EFFECTS OF FREEZE, VACUUM-OVEN AND HOT AIR DRYING ON VITAMIN A AND C CONTENT IN ORANGE-FLESHED SWEET POTATOES AND MANGOES

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ABSTRACT

Mangoes and orange fleshed sweet potatoes (OFSP) are highly consumed but perishable crops with large postharvest losses. Micronutrient deficiencies result from food insecurity and a lack of nutritious food consumption. Drying is one method of reducing post-harvest losses and increasing food shelf life to increase food security and micronutrient intake. Drying can affect the chemical and physical properties of fruits and vegetables.

The aim of this study was to determine how freeze, vacuum oven, and hot air-drying methods affect the vitamin A and C contents of mangoes and OFSP.

The results of this research indicated that drying processes had different impacts on the quality and nutritional content of mango and OFSP.

Total carotenoid concentrations were significantly affected by the drying methods used, as these compounds were sensitive to drying conditions. Freeze drying of OFSP preserved more carotenoids compared to other drying methods, whereas in mangoes hot air drying resulted in the greatest retention of carotenoids. Ascorbic acid concentrations in this study were not significantly affected by the specific drying methods and conditions used.

This research shows that when drying a product there is a need to consider what impact each drying method has on the product being dried and the properties that need to be preserved.

I dedicate this to my family, who have always inspired me to pursue my goals and further my education.

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LIST OF ABBREVIATIONS

ANOVA	Analysis Of Variance
AOAC	Association of Official Agricultural Chemists
CIE	Lab color space
COVID	Coronavirus Disease
DARS	Department of Agriculture Research Services
DB	Dry Basis
FAO	Food and Agriculture Organization
FW	Fresh Weight
HMF	Hydroxy Methyl Furfural
HPLC	High Performance Liquid Chromatography
IU	International Unit
MGDS	Malawi Growth and Development Strategy
MSU	Michigan State University
MT	Metric Tone
MV	Millivolts
NM	Nanometer
NC	North Carolina
OFSP	Orange-Fleshed Sweet Potatoes
RAE	Retinol Activity Equivalents
SAS	Statistical Analysis System
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa
TCEP	Tris (2-carboxyethyl) phosphine
USA	United States of America

VAD	Vitamin A Deficiency
VAS	Vitamin A Supplement
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1.BACKGROUND

Nutrients are classified into two types: macronutrients (carbohydrates, proteins, and fats) that are required in large amounts by the body and micronutrients (vitamins, minerals, and phytochemicals) that are required in small quantities by the body.

The World Health Organization (WHO) estimates that more than two billion people are affected by micronutrient deficiencies and a large proportion of these people come from low and middle income countries including Malawi, due to different factors like poor diet and limited access to nutritious food (World Health Organization, 2022).

Micronutrient deficiencies, which are also known as hidden hunger, are a type of malnutrition that are caused by lack of sufficient vitamins and minerals needed in the body for optimal health; an example of this type of deficiency is vitamin A deficiency (VAD) (World Health Organization, 2022).

Micronutrients, like other nutrients, are essential for the body. They include vitamins (for example, A,B,C) and minerals, and they are required in relatively small amounts. They are necessary to the body in both children and adults especially women in child bearing age. Insufficient micronutrient intake can result in deficiencies, which are considered a major global health issue because these micronutrient deficienciencies can affect both physical and mental development, and can cause life-threatening conditions (Ritchie & Roser, 2017; World Health Organization, 2022).

Vitamin A deficiency (VAD) is a major cause childhood blindness, contributing to the morbidity and mortality rate from various infections in children and pregnant women. It causes a variety of symptoms such as anemia and a weakened immune system, which leads to increased severity of infectious diseases and death (Manusevich Wiseman et al., 2017; Williams et al., 2021).

