying time (t) expressed in seconds was generated. D_{eff} value was then determined from the slope of lnMR versus t (s) as shown in Eq. 5 and Eq. 6 (Aidani *et al*., 2017; Delfya *et al*., 2022).

$$m = \frac{\pi^2 D_{eff}}{4L^2} \quad \text{(Eq. 5)}$$

$$D_{eff} = \frac{4mL^2}{\pi^2} \quad \text{(Eq. 6)}$$

The drying behaviour of food material is influenced by the bonding potential of moisture. In drying of food materials, activation energy, that represents the bonding potential of moisture, is termed as the amount of energy needed to transfer one mole of moisture from the interior to the surface (Doymaz, 2017). The effect of the temperature on the D_{eff} is described by an Arrhenius equation shown in Eq. 7 (Singh and Gupta, 2007; Wen *et al*., 2021).

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{R(T+273.15)}\right) \quad \text{(Eq. 7)}$$

Where D_0 represents the pre-exponential factor in the Arrhenius equation (m^2s^{-1}), E_a is the activation energy ($kJmol^{-1}$), R is the ideal gas constant ($kJmol^{-1} K^{-1}$) and T is the drying temperature (°C).

By plotting ln(D_{eff}) against the reciprocal of the temperature (1/T+273.15), E_a was calculated by multiplying the ideal gas constant by the slope (m_1) of the graph as shown in Eq. 8.

$$m_1 = -\frac{E_a}{R} \quad \text{(Eq. 8)}$$

3.7 Energy Consumption Measurement

The energy consumption for HAD of shea fruit leather was measured using a digital energy meter (D52-2066 DIN-Rail Multi-Functional Meter, Huabang, China). The energy consumption (kWh/kg) for drying was calculated by dividing the energy consumed in kWh (E_c) by the sample mass in kg (m_s), as presented in Eq. 9 (Hssaini *et al*., 2021; Torki-Harchegani *et al*., 2016).

$$SEC = \frac{E_c}{m_s} \qquad \text{(Eq. 9)}$$

3.8 Characterization of Shea Fruit Leather

The quality parameters of the shea fruit leathers were characterized according to the procedure outline in section Water Activity, Colour, Bioactive Compounds and Antioxidant Activity.

3.8.1 Determination of Water Activity

Water activity of the shea fruit leather was measured with the help of a LabSwift-aw water activity meter (Novasina AG, CH-8853 Lachen, Switzerland) (Figure 3.2) at room temperature (25±1 °C). Measurement of water activity were replicated twice for each sample and the mean values reported.

Figure 3. 2: Water activity meter

3.8.2 Measurement of Colour

The CIELAB colour parameters of the shea fruit puree and the shea fruit leather were determined using a colorimeter (CR-400 Minolta Konica Inc. Marunouchi, Japan). The measurement procedures of colour are described in a previous study by Korese *et al.* (2021). Before the experiment, the colour instrument was calibrated with a standard white plate at D65 illumination (Y = 80.1, x = 0.3219, y = 0.3394). Colour measurements were taken in quintuplicate and averaged. The colour saturation (C*), hue angle (H°), and overall colour change (ΔE) were calculated from L*, a*, and b* values using Eqs. 10 to 12, respectively (Jha and Sit, 2020; Ramallo and Mascheroni, 2012; Yemiş *et al*., 2012).

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad \text{(Eq. 10)}$$

$$H^\circ = tan^{-1}\left({b^*}/{a^*}\right) \quad \text{(Eq. 11)}$$

$$\Delta E = \sqrt{(L_0^* - L_t^*)^2 + (a_0^* - a_t^*)^2 + (b_0^* - b_t^*)^2} \quad \text{(Eq. 12)}$$

Where L^*, a^* and b^*, which represent lightness, redness, and yellowness respectively are the colour parameters of the fresh shea fruit puree before drying and the colour parameters of shea fruit leather after drying.

3.8.3 Measurement of Bioactive Compounds and Antioxidant Activity

In this current investigation, the total concentrations of carotenoids, phenolics, flavonoids and antioxidant activity in the shea fruit puree and shea fruit leather were determined in triplicates.

3.8.3.1 Determination of Total Carotenoid Content

The methodology for assessing the total carotenoid content (TCC) in the shea fruit leather samples followed the procedures outlined by Chikpah *et al*. (2023). Firstly, 5 g of ground shea fruit leather and 5g fresh shea fruit puree samples were placed in a 50 mL tube separately, secured in an aluminum foil. Next, about 25 mL of an extraction solvent composed of a mixture of hexane, acetone, and ethanol in a 2:1:1 ratio was added. The mixture was stirred for 5 minutes and cooled in a refrigerator at 4 °C until the sample whitened, which typically took about 1 hour to ensure thorough carotenoid extraction. Subsequently, the mixture was filtered using a Whatman No. 1 filter paper, with the extract collected into a 50 mL tube. To facilitate phase separation, 5 mL of distilled water was added. The upper hexane layer, which contained the pigments, was carefully transferred into a 50 mL volumetric flask, and the volume was then adjusted with additional hexane. The absorbance was then measured at 450 nm with a UV/V double-beam spectrophotometer (JENWAY 6850, Bibby Scientific Ltd., Staffordshire, UK). The total carotenoid content was determined according to Eq. 13.

$$TCC\ (\mu g.g^{-1}) = \frac{A \times V \times 10^4}{A_{1cm}^{1\%} \times W} \qquad \text{(Eq. 13)}$$

Where A is the absorbance at 450 nm,V is the made-up extract volume (ml),W is the sample weight (g) and$A_{1cm}^{1\%}$ = 2500, represents the extinction coefficient of carotene in hexane.

3.8.3.2 Determination of Total Phenolic Content and Total Flavonoid Content

The shea fruit leather samples were extracted in acidified methanol together with the fresh shea fruit puree, as explained in the procedure previously outlined by Chikpah *et al*. (2022). Specifically, 10 g of samples were weighed and placed into 100 mL extraction containers, which were wrapped with aluminum foil to prevent light absorption by the phenolic compound. Subsequently, 80 mL of 80% methanol was added to the sample, vigorously mixed, and left in a dark room at 25 ±1 °C for 12 hours with periodic agitation. The mixture was then centrifuged at 4000 rpm for 15 minutes using a centrifuge (Rotofix 32A, Andreas Hettich GmbH & Co. KG, Tuttlingen, Germany). The resulting supernatant was transferred to a clean extraction container and filtered through Whatman No. 1 filter paper into a 50 mL flask, which was wrapped in aluminium foil, properly labelled, and stored at 4 °C for subsequent analysis.

The measurement of total phenolic content (TPC) was conducted using the Folin-Ciocalteu phenol protocol (Singleton *et al.*, 1999), with gallic acid used to prepare the standard calibration curve. Approximately 500 µL of either the sample extract, standard, or blank solution was stirred with 5 mL of Folin-Ciocalteu reagent in a 15 mL volumetric flask. The mixture was thoroughly blended and left in a dark room for 3 minutes at ambient conditions (23 ± 1 °C). Following this, 4 mL of 7.5% sodium carbonate solution was added to the mixture, stirred for about 1 minute and left in the dark at room temperature for 2 hours. After the incubation period, a double-beam UV/V spectrophotometer (JENWAY 6850, Bibby Scientific Ltd., Staffordshire, UK) was used to determine the absorbance of the reaction mixture at a wavelength of 765 nm. TPC was determined from the Gallic acid calibration and expressed as mg GAE/ 100 g of sample on a dry basis (d.b.).

The total flavonoid content (TFC) was calculated by using aluminium chloride ($AlCl_3$) procedure (Turkmen *et al.*, 2005). In this method, 150 µl of 5% NaOH solution and 2 mL of distilled water was combined in a 15 mL tube. Then, 500 µL of the extract was added, mixed, and allowed to stand at room temperature for 5 minutes. Afterwards, 150 µL of 10% $AlCl_3$ solution was introduced. The mixture was mixed thoroughly and left at room temperature for an additional 5 minutes, after which 1 mL of NaOH solution was also added, stirred well, and incubated at a temperature of 25 ± 1 °C for 15 minutes. Following this, the absorbance of the mixture was determined at 415 nm using a double-beam UV/V spectrophotometer (JENWAY 6850, Bibby Scientific Ltd., Staffordshire, UK). A standard calibration graph was developed using quercetin.

The TFC was expressed as mg of quercetin equivalent (QE) per 100 grams of sample on dry basis (d.b).

3.8.3.3 Analysis of Antioxidant Activity

Antioxidant activity of the shea samples were measured per the 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical scavenging procedure (Chikpah *et al.*, 2022). In a 15 mL tube, approximately 1 mL of either sample extract or control (methanol without sample) was thoroughly mixed with 3 mL of 0.1 mM DPPH in methanol. The solution was vigorously mixed for 5 minutes and incubated in a dark room temperature (25±1°C) for 60 minutes and the reading of absorbance at a wavelength of 517nm using UV/V double-beam spectrophotometer (JENWAY 6850, Bibby Scientific Ltd., Staffordshire, UK) was read. The antioxidant activity was expressed as % scavenging activity of DPPH free radicals per Eq. 14.

$$Antioxidant\ activity\ (\%) = \frac{Control_{Abs} - Sample_{Abs}}{Control_{Abs}} \times 100 \qquad \text{(Eq. 14)}$$

3.9 Sensory Evaluation of Shea Fruit Leather

Texture, colour, aroma, sweetness, mouthfeel, appearance, and overall liking of the shea fruit leather were judged by twenty untrained evaluators. The judges comprised of 12 males and 8 females between the ages of 17 and 35 years, selected from the student population. The sensory evaluation of the shea leather samples was conducted at the Postharvest Technology Laboratory, located at the Engineering and Mechanisation Workshop. The selection criteria of these assessors included willingness, availability, health conditions, and prior sensory evaluation experience. The evaluation occurred in a room condition with natural air circulation at 23 ± 1°C (Korese *et al.*, 2021). The shea fruit leather was stored in well-labelled zip lock bags with three-digit coding.

Evaluators used a 9-point hedonic scale to rate the shea fruit leather's appearance, colour, aroma, sweetness, texture, and overall liking with scores varying from 1 (dislike extremely) to 9 (like extremely). Additionally, panels were provided with water to cleanse their mouth between evaluations to prevent interference of the previous sample's assessment to the others (Chikpah *et al*., 2023; Korese *et al*., 2021).

3.10 Statistical Analysis

The data obtained were analysed with SPSS software (IMB SPSS Statistics, version 25). To find the significant differences between the shea leather samples at the 5% significance level, a one-way ANOVA and Tukey's pairwise comparison were used. To determine the link between the quality characteristic of the shea fruit leather, Pearson's correlation analysis and principal component analysis (PCA) were also carried out. With PCA, the link between a sample's quality attributes and the key characteristics that set it apart from the others was ascertained.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Drying Kinetics of Shea Fruit Leather

Figure 4.1 shows the drying curves for shea fruit leather as influenced by different drying air temperatures (50 °C and 60 °C) and gelatin levels (0, 1, 2,3, and 4%). The average initial moisture content of the fresh shea fruit puree was 84.45% wet basis (w.b). Generally, drying air temperature significantly ($p<0.05$) influenced the drying time (Figure 4.1). It can be seen from Figure 4.1 that shea fruit leathers produced at 0, 1, 2, 3, and 4 % gelatin levels took 420, 780, 660, 300 and 480 minutes, respectively to reach final moisture content at 60 °C which represent a reduction of 41.67%, 53.57%, 21.43%, 54.55% and 33.33% when compared with the drying time required at 50 °C of the same gelatin levels. This suggests that, increasing the drying air temperature widens the temperature difference between the drying medium and the food product leading to a higher heat transfer rate, and in turn, a shorter drying time. Similar findings have been reported in literature (Quintero Ruiz *et al.*, 2014; Suna, 2019; Tontul and Topuz, 2017).

Drying times for different gelatin levels show a nonlinear pattern at 50 and 60 °C drying air temperature. Despite this, there were still noticeable differences in drying time among the various levels of gelatin. For the control samples at 50 °C, the drying duration was 720 minutes. When gelatin was introduced at 1%, the drying time significantly increased to 1680 minutes. This substantial increase indicates that the presence of gelatin initially impedes moisture removal (Jayakody *et al.*, 2023). The gelatin forms a gel- matrix which traps moisture and prolongs the drying time. As the level of gelatin increases to 2%, drying time is reduced (840 minutes), suggesting that high gelatin levels begin to optimize the drying process. This process allows an efficient way for moisture to escape. However, at 3% gelatin, the drying time decreases to 660 minutes, indicating that an optimal balance might have been reached between gel formation and moisture removal. At gelatin level of 4% (720 minutes), the drying duration was increased in contrast to 3% (660 minutes). This is an indication that excessive gelatin levels may hinder the drying process of food products (Jayakody *et al.*, 2023). The same pattern is observed at 60 °C, where the drying times for different gelatin levels follow a similar trend.