Malawi is one of the Sub-Saharan African countries that historically has suffered from micronutrient deficiencies, particularly vitamin A deficiency. Through various interventions, vitamin A deficiency has been reduced by more than 60% between 2001 (59%) and 2009 (23%), and in 2018, it was reduced to 4% in preschool children living in rural areas, making it a mild public health problem. However, the number of children benefiting from vitamin A interventions is decreasing (67%), which may result in an increase in VAD, so there is a need for more sustainable and cost-effective approaches to keep reducing VAD (Hummel et al., 2018; Williams et al., 2021).

Ascorbic acid, also known as vitamin C, is a water-soluble vitamin that is important to human health. It is used as a dietary supplement and in many medications for influenza, colds, and even COVID. It aids in the body's increased absorption of iron and calcium, the development of bones, teeth, tissues, and many immunological processes (Abdullah et al., 2022).

Vitamin C is sensitive to light, oxygen and heat, which means long processing (drying) and preparation (cooking) methods of fruits and vegetables can destroy much of the vitamin C natively present in fruit and vegetable products. The amount of vitamin C which is destroyed depends on the type and severity of the processing method, which makes it important to study different processing methods, which includes different methods of drying foods (Maxfield & Crane, 2022; Tincheva, 2019).

Consumption of fruits and vegetables, which contain a lot of micronutrients, including consumption of mangoes and orange fleshed sweet potatoes is being encouraged to reduce micronutrient deficiencies. In some developing countries in Asia and Africa, Supplementation, diet diversification, fortification, and biofortification were implemented as strategies to reduce deficiencies. Biofortification is the process of improving micronutrients in food; 1) through crop breeding methods 2) agronomic methods such as adding nutrient rich fertilizer to crops, 3) combining both methods (Bechoff et al., 2023; Lowe, 2021).

The government of Malawi partnered with other organizations to help reduce micronutrient deficiencies, hence they adopted the strategies put in place to reduce the deficiencies which included vitamin A supplementation for young, food fortification for staple foods (fortifying sugar and oil with vitamin A) and sweet potatoes biorfotification (National Statistics Office et al., 2017). Orange fleshed sweet potato biofortification was chosen as one strategy to reduce vitamin A deficiency in Malawi, because sweet potatoes are produced in several parts of Malawi and are the third most consumed crop after maize and cassava. A daily intake of 100 g of OFSP is estimated to be sufficient to meet the vitamin A requirement for a 5-year-old child (Babu et al., 2016).

Biofortification adoption in Malawi is still on the lower side, to ensure biofortified sweet potatoes are consumed in Malawi, biofortified OFSP varieties are being developed and farmers have been encouraged to grow more of the varieties, but there is need for more work to increase adoption of OFSP varieties (Babu et al., 2016).

Mangoes (*Mangifera indica L*.) and sweet potatoes (*Ipomoea batatas*) are highly nutritious fruits and vegetables that are widely grown and consumed throughout the world; they provide the body with essential micronutrients such as vitamins A and C.

Mangoes are rich in macro- and micro- nutrients which makes it a healthy fruit for humans, who increasingly are focused on healthy and sustainable food consumption. The nutritional value of mangoes varies depending on the variety of the fruit, climatic and locality conditions of its production area and maturity of the fruit. In terms of macro nutrients it contains carbohydrates, dietary fiber, proteins, amino acids and lipids. For micronutrients it contains vitamin C (ascorbic acid), vitamin A (carotenoids), calcium, phosphorus, iron and many phytochemicals that maintain normal health (Lebaka et al., 2021; Zafar & Sidhu, 2017).

Mangoes contain a high quantity of carotenoids which are responsible for peel and flesh color. The carotenoids in mangoes belong to two groups: xanthophylls or oxygenated derivatives (auraxanthin, antheraxanthin, neoxanthin, lutein, violaxanthin, cryptoxanthin and zeaxanthin) and hydrocarbon carotenoids or carotenes (α-, β-, and γ-carotene). Sixty percent of total carotenoids present in mangoes are β-carotenes and the content depends on the fruit's maturity stage and environment, fully ripe mangoes have the highest concentration of carotenoids compared to unripe mangoes (Lebaka et al., 2021).

Sweet potatoes are highly grown root and tuber vegetables and are considered one of the staple foods in both developed and underdeveloped countries. They are ranked the most important food crop after wheat, rice, maize, cassava and potato. In Asia sweet potatoes are mostly produced in China, Indonesia and Vietnam; in America it is mostly produced in The United States Of America and Brazil; and in Africa it is mostly produced in Malawi and Tanzania (Food and Agriculture Organization, 2023; Wang et al., 2016).

Sweet potatoes fulfill a lot of roles in the global food system where they meet food requirements, reduce poverty and increase food security (Truong et al., 2018).

Sweet potatoes vary in color from yellow, white, purple and orange. The differently colored sweet potato varieties can differ significantly in nutritional and sensory qualities. Orange fleshed sweet potatoes are high in β-carotene, anthocyanins, phenolics, non-digestible dietary fiber, minerals, vitamins and antioxidants. Due to the high content of carotenoids and good sensory characteristics of sweetpotatoes, they have attracted attention from scientists seeking to develop long term food-based strategies for reducing vitamin A deficiency (Neela & Fanta, 2019; Truong et al., 2018).

Carotenoids present in orange fleshed sweet potatoes exist in all trans configuration which makes them the highest provitamin A among carotenoids in other crops. Hence, consuming recommended amounts of orange fleshed sweet potatoes can improve vitamin A nutrition in developing countries (Truong et al., 2018).

Post harvest losses of fruits and vegetables due to spoilage or other causes is a global challenge, with half of many cultivated products being lost before consumption. The Food and Agriculture Organization (FAO) of the United Nations estimates that around 17% of world food production is wasted (11% in households, 5% in food service and 2% in retail) (Food and Agriculture Organization of the United Nations, 2023; Porat et al., 2017).

There numerous factors that cause the post harvest losses of fruits and vegetables from grower to consumer. In addition to spoilage losses, some of these losses occur during processing, storage and transportation, hence it is important to know where most losses occur to improve best post harvest approaches (Yanik et al., 2019). Reducing food loss and waste is increasingly a global priority to reduce global hunger and improve food security.

Malawi experiences high post-harvest losses of crops including fruits and vegetables. For instance, records show that Malawi experiences around 5 to 12% post-harvest losses of total farmers harvest depending on type of crops (Ambler & De Brauw, 2017). One of the key areas of the Malawi Growth and Development Strategy III (MGDS III) is to improve agriculture by promoting technologies that will reduce the losses caused during storage, preservation, and food processing to improve food security, economic status, and health among individuals (Government of Malawi, 2017).

Fruits and vegetables are processed in different ways to avoid post-harvest losses and improve shelf life which improves the utilization of the crops through-out the season and ensures people have access to nutrients including micronutrients from different fruits and vegetables even if they are out of season. Fruits and vegetables can be dried, be made into juices, pulps, jams and even be frozen for shelf stable products that are easy to store (Perera & Perera, 2019).

Diets of humans usually consist of food that is processed using different methods like cooking and drying. The processing methods have expanded the types and varieties of foods available for consumption. Processing changes the structure, chemical composition, nutritional value, and bioavailability of bioactive compounds. Vitamin A and C are some of the nutrients that are easily lost during processing; this causes confusion between the benefits of food processing and the reduction of micronutrient deficiencies in developing countries (Alissa & Ferns, 2017; Ohanenye et al., 2021).

Drying is one method of fruit and vegetable processing and preservation and drying methods vary depending on time, temperature, and other characteristics. Drying fruits and vegetables can cause reductions in vitamin A and C concentrations depending on the drying method and pretreatments that are being used. Few studies have evaluated which drying method is cost-effective, efficient, and appropriate in processing mangoes and sweet potatoes.