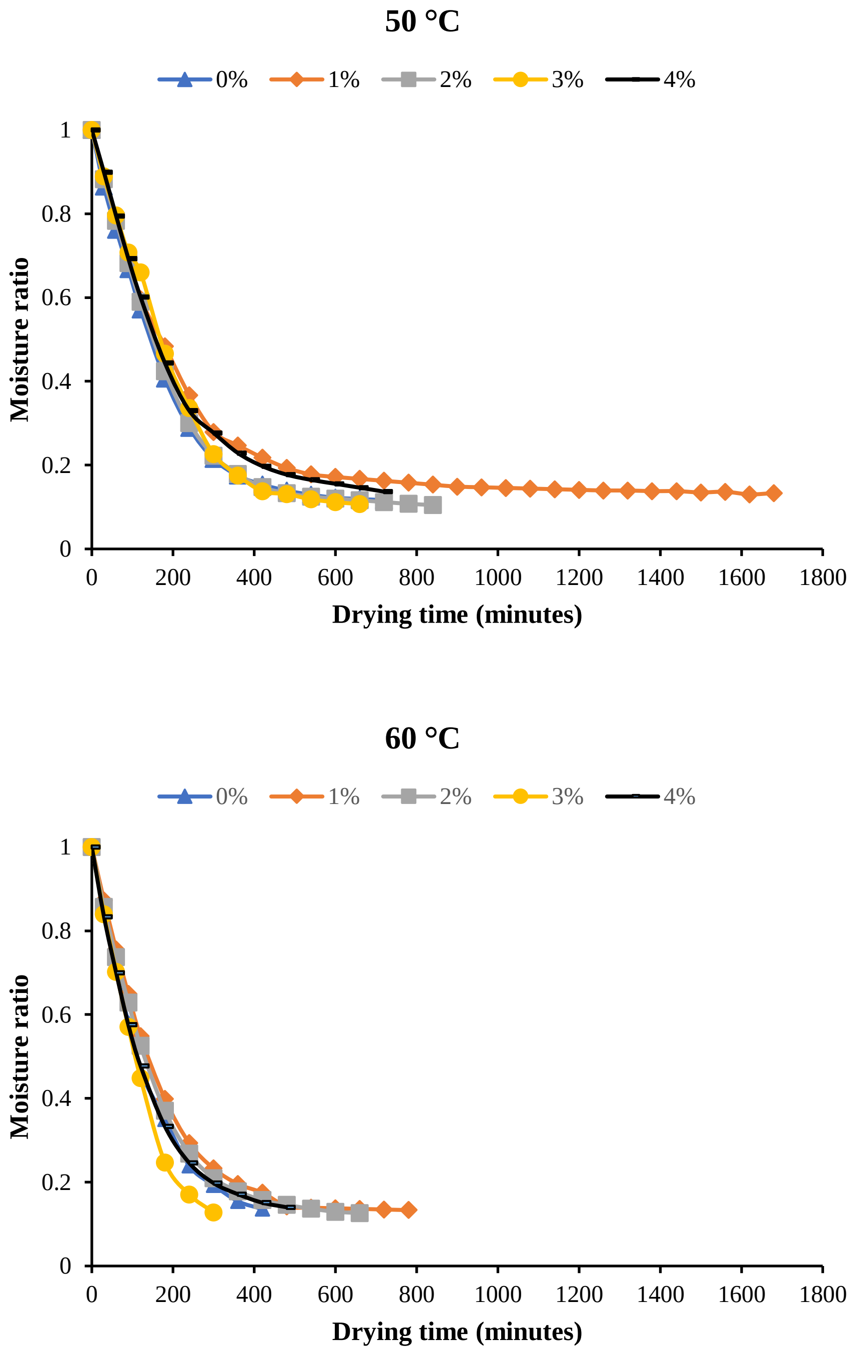

Figure 4. 1: Variation of moisture ratio with drying time of shea fruit leather at different gelatin levels (0%, 1%, 2%, 3%, 4%) and different drying air temperatures (50 °C and 60 °C).

4.1.1 Drying Rate of Shea Fruit Leather

Figure 4.2 shows changes in drying rate versus moisture content for shea fruit leather at different gelatin levels (0%, 1%, 2%, 3% and 4%) and drying air temperatures (50 °C and 60 ° C). Variations were observed in the drying rate of the shea fruits leather for the different gelatin level and drying air temperature. One of the key observations is that drying rates are consistently higher at 60 °C compared to 50 °C across all gelatin levels. This aligns with the basic principle that higher temperatures promote faster moisture evaporation. At 60 °C, the heat energy was sufficient to break the moisture bonds more effectively, resulting in quicker drying. In contrast, the lower drying air temperature (50 °C) slowed the drying process due to the reduced heat available for moisture evaporation. Also, it was noticeable that, gelatin level significantly impacts drying rates.

The highest drying rate was observed at 3% gelatin. The combined effect of lower temperature and higher gelatin level in moisture loss reduction is observed here (Figure 4.2). This is a result of gelatinised structure been more pronounced at lower temperatures, where the available heat is insufficient to overcome the barrier created by the gelatin. There was a sharp decline in drying rates during the initial phase of drying, particularly within the first few minutes. This trend was consistent across all gelatin levels and temperatures. The initial rapid moisture loss was due to the evaporation of free water on the surface of the gelatin. However, as drying progresses, the formation of a more resistant outer layer, especially in higher gelatin levels, slows the drying rate. Drying of shea fruit puree occurred in falling rate and no constant rate period was observed in any of the experimental treatments and runs for the entire duration.

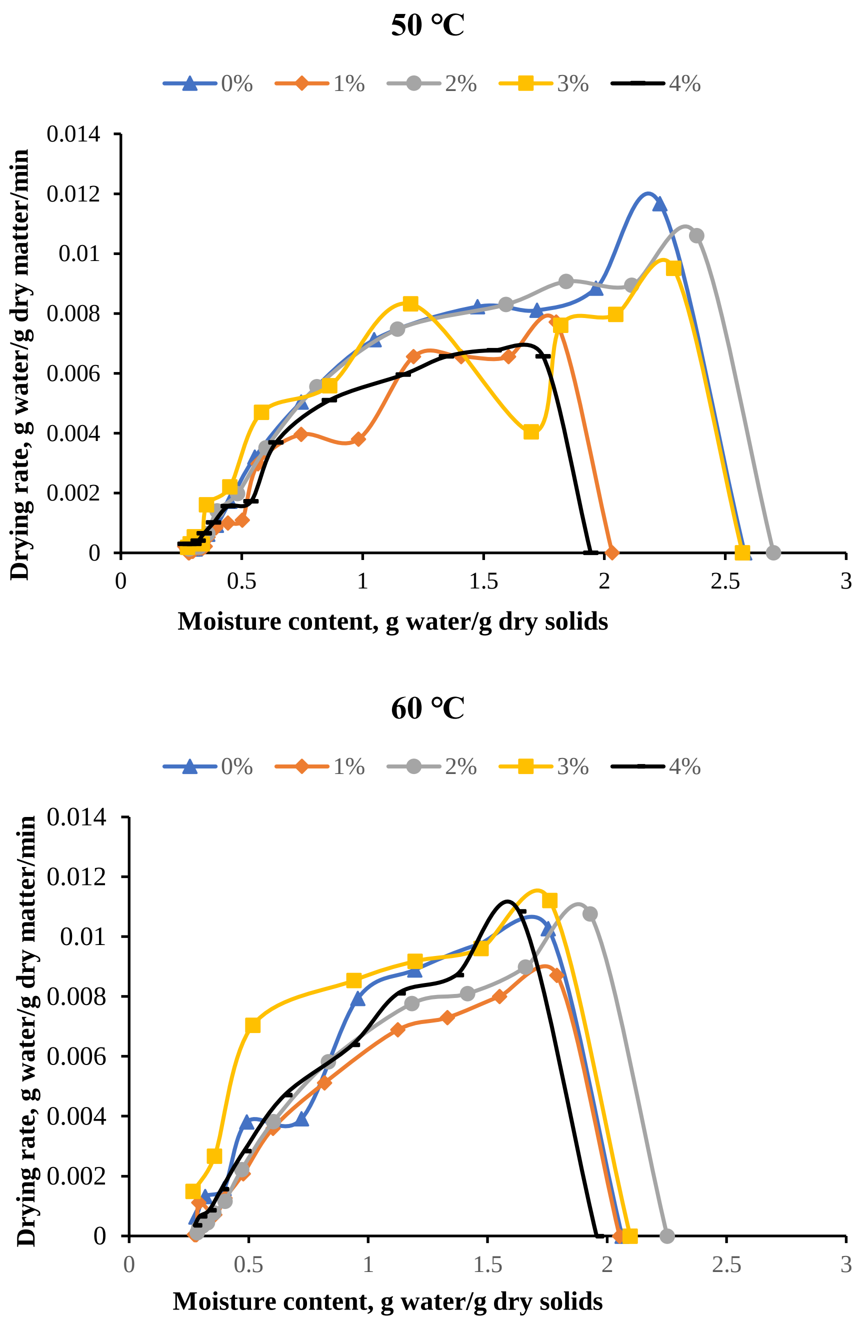

Figure 4. 2: Drying rate curves for shea fruit leather at different gelatin levels (0%, 1%, 2%, 3%, 4%) and drying air temperatures (50 °C and 60 °C).

4.1.2 Fitting of Drying Curves

The statistical parameters, RMSE, R^2, χ^2 and PE of the models employed are shown in Table 4.1. Generally, the RMSE values for all the models ranged from 0.0011-0.0166, while R^2 values varied from 0.9039-0.9998. The χ^2 and PE values varied between 0.000001 and 0.008890 and 0.09% - 19.29%. Considering the respective models, the RMSE values were found to vary between 0.0071–0.0156, 0.0011–0.0042, 0.0017–0.0084, 0.0019–0.0106, 0.0055–0.0102 and 0.0072–0.0166 for Henderson and Pabis, Midilli et al., Logarithmic, Diffusion Approach, Page and Lewis models, respectively. In the same order of model presentation, R^2 values of 0.9039–0.9948, 0.9933-0.9998, 0.9913-0.9991, 0.9853-0.9991, 0.9475-0.9974 and 0.9530-0.9951 were obtained. The χ^2, had values ranging between 0.000699-0.008026 for Henderson and Pabis, 0.000002-0.000077 for Midilli et al., 0.000001-0.001135 for logarithmic, 0.000144-0.002111 for Diffusion Approach, 0.000360-0.001886 for Page model and 0.000696-0.008890 for Lewis model respectively while PE values recorded ranged from 0.54-17.10% for Henderson and Pabis, 0.09-6.48% for Midilli et al., 0.65-19.29% for Logarithmic, 2.41-16.96% for Diffusion approach, 1.10-16.49% for Page and 1.76-19.20% for Lewis model.

Considering the criteria of goodness of fit and prediction accuracy, which include the highest R^2, lowest RMSE, lowest χ^2 and PE value, the Midilli et al. model was found to best fit the drying moisture data (Table 4.1) of the shea fruits leather as it recorded the lowest RMSE, χ^2 and PE and the highest R^2. Figure 4.3 illustrates a comparison of the experimental and predicted MR values using Midilli et al. model where consistency of fitting the drying data was observed in all drying operations and air temperatures. Thus, the Midilli et al. model provides a more accurate prediction of the drying behaviour of shea fruits leather under similar conditions.

Table 4. 1: Statistical results obtained from different drying models of shea fruit leather samples

Drying air temp. (°C)	Gelatin (%)	Model name	Constants	RMSE	R^2	χ^2	PE (%)
50	0	Henderson and Pabis	a= 0.9855; k= 0.0045	0.0099	0.9868	0.001701	6.13
	1		a= 0.8813; k= 0.0026	0.0156	0.9169	0.008026	11.97
	2		a= 0.9935; k= 0.0043	0.0103	0.9849	0.002078	17.10
	3		a= 1.0220; k= 0.0044	0.0082	0.9906	0.001196	1.89
	4		a= 0.9818; k= 0.0038	0.0105	0.9837	0.001964	2.11
	0	Midilli et al	a= 0.9930; k= 0.0026; b= 0.0002; n= 1.1400	**0.0022**	**0.9992**	**0.000002**	**0.14**
	1		a= 1.0250; k= 0.0085; b= 0.0001; n= 0.8739	**0.0036**	**0.9933**	**0.000022**	**0.48**
	2		a= 0.9974; k= 0.0022; b= 0.0001; n= 1.1572	**0.0021**	**0.9992**	**0.000061**	**0.92**
	3		a= 1.0092; k= 0.0033; b= 0.0001; n= 1.0474	**0.0041**	**0.9976**	**0.000030**	**1.24**
	4		a= 1.0055; k= 0.0029; b= 0.0002; n= 1.1014	**0.0024**	**0.9990**	**0.000037**	**0.12**
	0	Logarithmic	a= 0.9377; k= 0.0059; c= 0.0861	0.0048	0.9961	0.000428	3.98
	1		a= 0.8823; k= 0.0055; c= 0.1379	0.0071	0.9908	0.000031	0.65
	2		a= 0.9515; k= 0.0057; c= 0.0832	0.0049	0.9954	0.000533	13.00
	3		a= 1.0008; k= 0.0047; c= 0.0308	0.0079	0.9913	0.001135	1.59
	4		a= 0.9167; k= 0.0055; c= 0.1132	0.0039	0.9973	0.000388	10.66
	0	Diffusion	a= 0.9191; k= 0.0057; b= 0.0032	0.0052	0.9959	0.000549	6.22
	1		a= 0.8632; k= 0.0053; b= 0.0094	0.0019	0.9983	0.000167	10.72
	2		a= 0.9227; k= 0.0054; b= 0.0045	0.0057	0.9949	0.000700	12.90
	3		a= 0.0654; k= 0.0050; b= 0.8485	0.0086	0.9901	0.001374	3.11
	4		a= 0.0937; k= 0.0403; b= 0.0977	0.0106	0.9853	0.002111	2.41
	0	Page	k= 0.0078; n= 0.9006	0.0089	0.9874	0.001487	2.33
	1		k= 0.0313; n= 0.6055	0.0102	0.9475	0.000366	1.10
	2		k= 0.0073; n= 0.9071	0.0095	0.9842	0.001745	4.77
	3		k= 0.0030; n= 1.0622	0.0081	0.9912	0.001075	2.90
	4		k= 0.0078; n= 0.8770	0.0088	0.9869	0.001377	11.19
	0	Lewis	k=0.0046	0.0100	0.9879	0.001638	2.54
	1		k=0.0032	0.0166	0.9530	0.008890	3.44
	2		k=0.0044	0.0103	0.9855	0.001966	16.60
	3		k=0.0043	0.0086	0.9901	0.001175	1.76

	4		k=0.0039	0.0106	0.9853	0.001873	19.20
60	0	Henderson and Pabis	a= 0.9921; k= 0.0057	0.0071	0.9948	0.000699	2.32
	1		a= 0.9646; k= 0.0042	0.0125	0.9770	0.002854	10.80
	2		a= 0.9719; k= 0.0047	0.0113	0.9835	0.002000	0.54
	3		a= 1.0267; k= 0.0070	0.0084	0.9039	0.000775	6.49
	4		a= 0.9724; k= 0.0054	0.0100	0.9889	0.001360	5.96
	0	Midilli et al	a= 1.0029; k= 0.0046; b= 0.0002; n= 1.0723	**0.0026**	**0.9992**	**0.000077**	**1.89**
	1		a= 1.0021; k= 0.0037; b= 0.0002; n= 1.0774	**0.0017**	**0.9994**	**0.000053**	**0.09**
	2		a= 0.9997; k= 0.0039; b= 0.0002; n= 1.0805	**0.0018**	**0.9995**	**0.000035**	**0.45**
	3		a= 0.1878; k= 0.0075; b= 0.0005; n= 0.0764	**0.0042**	**0.9985**	**0.000060**	**1.54**
	4		a= 1.0373; k= 0.0184; b= 0.0002; n= 0.7808	**0.0011**	**0.9998**	**0.000066**	**2.94**
	0	Logarithmic	a= 0.9360; k= 0.0070; c= 0.0782	0.0036	0.9985	0.000275	2.01
	1		a= 0.9114; k= 0.0063; c= 0.1132	0.0034	0.9978	0.000277	7.59
	2		a= 0.9160; k= 0.0067; c= 0.1040	0.0036	0.9978	0.000285	19.29
	3		a= 1.0267; k= 0.0070; c= 0.0004	0.0084	0.9939	0.000905	17.23
	4		a= 0.9040; k= 0.0074; c= 0.1066	0.0025	0.9991	0.000576	3.48
	0	Diffusion	a= 0.9288; k= 0.0068; b= 0.0084	0.0039	0.9984	0.000207	6.88
	1		a= 0.8908; k= 0.0061; b= 0.0447	0.0039	0.9975	0.000354	9.47
	2		a= 0.9001; k= 0.0064; b= 0.0009	0.0041	0.9976	0.000386	11.21
	3		a= 0.0008; k= 0.1241; b= 0.0547	0.0094	0.9945	0.001197	16.96
	4		a= 0.8964; k= 0.0073; b= 0.0008	0.0028	0.9991	0.000144	13.66
	0	Page	k= 0.0081; n= 0.9333	0.0061	0.9958	0.000564	2.59
	1		k= 0.0118; n= 0.8196	0.0099	0.9822	0.001886	7.98
	2		k= 0.0108; n= 0.8515	0.0091	0.9871	0.001399	4.39
	3		k= 0.0035; n= 1.1384	0.0055	0.9974	0.000360	10.05
	4		k= 0.0114; n= 0.8626	0.0072	0.9932	0.000765	16.49
	0	Lewis	k=0.0058	0.0072	0.9951	0.000696	8.00
	1		k=0.0044	0.0129	0.9813	0.002877	12.52
	2		k=0.0049	0.0116	0.9863	0.002060	2.00
	3		k=0.0068	0.0094	0.9945	0.000880	7.04
	4		k=0.0056	0.0105	0.9910	0.001366	5.77

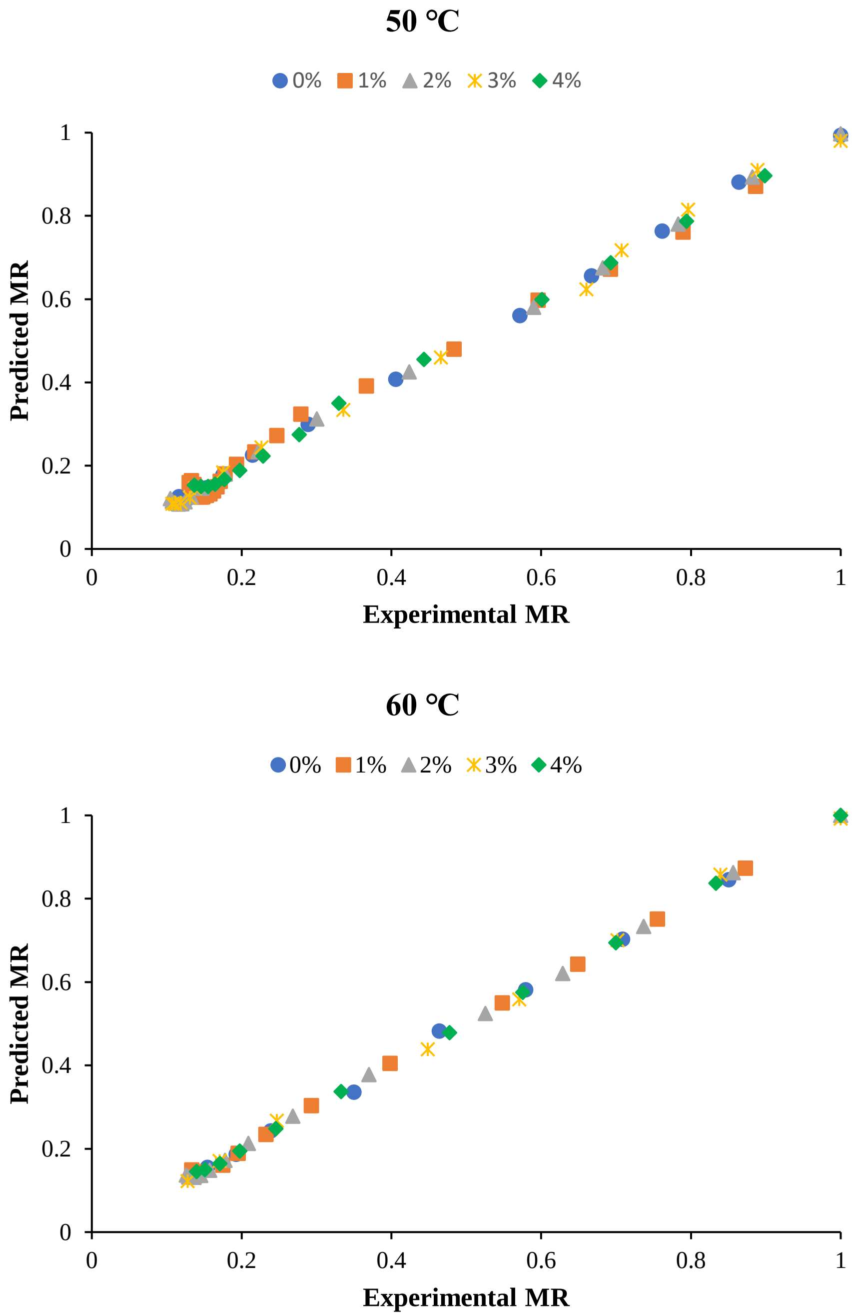

Figure 4. 3: Plots of experimental MR against Midilli et al. predicted MR values of shea fruit leather at different gelatin levels (0%, 1%, 2%, 3%, 4%) and drying air temperatures (50 °C and 60 °C).

4. 1.2 Effective Moisture Diffusivity and Activation Energy

Table 4.2 displays the effective moisture diffusivity (D_{eff}) and activation energy (E_a) for the drying process of shea fruit leathers. The D_{eff} which indicates how easily moisture moves from the centre of the sample to the surface for removal ranged from 3.91 x 10^{-12} – 1.44 x 10^{-11} m^2/s for 50 °C and 1.04 x 10^{-11} – 2.76 x 10^{-11} for 60 °C and fell within the range of biologically active dried products (Elhussein and Şahin, 2018; Nourhène *et al*., 2008). The diffusivity values (Table 4.2) increased as the drying air temperature rises. The observed temperature trend may be explained by increasing heat intensity, which increased with temperature and increased the activity of water molecules, contributing to higher diffusivity. The rapid mass transfer caused by temperature increase resulted in an increase in effective diffusivity (Aghbashlo *et al*., 2008; Arslan *et al*., 2010; Meziane, 2011). The differences in D_{eff} recorded for various agricultural products are mostly explained by changes in moisture content, moisture content disparity, cellular and morphological differences, and the kind of drier and drying method utilized (Miraei Ashtiani *et al*., 2018). As can be seen in Table 4.2, there was no observable trend as gelatin levels increased or decreased. Co-efficient of determination values ranging from 0.7130 – 0.9914 were obtained, suggesting a high prediction accuracy for the D_{eff} of the shea fruit leather samples when using Fick's second law equation.

Activation energy (E_a) values declined as the shea fruit leather sample's content of gelatin increased, suggesting that more energy was required to start the drying of 1% gelatin than 4% gelatin level. An exception occurred at 2% gelatin content, which showed the lowest E_a of all the values. The validity of the Arrhenius-type equation in estimating the activation energy of the shea fruit leather under identical gelatin levels and drying air temperature is confirmed by the R^2 range of 0.8984 – 0.9910.

Table 4. 2: Effective moisture diffusivity and activation energy of drying of shea leather samples

Temp. (°C)	Gelatin level (%)	Effective moisture diffusivity (m^2s^{-1})	Coefficient of determination (R^2)	Activation energy ($kJmol^{-1}$)	Coefficient of determination (R^2)
50	0	1.23×10^{-11}	0.9161	38.60	0.9770
	1	3.91×10^{-12}	0.9385	87.71	0.9910
	2	1.09×10^{-11}	0.7130	13.20	0.8984
	3	1.44×10^{-11}	0.9518	58.15	0.9882
	4	1.10×10^{-11}	0.8902	34.77	0.9854
60	0	1.88×10^{-11}	0.9819		
	1	1.04×10^{-11}	0.9572		
	2	1.26×10^{-11}	0.9179		
	3	2.76×10^{-11}	0.8822		
	4	1.63×10^{-11}	0.9914		

4.2 Energy Consumption of Shea Fruit Leather

Shea fruit leather's energy consumption (kWh/kg) is influenced by the drying technique and drying air temperature, as seen in Table 4.3. The study's findings indicate that as temperature increases, the energy consumption decreases with a non-linear trend recorded for gelatin levels. Energy consumption ranges between 4.66391×10^{-5} kWh /kg - 9.59835×10^{-5} kWh /kg with 3% gelatin at 60 °C recording less energy. The temperature at which the maximum energy consumption (9.59835×10^{-5} kWh /kg) was achieved was at 50 °C with 1% gelatin. This might be as a result of prolonged drying time recorded for 1% gelatin level at 50 °C as drying time corresponds with energy consumption accordingly (see Figure 4.1). There was no linear trend recorded for gelatin additions.