Traditional and modern drying technologies are used worldwide. Sun drying is one of the traditional technologies that has been used for centuries, where sunlight is used to supply heat and wind used as a convective agent, but it is a method that produces low quality products. Improved drying technologies, like convective air drying were then introduced and are the most widely used drying technique currently. In recent decades, more drying technologies were developed with the aim to produce higher quality products including, vacuum-oven, spray drying, microwave and freeze drying (Bourdoux et al., 2016).

This research, therefore, was conducted to compare effects of three drying methods; freeze, hot - air and vacuum-oven drying on the vitamin A and C content that is present in mangoes and orange-fleshed sweet potatoes. The study aims to determine the most effective method for preserving these vitamins. This is an important study because it will provide information to food processors, consumers, and nutritionists on better methods for preserving nutrients in fruits and vegetables.

1.2.PROBLEM STATEMENT

Micronutrient deficiency which is also known as hidden hunger is mainly caused by lack of vitamins and minerals in food consumed. The deficiencies compromising physical and cognitive capacity of millions of people contributing to poverty, poor health and underdeveopment. Developing countries like Malawi have a great burden of these micronutrient deficiencies , which means there is a need to find ways of how optimal food preservation methods can be used to make nutritious but perishable foods available throughout the year to reduce the deficiencies (Mildon et al., 2015).

Vitamin A deficiency is a most serious micronutrient deficiency that causes blindness in children and contributes to high morbidity and mortality rate from other infections mostly in pregnant women and children. The World Health Organization introduced universal supplementation of Vitamin A (VAS) with two annual doses of 200,000 IU preformed to under children under five or one dose of 100,000 IU to infants between 6 to 11 months every 4 to 6 months to prevent VAD and mortality (Williams et al., 2021).

The WHO estimates that 29% of children between the ages of six months to five years in low to middle income countries have vitamin A deficiency which leads to almost 250,000-500,000 vitamin A deficient children to become blind every year and half of the children die within 12 months of losing sight (Lockyer et al., 2018; World Health Organization, 2023).

The deficiency leads to death from different infections like measles and diarrhea in children, maternal mortality, and night blindness in third trimester. To prevent these outcomes, availability of vitamin A-rich foods has been increased by various means including home gardening, fortification of flours and oils, sugar fortification, biofortification of staple crops like orange-flesh sweet potatoes and micronutrient powders (Lockyer et al., 2018; Williams et al., 2021).

Vitamin C is essential for the functioning of the body, it regulates thousands of genes in the body and plays a pleiotropic role in human health and disease. Vitamin C is an important antioxidant, it is used to prevent hypovitaminosis C, deficiency and its consequences. Severe deficiency of vitamin C is associated with scurvy which is a fatal disease when left untreated. Humans do not process their own vitamin C like any other mammal and as such, humans must obtain vitamin C from the food they consume especially through fruits and vegetables (Carr & Rowe, 2020; Rowe & Carr, 2020).

Globally, 14% of the world's food (valued at USD400 billion) is lost from post-harvest up to but not including retail stage annually. Fruits and vegetables including roots and tubers have the highest levels of post-harvest losses. Food is lost across the whole chain, from the farm to consumption. Both developing and developed countries experience food losses, but more than 40% of food losses in developing countries happen at post-harvest and processing levels (Food and Agriculture Organization of the United Nations, 2011, 2019).

Fruits and vegetables experience high post-harvest losses throughout the world due to poor handling, storage and processing methods, which makes farmers suffer a big loss. These fruits and vegetable crops are easily bruised when harvesting, in storage and other handling techniques due to their soft texture (Yahaya & Mardiyya, 2019).

Approximately 40-50% of food losses are from fruits and vegetables of which 54% occur in stages of production, post-harvest handling and storage and 46% occur in processing, distribution and consumption (Santos et al., 2020). Fruits and vegetables that are fresh are highly perishable and are hard to preserve due to their high moisture contents and tender texture. The moisture promotes the growth of microorganisms which reduce shelf life of the crops and increase the post-harvest losses (Deng et al., 2017).