Table 4. 3: Energy consumption of shea fruit leather

Temperature (°C)	Levels of Gelatin (%)	Energy Consumption (kWh / kg)
50	0	6.91358×10^{-5}
	1	9.59835×10^{-5}
	2	7.53623×10^{-5}
	3	5.96806×10^{-5}
	4	6.91358×10^{-5}
60	0	4.80290×10^{-5}
	1	6.75299×10^{-5}
	2	6.11054×10^{-5}
	3	4.66391×10^{-5}
	4	5.02058×10^{-5}

4.3 Characterization of Shea Fruit Leather

4.3.1 Effect of Gelatin Levels and Drying Air Temperatures on Final Moisture Content and Water Activity

The final moisture content and water activity (a_w) (Table 4.4) of shea fruit leather were influenced ($p<0.05$) by both drying air temperature and gelatin levels. The moisture content ranged from 18.288% - 21.114%, and a_w values were between 0.1235 and 0.2565. Although these values were higher, they are regarded favorable for stability of dried products because they show a low amount of free water available for microbial growth and biochemical reactions during storage (Korese *et al*., 2021) ensuring product safety. Final moisture content and a_w values averagely increased at 50 °C with higher gelatin levels. This could be an indication that drying at 50 °C was less effective in removing moisture, especially, when gelatin was present. At 60°C, the drying process was more efficient, with lower moisture content (18.009% - 20.178%) and reduced a_w values (0.1215 -

0.1830). This higher temperature effectively reduced free water, prolonging the shelf life of the shea fruit leather.

Table 4. 4: Effect of gelatin levels and drying air temperatures on final moisture content and water activity of shea fruit leather.

Gelatin Level (%)	Temp. (℃)	Final moisture content (%)	Water Activity (a_w)
0	50	18.288 ± 0.0007[c]	0.1235 ± 0.0007[a]
1		19.120 ± 0.1648[bc]	0.1335 ± 0.0035[a]
2		19.670 ± 0.5339[abc]	0.1585 ± 0.0332[a]
3		20.820 ± 1.1434[ab]	0.1910 ± 0.0283[ab]
4		21.114 ± 0.2878[a]	0.2565 ± 0.0346[b]
0	60	18.009 ±0.0035[c]	0.1215 ± 0.0021[a]
1		18.073 ± 0.0735[c]	0.1280 ± 0.0071[a]
2		19.295 ± 0.0099[bc]	0.1450 ± 0.0014[a]
3		20.185 ± 0.2574[ab]	0.1830 ± 0.0214[ab]
4		20.178 ± 0.2503[ab]	0.1215 ± 0.0170[ab]
Pr>F (Model)		0.000	0.001
Significant		Yes	Yes

Values (mean ± standard deviation) with different superscripts in the same column are significantly different.

4.3.2 Effect of Gelatin Level and Drying Air Temperatures on Colour Parameters of Shea Fruit Leather

Colour is the first quality attributes which influences consumers choice, preferences and the market value of dried products (Korese and Chikpah, 2023; Mühlbauer and Müller, 2020). Colour is given critical attention during processing of agricultural produce (Korese and Achaglinkame, 2024). Table 4.5 presents the colour parameters of shea fruit leather dried at different drying air temperatures and gelatin levels. The different drying air temperatures and gelatin levels significantly ($p<0.05$) influenced the colour parameters of the shea fruit leather. The L* parameter was significantly ($p<0.05$) influenced by drying air temperature and gelatin addition. Higher drying air temperatures generally resulted in higher L* values across all gelatin levels except 4%. However, no clear trends were observed for the gelation levels. At higher drying temperatures, the L* values tend to increase, indicating that the shea fruit leather dried at 60 °C retains more brightness. The reason for this can be attributed to the shorter drying times associated with higher temperatures which decreases the exposure of the shea fruit leather to heat and air (Korese and Achaglinkame, 2024; Miraei Ashtiani *et al*., 2018).

The colour attribute a* was significantly ($p = 0.003$) affected by the different drying air temperature and gelatin levels. This caused the fading of the green colour and the revelation of redness (+ve a* values). The values had mixed trends as the drying air temperature increases. This findings could be associated with the decomposition of chlorophyll, carotenoid pigments and non-enzymatic Maillard browning (Mühlbauer and Müller, 2020; Izli *et al*., 2018) when the shea fruit puree were exposed to higher drying air temperature. The a* values at 60 °C increased as the gelatin level increased from 1% to 4%. Mixed trends were however observed for gelatin levels at 50 °C. The increase in redness (a*) at higher gelatin level at 60 °C particularly at 3% and 4%

gelatin levels suggests that gelatin might help stabilise red pigments. Similar trends and effects were observed for b* values with slight variations such as the mixed trends recorded for gelatin level at both drying air temperatures. These trends show that higher temperature might produce a* and b* values closer to the shea fruit puree samples.

Chroma value which is utilised to perceive the colour intensity, was affected significantly ($p = 0.001$) by the different drying air temperature and gelatin levels. When compared with the fresh shea fruit puree, C* values decreased significantly similar to reports by (Suna, 2019) on hot air drying, with no linear trends associated with temperature and gelatin levels. It was also observed that h* values were generally affected ($p = 0.028$) by both temperature and gelatin levels. Hue values increased as the drying air temperature also increased, except at 3% and 4% gelatin levels, which had lower values at 60 °C. The overall colour change (ΔE*) was noted to significantly ($p < 0.05$) increase as drying air temperature increased. This could be linked to the acceleration of browning reactions such as the Maillard reaction due to higher temperatures, leading to darker and more intense colour changes. The ΔE* values relatively decreased as gelatin levels increased for both 50 and 60 °C. This was due to higher gelatin levels reducing browning reactions, resulting in less colour change.

Table 4. 5: Effect of gelatin levels and different drying air temperatures on colour parameters of shea fruit leather.

Gelatin level (%)	Temp. (°C)	L*	a*	b*	C*	h*	ΔE*
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Fresh shea fruit puree		53.53 ± 3.14	-11.08 ±1.29	38.13 ± 4.62	39.71 ± 4.77	-73.78 ± 0.77	-
0	50	30.80 ± 4.62[a]	10.62 ± 3.28[a]	20.64 ± 3.28[a]	23.36 ± 3.60[a]	62.90 ± 7.74[a]	417.35 ± 62.14[ab]
1		18.68 ± 4.01[bc]	4.71 ± 1.12[b]	12.68 ±1.72[bc]	13.56 ± 1.80[bc]	69.64 ± 4.10[a]	307.79 ± 66.16[a]
2		24.32 ± 2.92[ab]	3.91 ± 1.59[b]	10.48 ± 0.86[c]	11.27 ± 0.99[c]	69.80 ± 7.83[a]	227.64 ± 34.31[cde]
3		23.13 ± 1.58[ab]	7.33 ± 4.17[ab]	14.83 ±3.30[abc]	16.71 ± 4.64[abc]	65.70 ± 9.87[a]	193 80 ± 47.65[def]
4		25.63 ± 1.87[ab]	3.70 ± 3.50[b]	18.32 ± 3.66[ab]	18.32 ± 3.67[ab]	78.22 ± 10.45[a]	101.00 ± 27.34[f]
0	60	22.30 ± 4.62[ab]	5.72 ± 1.70[ab]	13.21 ± 3.81[bc]	14.45 ± 3.83[bc]	66.15 ± 5.46[a]	511.73 ± 107.38[a]
1		22.04 ± 4.01[ab]	3.63 ± 0.67[b]	12.03 ±2.34[bc]	12.60 ± 2.69[bc]	73.97 ± 5.02[a]	462.55 ± 66.16[a]
2		28.34 ± 2.92[a]	4.89 ± 1.76[b]	14.10 ± 1.39[abc]	14.93 ± 1.49[bc]	70.90 ± 1.55[a]	334.41 ± 34.30[bc]
3		25.30 ± 1.58[ab]	5.62 ± 3.31[ab]	10.90 ± 1.23[c]	12.36 ± 1.28[bc]	62.88 ± 7.77[a]	237. 92 ± 47.65[cde]
4		10.28 ± 1.87[c]	5.63 + 1.70[ab]	18.10 ± 6.61[ab]	19.05 ± 7.00[ab]	74.00 ± 8.62[a]	132.72 ± 27.34[ef]
Temperature (T)		***	**	***	***	**	***
Gelatin level (GL)		***	**	***	***	**	***
T × GL		***	**	***	***	**	***

The value represents mean ± standard deviation (SD). Values with different superscripts in the same column are significantly different. Temperature and Gelatin effect significant at $P < 0.05$

4.3.3 Effect of Gelatin Level and Drying Air Temperatures on Bioactive Compounds and Antioxidant Activity of Shea Fruit Leather

Bioactive compounds are crucial in the human diet for supporting immune health, growth, and development (Lee and Kim, 2022). The composition of TCC, TPC, TFC and TAC of the shea fruit leathers dried at different temperatures and gelatin levels are shown in Table 4.6. Across the gelatin levels, TCC was higher in 50 than 60 °C, indicating that lower drying air temperature preserves carotenoids better than higher temperatures. Also, this could be due to carotenoids breaking down thermally at higher temperatures, as well as undergoing oxidation and isomerization (Suri *et al.*, 2022). At 1% gelatin level, an exception was observed where TCC was significantly higher at 60 °C than at 50 °C.

The TPC of the shea fruits leather at 50 and 60 °C differed from 229.70 to 384.03 mg/100 g and 245.10 to 410.87 mg/100 g, respectively. It was observed that both drying air temperature and gelatin levels had a great influence ($p<0.05$) on the TPC of the shea fruit leathers. This study shows varying trends in TPC values as drying air temperatures increase. This observation disagrees with the findings of Chen and Martynenko (2018) and Tontul and Topuz (2017), who suggests that higher drying temperatures reduce drying times leading to enzyme inactivation, which can result in higher phenolic content in the final fruit leather product. On the other hand, as gelatin level increased at 60 °C drying air temperature, TPC values also increased with 50 °C recording mixed trends.

The different drying temperature and gelatin levels had a significant ($p < 0.05$) effect on the TFC of the shea fruit leathers. The TFC of the shea fruit leather samples increased from 207.11 to 260.98 mg/100 g at 50 °C and from 220.94 to 544.57 mg/100 g at 60 °C as the temperature increased. This finding may be linked to earlier explanations that the rapid suppression of polyphenol oxidase activity at higher temperatures, combined with shorter drying times (Sturm *et al*., 2012; Zeng *et al.*, 2019), and the release of free phenols from bonded phenolic compounds due to the breakdown of the plant cell wall structure, contribute to this effect.

The drying air temperature showed a significant ($p < 0.05$) influence on the DPPH radical scavenging activity of the shea fruit leathers. The highest TAA values, 82.97% at 50 °C and 81.59% at 60 °C, were recorded, while the lowest TAA values, 41.88% and 44.61%, at 50 and 60 °C were also observed respectively. As the temperature increased, DPPH scavenging activity also increased, whereas an increase in gelatin levels led to a decrease in DPPH activity.

Table 4. 6: Effect of gelatin level and drying air temperatures on bioactive compounds and antioxidant activity of shea fruit leather.

Gelatin Level (%)	Temp. (°C)	TCC (µg/100 g d.b.)	TPC (mg GAE/100 g d.b.)	TFC (mg QE/100 g d.b.)	TAA (%)
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Fresh shea fruit puree		8356.33 ± 51.96	2567.22 ± 10.88	1888.31 ± 0.81	87.19 ± 0.09
0	50	1848.15 ± 10.79^{b}	332.42 ± 5.93^{c}	256.78±0.32^{e}	82.97 ± 0.13^{a}
1		879.49 ± 6.44^{g}	384.03 ± 0.90^{b}	260.98 ± 0.09^{d}	60.43 ± 0.07^{e}
2		3732.39 ± 6.23^{a}	246.33 ± 0.17^{g}	228.44 ± 0.23^{de}	54.21 ± 0.07^{f}
3		990.32 ± 5.22^{f}	270.32 ± 1.06^{f}	207.63 ± 0.13^{h}	41.88 ± 0.11^{i}
4		694.24 ± 17.37^{h}	229.70 ± 0.12^{h}	207.11 ± 0.12^{h}	44.16 ± 0.01^{h}
0	60	1787.18 ± 8.07^{c}	410.87 ± 6.15^{a}	262.05 ± 1.35^{d}	81.59 ± 0.20^{b}
1		1614.99 ± 21.94^{d}	318.29 ± 0.72^{d}	544.57 ± 0.05^{a}	63.31 ± 0.34^{c}
2		1521.46 ± 12.50^{e}	275.99 ± 6.56^{e}	423.30 ± 0.99^{b}	61.32 ± 0.05^{d}
3		970.86 ± 1.24^{f}	261.10 ± 0.04^{f}	348.90 ± 0.04^{c}	47.38 ± 0.02^{g}
4		548.23 ± 1.24^{i}	245.10 ± 0.62^{i}	220.94 ± 0.13^{g}	44.61 ± 0.03^{h}
Pr>F (Model)		<0.0001	<0.0001	<0.0001	<0.0001
Significant		Yes	Yes	Yes	Yes

The value represents mean ± standard deviation (SD. 0% is the control shea fruit leather with no gelatin added to it. Values within the column having no common superscript are statistically different (p< 0.05).

4.4 Sensory Characteristics of shea fruit leather

The results of the sensory evaluation of shea fruit leathers produced at different drying air temperature and gelatin levels are shown in Figure 4.4. At 50 °C, the shea fruit leather appearance scores range from 5.40 to 5.90, with hot air drying at 50 °C and 4% gelatin level (HA50-4) achieving the highest score. This suggests that increasing gelatin level improves the visual appeal of the shea fruit leather slightly. At 60 °C, shea fruit leather appearance scores are similar, ranging from 5.27 (HA60-4) to 5.93 (HA60-1), indicating a trend which is comparable to 50 °C but with slightly lower scores at higher gelatin levels. The drying air temperature appears to have minimal impact on appearance, with differences likely attributed to the variations in gelatin levels.

Colour scores at 50 °C varies between 5.00 (HA50-1) and 5.63 (HA50-3). At 60 °C, colour scores are slightly higher, varying from 5.37 (HA60-2) to 6.40 (HA60-2), with HA60-2 achieving the highest score overall. The reason could be that, higher drying air temperatures may improve upon colour due to Maillard reactions at higher temperatures. On the other hand, aroma scores are relatively consistent across the shea fruit leather samples, with slight variations. Drying air temperature 50 °C, generated scores varying from 5.23 (HA50-3) to 5.80 (HA50-1), indicating that gelatin level does not drastically affect aroma. At 60 °C, the score is similar (5.37 to 6.03), but HA60-3 (3% gelatin) had the highest score. This might suggest that mid-range gelatin levels retain aroma better at higher temperatures. The aroma of food products results from volatile substances such as esters, ketones, aldehydes (Zhao *et al.*, 2023). The loss of these volatiles result in decreased aroma in food products. High aroma acceptability for drying air temperature of 60 °C could be attributed to short drying time used as opposed to 50 °C. Furthermore, longer drying periods could allow for greater loss of volatile substances

Generally, sweetness scores were fairly high across all the shea fruit leather samples. The scores were uniform, varying from 5.43 to 5.77 at 50 °C, but a slight decline of sweetness scores was observed at drying air temperature of 60 °C (5.97 to 6.30). Notably, sweetness may be influenced by and correlated with aroma (Bertelsen *et al.*, 2020). Consequently, the enhanced aroma observed at 60 °C likely contributed to improving the sweetness of the shea fruit leathers produced at this temperature. Scores for texture reveal some differences based on drying air temperature and gelatin levels. Texture scores deferred between 5.20 and 5.60 for 50 °C air temperature, while, 60 °C, scores were slightly more varied, ranging from 4.70 to 6.13, with HA60-4 scoring the lowest. The lower texture scores at higher temperatures with high gelatin levels might indicate that excessive gelatin could lead to a less desirable texture.

Mouthfeel scores were consistent with 50 °C samples ranging from 5.17 to 5.87, and 60 °C samples ranging from 5.67 to 6.13. The slightly higher scores suggest that the higher drying temperature provides a more favourable mouthfeel, potentially due to a more uniform drying process that better balances moisture retention and texture. Overall liking scores depicts the combined sensory attributes. Overall liking at 50 °C ranges from 5.77 to 6.27, with the highest scores for HA50-3 (3% gelatin). At 60 °C, scores are slightly higher, ranging from 5.80 to 6.27, with no single sample standing out significantly. This suggests that while both temperature and gelatin level play a role in overall liking of the shea fruit leather, a slight difference, with mid-range gelatin levels (2 to 3 %) were generally preferred.

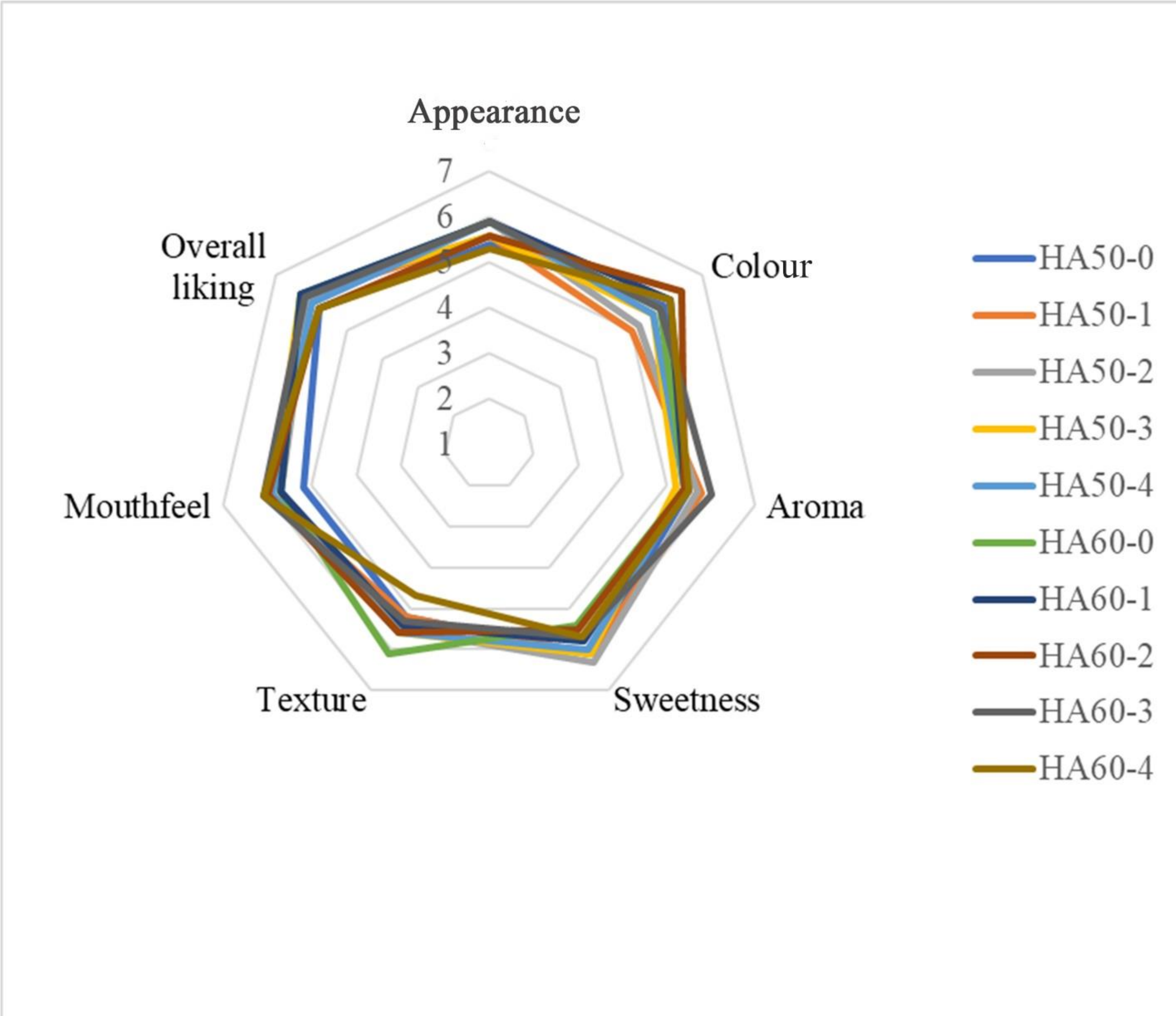

Figure 4. 4: Sensory properties of the shea fruit leather. Sample HA50-0, HA50-1, HA50-2, HA50-3, HA50-4 and HA60-0, HA60-1, HA60-2, HA60-3, HA60-4 represent Hot air drying at 50 °C and 60 °C at 0, 1, 2, 3 and 4% gelatin levels.

4.4.1 Principal Component Analysis (PCA)

In this study, PCA was conducted to analyze the relationships among the quality characteristics of the shea fruit leather and to assess whether the samples were different or similar in terms of their quality attributes (Azam *et al*., 2019**;** Li *et al*., 2020). The correlation loading plot, shown in Figure 4.5, shows the correlation between the quality attributes of the shea fruit leather that were produced at different gelatin levels and drying air temperatures. The PCA results revealed two major components, F1 and F2, which together accounted for approximately 31.25% and 18.23% of the variation in the original data.

The score graphs (Figure 4.5) showed considerable variances in the various shea fruit leathers due to the consistent distribution of the samples among the two quadrates. The correlation loading plot in Figure 4.5 revealed that the positive axis of F1 was defined by quality parameters such as moisture, redness (a*), colour, mouthfeel, water activity, and lightness (L*). Shea fruit leather samples HA60-2, HA50-3, HA50-4, HA60-3 and HA60-4 dominated these characteristics. There was a negative correlation between HA50-0 and HA50-1 which had quality attributes such as flavonoids, b*, antioxidant and phenolics. Furthermore, shea fruit leather quality characteristics that are predominant in HA50-2, HA60-0, and HA60-1 include carotenoids, sweetness, appearance, texture, aroma and overall liking defined the positive axis of F1.

The PCA reveals a substantial positive association between a*, L* and water activity of the shea fruit leather. Nonetheless, there was a clear correlation found between moisture and other sensory qualities including mouthfeel. This implies that the shea fruit leather's texture gets better as the ultimate moisture level rises. Additionally, there is a positive correlation between the colour of the shea fruit leather and its redness (a*). This means that a significant change in a* will lead to a corresponding change in the shea fruit leather samples' colour likeness.