Mangoes are climacteric and highly perishable because of high respiration rate and ethylene production under postharvest conditions. They rapidly ripen and soften up during postharvest handling. Ethylene leads to chlorophyll degradation, carotenoids accumulation and cell walls polysaccharides disassembly, during that process, de-esterification, solubilization and disassembly takes place in response to other hydrolytic enzymes (Ali et al., 2022).

In Malawi mangoes are highly cultivated and are a source of income and nutrition for smallholder farmers, who sell fresh mangoes from their homes, by roadsides and in small markets. Due to the high perishability of mangoes, the farmers face high post-harvest looses which reduces their economic and nutrition status. Drying is one way of preserving the mangoes to increase shelf life, but drying processes can destroy nutrients in the product thereby reducing quality of the finished product.

Orange fleshed sweet potato is one of the crops that is extensively grown in sub-saharan africa and is considered as one of the primary staple foods in four sub saharan african countries (Malawi, Burundi, Rwanda and Tanzania). The high beta-carotene content of OFSP has made the crop to be given much attention for its potential use as a biofortified food that can reduce vitamin A deficiency (Low et al., 2020).

Orange fleshed sweet potatoes are highly perishable vegetable due to their high water content, this reduces its availability throughout the season. Therefore, one way of preserving is processing the OFSP by drying. The drying methods which are used in processing OFSP have an effect on the contents of the potato, including the degradation of beta-carotene. The reduction in carotenoid concentrations during drying depend on the conditions that are used in processing (Kourouma et al., 2019; Moyo et al., 2022).

Due to high post harvest losses that come from limited and poor food preservation techniques, food,economic and nutrition security remains a problem in developing countries. This results in a high prevalence of micronutrient deficiency disorders including vitamin A deficiency, nutritional anemias, scurvy, iodine deficiency disorders, and protein energy malnutrition since availability of nutritious crops is seasonal (Okoye & Oni, 2017).

To ensure the human diet has the required nutrients to reduce micronutrient deficiencies, food is processed using different methods like drying, enables perishable foods to be available throughout the year. However, preservation processes can destroy the nutrients present in the food when not done properly. In particular, vitamins A and C are highly sensitive to processing conditions like light and heat . In Malawi, there are different drying methods that are used of which most drying methods are traditional methods which produce poor quality products with less retained nutrients, for example; open air drying method and solar drying method (Ohanenye et al., 2021).

Traditional drying methods used in preserving mangoes and orange fleshed sweet potatoes can lead to a high loss of the important nutrients, especially vitamins A and C. Hence there is a need to determine the most effective drying methods for preserving the nutrients to improve nutritional quality of dried products and improve food security.

1.3.JUSTIFICATION

In 2015 all United Nations member countries adopted the 2030 agenda for sustainable development. A total of 17 sustainable development goals (SDG's) were developed that need to be achieved by 2030. Goal number 2's target is ending hunger: achieving food security, improving nutrition and promoting sustainable agriculture by 2030 (Food and Agriculture Organization, 2019).

Due to COVID-19 and an increase in post harvest losses developing countries are facing economic crisis and lack of available and nutritious food continously, which has increased the prevalence of food insecurity and micronutrient deficiencies. Hence, there is need for more innovations and processing ideas on how people can have access to nutritious food at all times, and prevent post harvest losses to improve public health (Lockyer et al., 2018; United Nations, 2022).

Recognizing, promoting and using of improved technologies, knowledge, skills and practices in food processing, promotion and utilization of fruits and vegetables will be one way of reducing post harvest losses, which will improve food security, nutrition, and public health, and reduce micronutrient deficiencies. Some indigenous knowledge on preservation, like vegetable drying, has been used in communities at lower level for consumption at home, where products produced are of poor quality, but the technologies can be improved to ensure the products are produced in large quantities with high nutrient retention (Okoye & Oni, 2017).