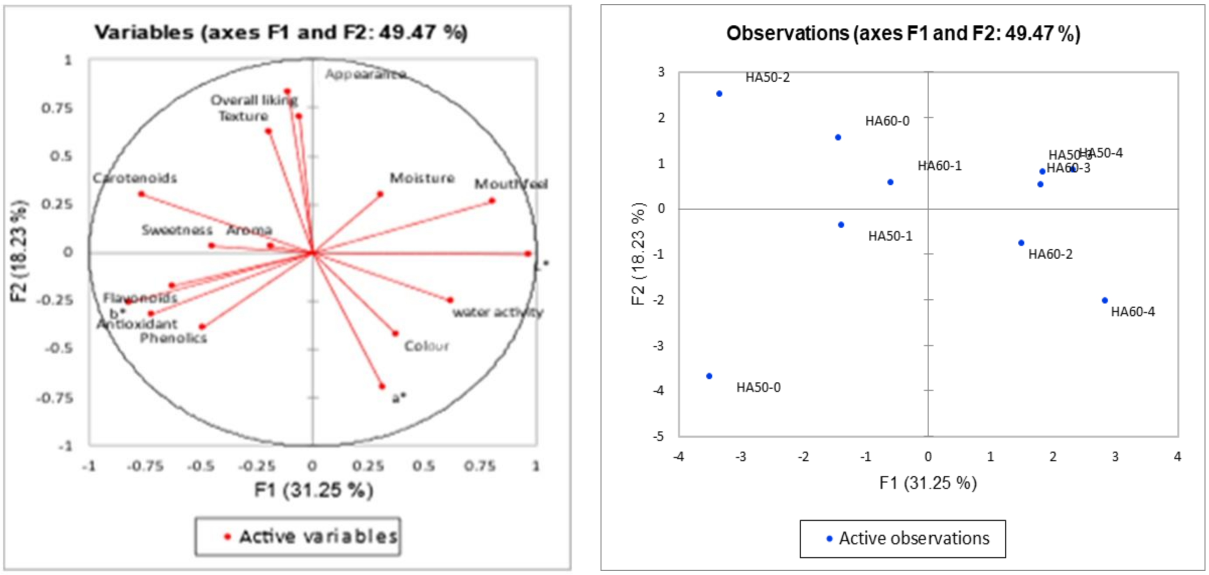

Figure 4. 5: Sample HA50-0, HA50-1, HA50-2, HA50-3, HA50-4 and HA60-0, HA60-1, HA60-2, HA60-3, HA60-4 represent hot air drying at 50 °C for 0, 1, 2, 3, and 4% gelatin levels and hot air drying at 60 °C for 0, 1, 2, 3, and 4% gelatin levels, respectively.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study was to investigate the effect of different gelatin addition and drying air temperature on the drying kinetics, energy consumption and the quality of shea fruit leather. It was observed that higher gelatin levels led to shorter drying periods as the results demonstrated that gelatin had a positive influence on drying efficiency. Non-linear trends were recorded for drying air temperature. The experimental data was fitted to six thin-layer drying models and the Midilli et al model was found to be a better model describing the drying process of the shea fruit leather. The values of D_{eff} increased from 3.91×10^{-12} to 1.44×10^{-11} for 50 °C and 1.04×10^{-11} to 2.76×10^{-11} for 60 °C for shea fruit leather samples while E_a varied from 13.20 to 87.71 $kJmol^{-1}$. The study's findings indicate that as the drying air temperature increases, the energy consumption decreases with a non-linear trend recorded for gelatin levels. The final moisture content ranged from 18.288% - 21.114%, and a_w values were between 0.1235 and 0.2565. The different gelatin levels and drying air temperatures significantly ($p = 0.001$) influenced the colour parameters of the shea fruit leather. The overall colour change (ΔE^*) significantly ($p = 0.001$) increased as drying air temperature increased and decreased as gelatin levels increased. Generally, drying of the shea fruit leather at reduced temperature (50 °C) was observed to reduce TCC while the highest retention of TFC, TPC and TAC was observed at 60 °C. Overall liking ranges between 5.77 and 6.27 for 50 °C and 5.80 and 6.27 for 60 °C with mid-range (2 and 3 %) gelatin levels generally preferred.

5.2 Recommendations

The findings of this work contribute to a better understanding of shea fruit leather drying behaviour during hot air drying along with different levels of gelatin and the established models are a good tool for predicting, evaluating and controlling quality change of shea fruit leather components during its drying process. However, further research be conducted on other hydrocolloids (guar gum, potato starch etc) for further optimization. Also, different drying techniques (solar, hybrid dryers etc) can be employed for further research. Lastly, research can be conducted to determine the storage stability of the developed shea fruit leather products.

REFERENCES

Addai, Z. R., Abdullah, A., Mutalib, S. A., & Musa, K. H. (2016). Evaluation of fruit leather made from two cultivars of papaya. *Italian Journal of Food Science*, *28*(1), 73–82.

Aghbashlo, M., kianmehr, M. H., & Samimi-Akhijahani, H. (2008). Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (Berberidaceae). *Energy Conversion and Management*, *49*(10), 2865–2871.

Aguzue, O. C., Akanji, F. T., Tafida, M. A., & Kamal, M. J. (2013). Nutritional and some elemental composition of shea (Vitellaria paradoxa) fruit pulp. *Archives of Applied Science and Research*, *5*, 63-65.

Aidani, E., Hadadkhodaparast, M., & Kashaninejad, M. (2017). Experimental and modeling investigation of mass transfer during com_bined infrared-vacuum drying of Hayward kiwifruits. *Food Sci Nutr*, *5*, 596–601.

Akgun, N. A., & Doymaz, I. (2005). Modelling of olive cake thin-layer drying process. *Journal of Food Engineering*, *68*(4), 455–461.

Akoma, O., Nma, N., Musa, S., & Salihu, A. (2018). Nutritional and phytochemical composition of Vitellaria paradoxa (Shea Fruit Pulp). *International Journal of Biochemistry Research Review 22:1–7*.

Al-Hinai, K. Z., Guizani, N., Singh, V., Rahman, M. S., & Al-Subhi, L. (2013). Instrumental texture profile analysis of date-tamarind fruit leather with different types of hydrocolloids. *Food Science and Technology Research*, *19(4)*, 531-538.

Ali, M. A., Yusof, Y. A., Chin, N. L., & Ibrahim, M. N. (2016). Effect of different drying treatments on colour quality and ascorbic acid concentration of guava fruit. *International Food Research Journal*, 23.

Alu, S. E., & Randa, E. A. (2019). Nutritional value of Shea Butter (Vitellaria paradoxa) seed Meal (SBSM) as affected by different days of Natural fermentation. *Nigerian Annals of Pure and Applied Sciences*, *1*, 196–201.

Amit, S. K., Uddin, M. M., Rahman, R., Islam, S. M. R., & Khan, M. S. (2017). A review on mechanisms and commercial aspects of food preservation and processing. *Agriculture and Food Security*, *6*(1), 1–22.

Aremu, M. O., Andrew, C., Salau, R. B., Atolaiye, B. O., Yebpella, G. G., & Enemali, M. O. (2019). Comparative Studies on the Lipid Profile of Shea (Vitellaria paradoxa C.F. Gaertn.) Fruit Kernel and Pulp. *Journal of Applied Sciences*, *19*(5), 480–486.

Argyropoulos, D., & Müller, J. (2014). Kinetics of change in colour and rosmarinic acid equivalents during convective drying of lemon balm (Melissa officinalis L.). *Journal of Applied Research on Medicinal and Aromatic Plants*, *1*(1), e15–e22.

Arslan, D., Özcan, M. M., & Mengeş, H. O. (2010). Evaluation of drying methods with respect to drying parameters, some nutritional and colour characteristics of peppermint (Mentha x piperita L.). *Energy Conversion and Management*, *51*, 2769–2775.

Azeredo, H. M. C., Brito, E. S., Moreira, G. E. G., Farias, V. L., & Bruno, L. M. (2006). Effect of drying and storage time on the physico-chemical properties of mango leathers. *International Journal of Food Science and Technology*, *41*(6), 635–638.

Barbosa-Cánovas, G. V, Fontana, A. J. J., Schmidt, S. J., & Labuza, T. P. (2007). Water activity in foods. *Fundamentals and Applications.*, *Washington*, *USA.: Blackwell Publishing.*

Basumatary, B., Bhattacharya, S., & Das, A. B. (2020). Olive (Elaeagnus latifolia) pulp and leather: Characterization after thermal treatment and interrelations among quality attributes. *Journal of Food Engineering*, *278*, 109948.

Bertelsen, A. S., Mielby, L. A., Alexi, N., Byrne, D. V., & Kidmose, U. (2020). Individual differences in sweetness ratings and cross-modal aroma-taste interactions. *Foods*, *9*(2).

Byakagaba, P., Eilu, G., Okullo, J. B. L., & Al, E. (2011). Population structure and regeneration status of Vitellaria paradoxa (CF Gaertn.) under different land management regimes in Uganda. *Agric Journal*, *6*, 14–22.

Cardi, C., Vaillant, A., Sanou, H., Kelly, B., & Bouvet, J. M. (2005). Characterization of microsatellite markers in the shea tree (Vitellaria paradoxa C. F. Gaertn.) in Mali. *Mol Ecol Notes*, *5*, 524–526.

Chakravarty, S., Bhutia, K. D., Suresh, C. P., Shukla, G., & Pala, N. A. (2016). A review on diversity, conservation and nutrition of wild edible fruits. *Journal of Applied and Natural Science*, *8*(4), 2346–2353.

Chayjan, R. A., Kaveh, M., & Khayati, S. (2014). Modeling some drying characteristics of sour cherry (Prunus cerasus L .) under infrared radiation using mathematical models and artificial neural networks. *Agric Eng Int: CIGR Journal*, *16*(1), 265－279.

Chen, Y., & Martynenko, A. (2018). Combination of hydrothermodynamic (HTD) processing and different drying methods for natural blueberry leather. *LWT*, *87*, 470-477.

Chikpah, S. K., Korese, J. K., Hensel, O., Sturm, B., & Pawelzik, E. (2023). Influence of blend proportion and baking conditions on the quality attributes of wheat, orange-fleshed sweet potato and pumpkin composite flour dough and bread: optimization of processing factors. *Discover Food*, *3(1)*, 2.

Chikpah, S. K., Korese, J. K., & Osman, S. (2023). Characterization of physicochemical , antioxidants and sensory properties of cookies enriched with shea (Vitellaria paradoxa) fruit pulp as a functional ingredient. *Food Production, Processing and Nutrition*, 1–16.

Chikpah, S. K., Korese, J. K., Sturm, B., & Hensel, O. (2022). Colour change kinetics of pumpkin (Cucurbita moschata) slices during convective air drying and bioactive compounds of the dried products. *Journal of Agriculture and Food Research*, *10*, 100409.

Cichella Frabetti, A. C., de Moraes, J. O., Porto, A. S., Simão, R. da S., & Laurindo, J. B. (2021). Strawberry-hydrocolloids dried by continuous cast-tape drying to produce leather and powder. *Food Hydrocolloids*, *121*(July).

Concha-Meyer, A. A., D'Ignoti, V., Saez, B., Diaz, R. I., & Torres, C. A. (2016). Effect of storage on the physico-chemical and antioxidant properties of strawberry and kiwi leathers. *J Food Sci*, *81*, 569–577.

da Silva Simão, R., de Moraes, J. O., Carciofi, B. A. M., & Laurindo, J. B. (2020). Recent Advances in the Production of Fruit Leathers. *Food Engineering Reviews*, *12*(1), 68–82.

da Silva Simão, R., de Moraes, J. O., de Souza, P. G., Carciofi, B. A. M., & Laurindo, J. B. (2019). Production of mango leathers by cast-tape drying: Product characteristics and sensory evaluation. *LWT*, *99*, 445-452.

Delfya, D. S. A., Prashob, K., Murali, S., Alfya, P. V, Samuel, M. P., & Pandiselvam, R. (2022). Drying kinetics of food materials in infrared radiation drying: A review. *J Food Process Eng*, *45*, 1–19.

Demarchi, S. M., Ruiz, N. A. Q., Concellón, A., & Giner, S. A. (2013). Effect of temperature on hot-air drying rate and on retention of antioxidant capacity in apple leathers. *Food and Bioproducts Processing*, *91(4)*, 310-318.

Di Vincenzo, D., Maranz, S., Serraiocco, A., Vito, R., Wiesman, Z., & Bianchi, G. (2005). Regional variation in shea butter lipid and triterpene composition in four African countries. *Journal of Agricultural and Food Chemistry*, *53*(19), 7473–7479.

Diamante, L. M., Bai, X., & Busch, J. (2014). Fruit leathers: method of preparation and effect of different conditions on qualities. *International Journal of Food Science*.

Diamante, L. M., Li, S., Xu, Q., & Busch, J. (2013). Effects of apple juice concentrate, blackcurrant concentrate and pectin levels on selected qualities of apple-blackcurrant fruit leather. *Foods*, *2*(3), 430–443.

Dinrifo, R. R. (2012). Effects of pre-treatments on drying kinetics of sweet potato slices. *Agricultural Engineering International: CIGR Journal*, *14*(3), 136–145.

Donkor, M. N., Mosobil, R., Abaah, E. A., & Al, E. (2021). Potential of shea fruit-based ingredients for the feed industry. *Agricultural Food Security*, 10:54.

Doymaz, I. (2007). The kinetics of forced convective air-drying of pumpkin slices. *Journal of Food Engineering*, *79*(1), 243–248.

Doymaz, İ. (2017). *Drying kinetics, rehydration and colour characteristics of convective hot-air* *drying of carrot slices. Heat Mass Transfer*. *53*, 25–35.

Doymaz, I., Karasu, S., & Baslar, M. (2016). Effects of infrared heating on drying kinetics, antioxidant activity, phenolic content, and color of jujube fruit. *Journal of Food Measurement and Characterization*.

El-Mesery, H. S., Farag, H. A., Kamel, R. M., & Alshaer, W. G. (2023). Convective hot air drying of grapes: drying kinetics, mathematical modeling, energy, thermal analysis. *Journal of Thermal Analysis and Calorimetry*, *148(14)*, 6893-6908.