Drying of fruits and vegetables is one processing and preservation method used to prevent post-harvest losses which promotes food security. It increases shelf life of food by reducing the water content and water activity in the crops, which reduces the growth and reproduction of micro-organisms, and reduces chemical reactions induced by high water levels . Determining a good drying method, which preserves vitamins A and C in the products, will help in ensuring that there is consistent and sufficient supply of fruits and vegetables which will improve food security (Deng et al., 2017; Guiné, 2018).

According to 1996 world food summit, food security is defined as; people having physical and economic access to sufficient safe and nutritious food which meets their dietary needs and preferences at all times for an active and healthy life (United States Department of Agriculture, 2023). Food processing and preservation is one way of improving food availability and food security, including improving traditional drying to modern drying technologies. To achieve food security there is need to formulate and identify appropriate modern drying technologies to ensure food is consistently available and well preserved (Adeyeye, 2017).

During drying the quality of food decreases, it changes physical, nutrient and chemical properties of the food. Orange fleshed sweet potatoes and mangoes are high in nutrients which include vitamins A and C. During drying processes these nutrients are easily lost.Therefore, comparing the effects of freeze, vacuum-oven and hot air drying on vitamin A and C contents of OFSP and mangoes will help in determining a good preservation method for retaining the important nutrients and facilitating production of quality products (Guiné, 2018).

Each drying technique has advantages and disadvantages. Hence, each final product has different nutritional, chemical and physical properties. The drying techniques retain nutrients differently due to the type of heating parameters (e.g. time, temperature) they use. Producing high quality nutritious dried products is the goal for every producer since today's consumers demand convenient health products that are of similar quality as fresh products, which is a challenge for producers and food researchers. This study will help food processors by providing information on which drying technique they can use to preserve nutrition quality of their dried fruits and vegetables especially with respect to the contents of vitamins A and C (Izli et al., 2017).

Consumer demand for dried fruits and vegetables is increasing, as people add the dried fruits and vegetables in other food products to improve nutritive value of the other food products. These dried products are used in confectionary, bakeries, distilling industries, and used in complementary feeding by adding to sauces, teas, puddings and garnishments. The dried fruit and vegetable products can also be further processed into powder where they are used as food additives, flavouring agents or natural colorants to improve nutrients of other products (Karam et al., 2016).

1.4. OBJECTIVES

The main objective of this research is to determine the effects of freeze drying, vacuum-oven drying, and hot-air drying on vitamin A and C contents present in orange-fleshed sweet potatoes and mangoes without any pretreatments.

1.4.1. SPECIFIC OBJECTIVES

1. To determine which drying method (freeze drying, vacuum oven drying, and hot air drying) retains the highest amount of vitamins A and C in dried orange fleshed sweet potatoes and mangoes.
2. To determine how drying method affects the physical quality of the final products by quantifying effects of drying on the color and water activity levels of the final products.

CHAPTER 2: LITERATURE REVIEW

2.1. VITAMIN A

Micronutrients are elements that are needed by the body just as other nutrients, these include vitamins (A,B,C) and minerals, and they are consumed in smaller quantities. They are essential in the body since they are used for physical and mental development (Ritchie & Roser, 2017). Insufficient intake of the nutrients leads to deficiencies, which is taken as an important world health issue since it affects physical and mental development in children, and deficiency of micronutrients (hidden hunger) can cause life threatening condition (World Health Organization, 2022).

Vitamin A is a fat-soluble micronutrient that is essential for the human body. It plays a role in maintaining healthy vision, proper growth, immune function, cell growth and differentiation. It is present in two forms; preformed vitamin A (retinol) which is present in animal products and pro vitamin A (carotenoids) which is present in fruits and vegetables (Manusevich Wiseman et al., 2017).

Vitamin A is not processed by the human body; hence humans need to obtain it from diet or supplementation. Humans need to consume a balanced diet to have a recommended supply of nutrients in the body. The recommended daily allowance for vitamin A depends on age and sex; from birth to 13years the recommended daily allowance ranges from 400-600 µg/day, teen males and females aged between 14 years to adults daily allowance ranges from 700-900 (National Institutes of Health, 2022).

Carotenoids are divided into two classes based on their functional groups; carotenes with a hydrocarbon chain but no functional group, such as alpha-carotene, lycopene, and beta-carotenes, and xanthophylls with an oxygen functional group, such as lutein and zeaxanthin (Kumar Saini et al., 2015).

Carotenoids are hydrocarbon pigments which are responsible for red, yellow, and orange color in different fruits and vegetables (orange fleshed sweet potatoes, carrots, mangoes, and pumpkins), and are present in plants, algae, and some bacteria. They exist as α-carotene, β-carotene, β-cryptoxanthin, lutein and lycopene. β-carotene is the most studied type of vitamin A (Gonçalves et al., 2016; Kamiloglu et al., 2016).

Beta-carotene is the most important precursor of vitamin A; it accounts for 80% of the vitamin A content in fruits and vegetables. It is a powerful antioxidant hence its demand has increased, it protects cells from damage, which is caused by free radicals, it reduces the risk of some types of cancer, improves skin health, supports immune function, and maintains healthy vision. A lack of vitamin A in the body leads to vitamin A deficiency (Burton et al., 2021; Kamiloglu et al., 2016). Vitamin A deficiency is a global problem and widespread, which occurs when one lacks enough vitamin A in the body. It is common in children and pregnant women from low to middle income countries. It causes preventable blindness in young children which increases the risk of disease and death from other infections like diarrhea and measles. VAD affects pregnant women during their last trimester (World Health Organization, 2023).

Beta-carotene is sensitive to heat, light, and oxygen and can easily degrade through different processing and storage conditions. Drying processes that use high heat or expose products to air for an extended period reduce beta-carotene levels (Bouzari et al., 2015; Kamiloglu et al., 2016).

2.2.VITAMIN C

Vitamin C (Ascorbic acid) is an essential micronutrient, it plays many functions in the body, acting as an antioxidant which protects cells from being damaged by free radicals and a cofactor for a family of biosynthetic and gene regulatory enzymes. It supports different cellular functions in the immune system, both innate and adaptive immune system. Vitamin C also plays a role in helping absorption of other nutrients in the body; it increases the absorption of iron, calcium and folic acid which help in reduction of allergic reactions, boost immune system, stimulates formation of bile in gall bladder and helps in excretion of various steroids(Ali Sheraz et al., 2015; Carr & Maggini, 2017).

Vitamin C has shown a lot of prominent pharmacological effects in a number of diseases like common cold,hypertension, heart diseases, cancer, asthma, wound healing, pregnancy, gout, and eye disease furthermore it has antiviral effects (Ali Sheraz et al., 2015).

During the COVID pandemic, vitamin C was shown to play a role in reducing COVID symptoms. It was shown that high doses of vitamin C have beneficial effects against the common cold, where it reduces symptoms of the flu and cold in patients, like chest pains and fever, making it an important micronutrient to boost immunity (Bae & Kim, 2020).

Vitamin C is a compound that is not synthesized by the human body due to lack of L-gulono-gamma-lactone oxidase enzyme, hence it needs to be supplied in the body by food and supplements (Mieszczakowska-Fr et al., 2021; Rowe & Carr, 2020). Recommended dietary intake of vitamin C is between 15 to 120 mg/day depending on age, gender, and health conditions, smokers are recommended to at least add 35mg/day to the daily allowance (National Institutes of Health, 2021). The best dietary sources of vitamin C are fruits and vegetables, with mangoes, citrus fruits, berries, tomatoes, leafy vegetables, and many others contributing for around 90%. Although fruits and vegetables have high vitamin C content, food availability, food choice, food processing and consumption pattern among different people influences the primary food sources of vitamin C (Duerbeck et al., 2016; Jia et al., 2018).