Elhussein, E. A. A., & Şahin, S. (2018). Drying behaviour, effective diffusivity and energy of activation of olive leaves dried by microwave, vacuum and oven drying methods. *Heat and Mass Transfer/Waerme- Und Stoffuebertragung*, *54*(7), 1901–1911.

Eyiz, V., Tontul, İ., & Türker, S. (2020). Effect of variety, drying methods and drying temperature on physical and chemical properties of hawthorn leather. *Journal of Food Measurement and Characterization*, *14*(6), 3263–3269.

Fontaine, C., Lovett, P. N., Sanou, H., Maley, J., & Bouvet, J. M. (2004). Genetic diversity of the shea tree (Vitellaria paradoxa C.F. Gaertn.), detected by RAPD and chloroplast microsatellite markers. *Heredity*, *93*, 639-648.

Fulchand, C. R., Gunvantrao, J. V., & Pralhad, I. M. (2015). Studies on effect of drying temperature and storage time on vitamin-C retention capacity and moisture content of papaya-apple fruit leather. *Asian Journal of Dairy and Food Research*, *34*(4).

Giacalone, D. (2018). Sensory and Consumer Approaches for Targeted Product Development in the Agro-Food Sector. In *Case Studies in the Traditional Food Sector: A Volume in the*

Consumer Science and Strategic Marketing Series. Elsevier Ltd.

Gómez-Pérez, L. S., Navarrete, C., Moraga, N., Rodríguez, A., & Vega-Gálvez, A. (2020). Evaluation of different hydrocolloids and drying temperatures in the drying kinetics, modeling, color, and texture profile of murta (Ugni molinae Turcz) berry leather. *Journal of Food Process Engineering*, *43(2)*, e13316.

Gujral, H. S., & Brar, S. S. (2003). Effect of hydrocolloids on the dehydration kinetics, color, and texture of mango leather. *International Journal of Food Properties*, *6*(2), 269–279.

Gujral, H. S., & Khanna, G. (2002). Effect of skim milk powder, soy protein concentrate and sucrose on the dehydration behaviour, texture, color and acceptability of mango leather. *Journal of Food Engineering*, *55*(4), 343–348.

Gujral, H. S., Oberoi, D. P. S., Singh, R., & Gera, M. (2013). Moisture diffusivity during drying of pineapple and mango leather as affected by sucrose, pectin, and maltodextrin. *International Journal of Food Properties*, *16*(2), 359–368.

Gwali, S., Vaillant, C. A., Nakabongea, G., Okulloa, J., Eilua, G., Muchugid, A., & Bouvet, C. . J. (2014). Genetic diversity in shea tree (Vitellaria paradoxa subspecies nilotica) ethno-varieties in Uganda assessed with microsatellite markers. *Forests Trees and Livelihoods*, *24(3)*, 163–175.

Gyedu-Akoto, E., Amon-Armah, F., & Yabani, D. (2017). Utilization of shea fruit to enhance food security and reduce poverty in Ghana. *African Journal of Science, Technology, Innovation and Development*, *9*(6), 697–705.

Hall, J. B., Aebischer, D. P., Tomlinson, H. F., Osei-Amaning, E., & Hindle, J. R. (1996).

Vitellaria paradoxa. A monograph. University of Wales, Bangor. 8.

Hatskevich, A., Jeníček, V., & Darkwah, S. A. (2011). Shea industry - a means of poverty reduction in northern in Ghana. *Agricultura Tropica et Subtropica*, *44*(4), 223–228.

Heaton, J. C., & Jones, K. (2008). Microbial contamination of fruit and vegetables and the behaviour of enteropathogens in the phyllosphere: a review. *Journal of Applied Microbiology*, *104(3)*, 613-626.

Henderson, S. M., & Pabis, S. (1961). Grain drying theory I: Temperature effect on drying coefficient. *Journal of Agriculture Research Engineering*, *6*, 169–174.

Honfo, F. G., Akissoe, N., Linnemann, A. R., Soumanou, M., & Van Boekel, M. A. J. S. (2014). Nutritional Composition of Shea Products and Chemical Properties of Shea Butter: A Review. *Critical Reviews in Food Science and Nutrition*, *54*(5), 673–686.

Hssaini, L., Ouaabou, R., Hanine, H., Razouk, R., & Idlimam, A. (2021). Kinetics, energy efficiency and mathematical modeling of thin layer solar drying of figs (Ficus carica L.). *Scientific Reports*, *11*(1), 1–21.

Huang, X., & Hsieh, F. H. (2005). Physical properties, sensory attributes, and consumer preference of pear fruit leather. *Journal of Food Science*, *70*(3).

Iddrisu, A., Zakpaa, H. D., Mills-Robertson, F. C., & Lowor, S. T. (2020). Vitellaria paradoxa fruit pulp bioethanol production potential: a review. *African Journal of Biochemistry Reserve*, *14*, 33–45.

Izli, N., Izli, G., & Taskin, O. (2018). Impact of different drying methods on the drying kinetics, color, total phenolic content and antioxidant capacity of pineapple. *CYTA - Journal of Food*, *16*(1), 213–221.

Jayakody, M. M., Kaushani, K. G., Vanniarachchy, M. P. G., & Wijesekara, I. (2023). Hydrocolloid and water soluble polymers used in the food industry and their functional properties: a review. *Polymer Bulletin*, *80*(4), 3585–3610.

Jha, A. K., & Sit, N. (2020). Drying characteristics and kinetics of colour change and degradation of phytocomponents and antioxidant activity during convective drying of deseeded Terminalia chebula fruit. *Journal of Food Measurement and Characterization*, *14*(4), 2067–2077.

Jiménez-Moreno, N., Esparza, I., Bimbela, F., & Gandía, L. M Ancín Azpilicueta, C. (2020). Valorization of selected fruit and vegetable wastes as bioactive compounds: Opportunities and challenges. *Critical Review of Environmental Science and Technology*, *50*, 2061–2108.

Juthong, T., Theppradit, R., Jitkaew, J., & Kasemsa, O. (2019). Effect of pectin and maltodextrin and drying temperature on qualities of tamarind leather. *Bioresearch Communications-(BRC)*, *05*(01), 610–615.

Kalinganire, A., Weber, J. C., Uwamariya, A., & Kone, B. (2008). Improving rural livelihoods through domestication of indigenous fruit trees in the parklands of the Sahel. *Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization*, 186–203.

Karabacak, A. Ö., Suna, S., Çopur, U., & Dorak, S. (2021). Drying Characteristics, Mineral Content, Texture and Sensorial Properties of Pumpkin Fruit Leather. *Latin American Applied Research*, *51*(3), 193–201.

Karam, M. C., Petit, J., Zimmer, D., Baudelaire Djantou, E., & Scher, J. (2016). Effects of drying and grinding in production of fruit and vegetable powders: A review. *Journal of Food Engineering*, *188*, 32–49.

Karambiri, M., Elias, M., Vinceti, B., & Grosse, A. (2017). *Exploring local knowledge and preferences for shea (Vitellaria paradoxa) ethnovarieties in Southwest Burkina Faso through a gender and ethnic lens. Forests, Trees and Livelihoods*. *26*, 13–28.

Kelly, B. A., Bouvet, J. M., & Picard, N. (2004). Size class distribution and spatial pattern of Vitellaria paradoxa in relation to farmers' practices in Mali. *Agroforestry Systems*, *60*, 3-11.

Korese, J. K., & Achaglinkame, M. A. (2024). Convective drying of Gardenia erubescens fruits: Effect of pretreatment, slice thickness and drying air temperature on drying kinetics and product quality. *Heliyon*, *10*(4), e25968.

Korese, J. K., Achaglinkame, M. A., & Chikpah, S. K. (2021). Effect of hot air temperature on drying kinetics of palmyra (Borassus aethiopum Mart.) seed-sprout fleshy scale slices and quality attributes of its flour. *J. Agric. Food Reservation*, *6*, 1–10.

Korese, J. K., Achaglinkame, M. A., & Chikpah, S. K. (2021c). Effect of hot air temperature on drying kinetics of palmyra (Borassus aethiopum Mart.) seed-sprout fleshy scale slices and quality attributes of its flour. *Journal of Agriculture and Food Research*, *6*(December).

Korese, J. K., & Chikpah, S. K. (2023). Understanding infrared drying behavior of shea (Vitellaria paradoxa) fruit by-product for the production of value-added products. *Biomass Conversion and Biorefinery*, *13(16)*, 15001-15015.

Korese, J. K., Chikpah, S. K., Hensel, O., Pawelzik, E., & Sturm, B. (2021). Effect of orange-fleshed sweet potato flour particle size and degree of wheat flour substitution on physical, nutritional, textural and sensory properties of cookies. *European Food Research and Technology*, *247*(4), 889–905.

Kumar, R., Mandal, G., & Jain, R. K. (2005). Storage stability of guava leather in different packing materials. *In I International Guava Symposium*, *735*, 621-625).

Lamien-Meda, A., Lamien, C. E., Compaoré, M. M., Meda, R. N., Kiendrebeogo, M., Zeba, B., & Nacoulma, O. G. (2008). Polyphenol content and antioxidant activity of fourteen wild edible fruits from Burkina Faso. *Molecules*, *13(3)*, 581-594.

Lee, B., & Kim, C. Y. (2022). Dietary Bioactive Compounds and Health. *Foods*, *11*(16), 10–12.

Li, P., Qi, X., Wu, G., Yang, D., Jin, Q., & Wang, X. (2020). *Applying sensory and instrumental techniques to evaluate the texture of French fries from fast food restaurant*. *January*, 521–531.

Maanikuu, P. M. I., & Peker, K. (2017). Medicinal and nutritional benefits from the shea tree- (Vitellaria Paradoxa). *Journal of Biology, Agriculture and Healthcare*, *7(22)*, 51-57.

Maranz, S., Kpikpi, W., Wiesman, Z., & Al, E. (2004). Nutritional values and indigenous preferences for shea fruits (vitellaria paradoxa C.F. Gaertn. F.) in African Agroforestry Parklands. *Econ Bot*, *58*, 588–600.

Maranz, S., & Weisman, Z. (2003). Evidence for indigenous selection and distribution of the shea tree, Vitellaria paradoxa, and its potential significance to prevailing parkland savanna tree patterns in sub-Saharan Africa north of the equator. *Journal of Biogeography*, *30*, 1505-1516.

Maskan, A., Kaya, S., & Maskan, M. (2002). Hot air and sun drying of grape leather (pestil). *Journal of Food Engineering*, *54(1)*, 81-88.

Meziane, S. (2011). Drying kinetics of olive pomace in a fluidized bed dryer. *Energy Conversion and Management*, *52*(3), 1644–1649.

Midilli, A., Kucuk, H., & Yapar, Z. A. (2002). New model for single layer drying. *Drying Technology*, *20*, 1503–1513.

Miraei Ashtiani, S. H., Sturm, B., & Nasirahmadi, A. (2018). Effects of hot-air and hybrid hot air-microwave drying on drying kinetics and textural quality of nectarine slices. *Heat and Mass Transfer/Waerme- Und Stoffuebertragung*, *54*(4), 915–927.

Moradi, M., Niakousari, M., & Mousavi Khaneghah, A. (2019). Kinetics and mathematical modeling of thin layer drying of osmo-treated Aloe vera (Aloe barbadensis) gel slices. *Journal of Food Process Engineering*, *42*(6).

Moreira, G. E. G., Farias, V. L., & Bruno, L. M. (2006). Azeredo HMC, Brito ES, Effect of drying and storage time on the physico-chemical properties of mango leathers. *International Journal of Food Science and Technology*, *41*, 635–638.

Mphaphuli, T., Manhivi, V. E., Slabbert, R., Sultanbawa, Y., & Sivakumar, D. (2020). Enrichment of mango fruit leathers with Natal plum. *Foods*, *9*(431), 1–14.

Mühlbauer, H. W., & Müller, J. (2020). Drying Atlas: Drying kinetics and quality of agricultural products. *Woodhead Publishing*.

Naughton, C. C., Lovett, P. N., & Mihelcic, J. R. (2015). Land suitability modeling of shea (Vitellaria paradoxa) distribution across sub_Saharan Africa. *Applied Geography*, 58:217–227.

Ndlovu, P. F. (2016). The development of indigenous marula (sclerocarya birrea) fruit leather:

effect of drying temperature and sugar concentration on the drying characteristics, physico-chemical and consumer sensory properties of marula fruit leathers. *(Doctoral Dissertation), . M.Sc. Thesis, University of KwaZulu-Natal, South Africa.*

Nourhène, B., Mohammed, K., & Nabil, K. (2008). Experimental and mathematical investigations of convective solar drying of four varieties of olive leaves. *Food and Bioproducts Processing*, *86*(3), 176–184.

Nyarko, G., Mahunu, G. K., Chimsah, F. A., Yidana, J. A., Abubakari, A. H., Abagale, F. K., Quainoo, A., & Poudyal, M. (2012). Leaf and fruit characteristics of Shea (Vitellaria paradoxa) in Northern Ghana. *Res. Plant Biol*ogy, *2(3)*, 38-45.

Offia-Olua, B. I., & Ekwunife, O. A. (2015). Production and evaluation of the physico-chemical and sensory qualities of mixed fruit leather and cakes produced from apple (Musa Pumila), banana (Musa Sapientum), pineapple (Ananas Comosus). *Nigerian Food Journal*, *33*(1), 22–28.

Okiror, P., Agea, J. G., Okia, C. A., & Okullo, J. B. L. (2012). On-Farm Management of Vitellaria paradoxa C. F. Gaertn. In Amuria District, Eastern Uganda. *International Journal of Forestry.*

Okullo, J. B. ., Hall, J. ., & Obua, J. (2004). Leafing, Flowering and Fruiting of Vitellaria paradoxa Subsp. Nilotica in Savanna Parklands in Uganda. *Agrofor. Syst.*, *60*, 77–91.

Okullo, J. B. L. (2004). Vitellaria paradoxa in Uganda: Population structures and reproductive characteristics. *University of Wales, Bangor*.

Okullo, J. B. L., Omujal, F., Agea, J. G., Vuzi, P. C., Namutebi, A., Okello, J. B. A., & Nyanzi, S. A. (2010). Proximate and mineral composition of shea (Vitellaria paradoxa CF Gaertn) fruit pulp in Uganda. *African Journal of Food, Agriculture, Nutrition and Development*, *10(11).*

Pathare, P. B., Opara, U. L., & Al-Said, F. A. J. (2013). Colour Measurement and Analysis in Fresh and Processed Foods: A Review. *Food and Bioprocess Technology*, *6*(1), 36–60.

Patil, S., Shere, P., Sawate, A., & Mete, B. (2017). Effect of hydrocolloids on textural and sensory quality of date-mango leather. *Journal of Pharmacognosy and Phytochemistry*, *6*(5), 399–402.

Perez, N. E., & Schmalko, M. E. (2009). Convective drying of pumpkin: Influence of pretreatment and drying temperature. *Journal of Food Process Engineering*, *32*(1), 88–103.

Quintero Ruiz, N. A., Demarchi, S. M., & Giner, S. A. (2014). Effect of hot air, vacuum and infrared drying methods on quality of rose hip (Rosa rubiginosa) leathers. *International Journal of Food Science & Technology*, *49(8)*, 1799-1804.

Rahman, M. S. (2007). Handbook of food preservation. *CRC Press.*, 3–18.

Raj, G. B., & Dash, K. K. (2022). Development of Hydrocolloids Incorporated Dragon Fruit Leather by conductive hydro drying: Characterization and Sensory Evaluation. *Food Hydrocolloids for Health*, *2*(March), 100086.

Ramallo, L. A., & Mascheroni, R. H. (2012). Quality evaluation of pineapple fruit during drying process. *Food and Bioproducts Processing*, *90*(2), 275–283.

Raponi, F., Moscetti, R., Monarca, D., Colantoni, A., & Massantini, R. (2017). Monitoring and optimization of the process of drying fruits and vegetables using computer vision: A review. *Sustainability (Switzerland)*, *9*(11).

Rascón-Díaz, M. P., Tejero, J. M., Mendoza-Garcia, P. G., García, H. S., & Salgado-Cervantes,

M. A. (2012). Spray Drying Yogurt Incorporating Hydrocolloids: Structural Analysis, Acetaldehyde Content, Viable Bacteria, and Rheological Properties. *Food and Bioprocess Technology*, *5*(2), 560–567.

Ravani, A., & Joshi, D. (2013). Mango and it's by product utilization–a review. *Energy (Kcal)*, *74(44)*.

Roknul Azam, S. M., Zhang, M., Law, C. L., & Mujumdar, A. S. (2019). Effects of drying methods on quality attributes of peach (Prunus persica) leather. *Drying Technology*, *37*(3), 341–351.

Ruiz, N. A. Q., Demarchi, S. M., Massolo, J. F., Rodoni, L. M., & Giner, S. A. (2012). Evaluation of quality during storage of apple leather. *LWT*, *47(2)*, 485-492.

Sadeghi, E., Asl, A. H., & Movagharnejad, K. (2019a). Mathematical modelling of infrared - dried kiwifruit slices under natural and forced convection. *Food Science and Nutrition*, *7*, 3589–3606.

Sadeghi, E., Asl, A. H., & Movagharnejad, K. (2019b). Mathematical modelling of infrared - dried kiwifruit slices under natural and forced convection. *Food Science and Nutrition*, 1–18.

Sanou, H., & Lamien, N. (2011). Vitellaria paradoxa, shea butter tree conservation and sustainable use of genetic resources of priority food tree species in sub-Saharan Africa Rome. *Bioversity International*.

Sanou, H., Lovett, P. N., & Bouvet, J. M. (2005). Comparison of quantitative and molecular variation in agroforestry populations of the shea tree (Vitellaria paradoxa C.F. Gaertn.) in Mali. *Molecular Ecology*, *14(8)*, 2601-2610.

Sanou, H., Piscard, P. N., Lovett, P. N., & Al, E. (2006). Phenotypic variation of agromorphological traits of the Shea tree, Vitellaria paradoxa C. F. Gaertn., in Mali. *Genetics Resource of Crop Evolution*, *53*, 145–161.

Septembre-Malaterre, A., Remize, F., & Poucheret, P. (2018). Fruits and vegetables, as a source of nutritional compounds and phytochemicals: Changes in bioactive compounds during lactic fermentation. *Food Research International*, *104*, 86–99.

Sharma, P., Ramchiary, M., Samyor, D., & Das, A. B. (2016). Study on the phytochemical properties of pineapple fruit leather processed by extrusion cooking. *Lwt*, *72*, 534–543.

Singh, B., & Gupta, A. K. (2007). Mass transfer kinetics and determination of effective diffusivity during convective dehydration of pre-osmosed carrot cubes. *Journal of Food Engineering*, *79*(2), 459–470.

Singleton, V. L., Orthorfer, R., & Lamuela-Raventós, R. M. (1999). Analysis of Total Phenols and Other Oxidation Substrates and Antioxidants by Means of Folin-Ciocalteu Reagent. *Methods Enzymol.*, *299*, 152–178.

Stępień, A. E., Gorzelany, J., Matłok, N., Lech, K., & Figiel, A. (2019). The effect of drying methods on the energy consumption, bioactive potential and colour of dried leaves of Pink Rock Rose (Cistus creticus). *Journal of Food Science and Technology*, *56*(5), 2386–2394.

Sturm, B., Hofacker, W. C., & Hensel, O. (2012). Optimizing the Drying Parameters for Hot-Air-Dried Apples. *Drying Technology*, *30*(14), 1570–1582.

Suna, S. (2019). Effects of hot air, microwave and vacuum drying on drying characteristics and in vitro bioaccessibility of medlar fruit leather (pestil). *Food Science and Biotechnology*, *28*(5), 1465–1474.

Suna, S., & Özkan-Karabacak, A. (2019). Investigation of drying kinetics and physicochemical properties of mulberry leather (pestil) dried with different methods. *Journal of Food Processing and Preservation*, *43*(8), 1–9.

Suri, S., Singh, A., & Nema, P. K. (2022). Infrared drying of Kinnow (Citrus reticulata) peel waste: kinetics and quality characterization. *Biomass Conversion of Biorefinery*.

Swain, S., Samuel, D. V. K., Bal, L. M., & Kar, A. (2014). Thermal kinetics of colour degradation of yellow sweet pepper (Capsicum Annum L.) undergoing microwave assisted convective drying. *International Journal of Food Properties*, *17*(9), 1946–1964.

Tana, W., & Bie, A. (2021). *applied sciences Effect of By-Products from Selected Fruits and Vegetables on Gluten-Free Dough Rheology and Bread Properties*.

Tontul, I., & Topuz, A. (2017). Effects of different drying methods on the physicochemical properties of pomegranate leather (pestil). *LWT*, *80*, 294-303.

Tontul, I., & Topuz, A. (2018). Production of pomegranate fruit leather (pestil) using different hydrocolloid mixtures: An optimization study by mixture design. *Journal of Food Process Engineering*, *41*(3).

Torki-Harchegani, M., Ghanbarian, D., Ghasemi Pirbalouti, A., & Sadeghi, M. (2016). Dehydration behaviour, mathematical modelling, energy efficiency and essential oil yield of peppermint leaves undergoing microwave and hot air treatments. *Renewable and Sustainable Energy Reviews*, *58*, 407–418.

Torres, C. A., Romero, L. A., & Diaz, R. I. (2015). Quality and sensory attributes of apple and quince leathers made without preservatives and with enhanced antioxidant activity. *LWT-*

Food Science and Technology, 62(2), 996-1003.

Turkmen, N., Sari, F., & Velioglu, Y. S. (2005). The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. *Food Chemistry*, *93*, 713–718.

Ueda, J. M., Pedrosa, M. C., Heleno, S., & Al, E. (2022). Food additives from fruit and vegetable by-products and bio-residues. *A Comprehensive Review Focused on Sustainability.*, *14*, 5212.

Ugese, F. D., Baiyeri, K. P., & Mbah, N. B. (2008a). Mineral content of the pulp of shea butter fruit (Vitellaria paradoxa CF Gaertn.) sourced from seven locations in the savanna ecology of Nigeria. *Tree and Forestry Science and Biotechnology*, *2*(1), 40–42.

Ugese, F. D., Baiyeri, P. K., & Mbah, B. N. (2008b). Nutritional composition of shea (Vitellaria paradoxa) fruit pulp across its major distribution zones in Nigeria. *Fruits*, *63(3)*, 163-170.

Uleria, H. A. R., Barrow, C. J., & Dunshea, F. R. (2020). Screening and char_acterization of phenolic compounds and their antioxidant capacity in diferent fruit peel. *Foods*, *9*, 1206.

Valenzuela, C., & Aguilera, J. M. (2013). Aerated apple leathers: effect of microstructure on drying and mechanical properties. *Drying Technology*, *31(16)*, 1951-1959.

Valenzuela, C., & Aguilera, J. M. (2015). Effects of maltodextrin on hygroscopicity and crispness of apple leathers. *Journal of Food Engineering*, *144*, 1-9.

Villamiel, M., Del Castillo, M. D., Villamiel, M., Del Castillo, M. D., & Corzo, N. (2006). Browning reactions. *Food Biochemistry and Food Processing,* 71-100.

Wandi, I. R., & Man, Y. B. C. (1996). Durian leather: development, properties and storage stability. *Journal of Food Quality*, *19(6)*, 479–489.

Wang, Z., Sun, J., Liao, X., Chen, F., Zhao, G., Wu, J., & Hu, X. (2007). Mathematical modeling on hot air drying of thin layer apple pomace. *Food Research International*, *40*(1), 39–46.

Wen, Y. X., Chen, L. Y., Li, B. S., Ruan, Z., & Pan, Q. (2021). Effect of infrared radiation-hot air (IR-HA) drying on kinetics and quality changes of star anise (Illicium verum). *Drying Technology*, *39*(1), 90–103.

Yaldiz, O., & Ertekin, C. (2001). Thin layer solar drying of some vegetables. *Drying Technology*, *19*, 583–597.

Yemiş, O., Bakkalbaşı, E., & Artık, N. (2012). Changes in pigment profile and surface colour of fig (Ficus carica L.) during drying. *International Journal Food Science and Technology*, *47(8)*, 1710–1719.

Yılmaz, F. M., Yüksekkaya, S., Vardin, H., & Karaaslan, M. (2017). The effects of drying conditions on moisture transfer and quality of pomegranate fruit leather (pestil). *Journal of the Saudi Society of Agricultural Sciences*, *16(1)*, 33-40.

Zeng, Y., Liu, Y., Zhang, J., Xi, H., & Duan, X. (2019). Effects of far-infrared radiation temperature on drying characteristics, water status, microstructure and quality of kiwifruit slices. *Journal of Food Measurement and Characterization*, *13*(4), 3086–3096.

Zhao, X., Guo, Y., Zhang, Y., Pang, X., Wang, Y., Lv, J., & Zhang, S. (2023). Effects of different heat treatments on Maillard reaction products and volatile substances of camel milk. *Frontiers in Nutrition*, *10*.