Vitamin C deficiency (hypovitaminosis C) is associated with different symptoms like low mood and a decline in immune function. More severe lack of vitamin C leads to the clinical syndrome of scurvy, which when left untreated can cause death. Scurvy is associated with corksrew hairs, perifollicular hemorrhage, and gingival bleeding, and it increases cases of pneumonia. Vitamin C deficiency has never been a serious condition, but still affects individuals in developing countries due to lack of intake of nutritious food and processing conditions that destroy the vitamin (Maxfield & Crane, 2022).

Vitamin C is a water-soluble and heat-labile vitamin that is affected by oxygen, temperature, light, pH, and storage conditions. The amount of vitamin C present in food is destroyed through processing and preservation procedures such as drying. The vitamin C concentration of food is affected by harvesting time, transportation, storage, and food processing and preparation methods (Carr & Rowe, 2020).

2.3.PRODUCTION AND PROCESSING OF MANGOES

Mangoes are a highly produced fruit in the world, they are grown in both tropical and subtropical regions. Mangoes are mostly consumed as fresh fruit in the world and are a reliable source of vitamins B, C (36.4mg/100g), and are a beta-carotene-precursor of vitamin A (640µg/100g) (United States Department of Agriculture, 2019). According to Mango nutrition board, a ¾ cup of sliced mango contains 70 calories, with 20 different vitamins and minerals. The cup provides 50% of daily vitamin C, 8% of vitamin A and 8% of vitamin B6, making it a highly nutritious fruit (Braga et al., 2019; National Mango Board, 2022).

Mango is utilized in all stages of its maturity from unripe stage to ripe stage, it has a blend of acids, sugar, polyphenols (beta carotenes) and high amounts of antioxidants (70% of ascorbic acid). Green unripe and matured mangoes contain starch that supplies carbohydrates which then converts to reducing sugars (glucose, sucrose and fructose). Ripe mangoes also have small quantities of cellulose, hemicellulose and pectin (Deeksha & Sunita, 2018; Lebaka et al., 2021).

There are over a thousand different cultivars of mangoes with different shapes, colours, sizes, texture and nutrition properties, the same cultivar may have a different name in different countries (Tiyayon & Paull, 2017). In the United States of America, there are different varieties of mangoes but the common ones are; Haden, Keitt, Kent, Ataulfo (honey) and Tommy Atkins (Brecht, 2017). About 99% of varieties grown in Malawi are local, and they are called Boloma and Kalisele, and only 1% are improved varieties like Tommy atkins and Kent (Nyirenda et al., 2019).

Carotenes are lipid soluble pigments that are responsible for the yellow, orange and color of mango skin, containing two classes of carotenoids; hydrocarbon carotenoids (α-carotene,β-carotene, γ-carotene) and oxygenated carotene known as xanthophylls (auraxanthin, antheraxanthin, neoxanthin, lutein, violaxanthin and zeaxanthin) where the most abundant carotenoids in mango flesh are all-trans-β-carotene and all-trans-and 9-cis-violaxanthin (Burton-Freeman et al., 2017).

The total carotene content in mangoes depends on fruit maturity, type of cultivar and environment. A study was conducted to investigate the number of carotenoids in four different varieties of mangoes where fully ripened mangoes showed high content of carotenoids (4.138 mg/100) compared to unripe. Tommy Atkins has 0.64mg β-carotene, 0.009 mg α-carotene, 0.01 mg β-cryptoxanthin and lutein and 0.023 mg zeaxanthin per 100g (Lebaka et al., 2021).

Mango fruit is known to be beneficial to the body due to its high compounds, as different parts of mangoes have various benefits including anti-inflammatory, antioxidant, anticancer, antidiabetic, antimicrobial, and many other benefits. The benefits help in some chronic diseases like diabetes, cancer, asthma, and hypertension. It is also beneficial to skin health, brain health, intestinal health, and metabolic health (Burton-Freeman et al., 2017; Lebaka et al., 2021).

Mangoes are cultivated in more than one hundred countries including Malawi, and despite its nutritional value, popularity, and high potential for export revenues in developing countries, only a small portion of the produce enters into international trade. Most of the produce is consumed in the producing country (Evans et al., 2017) . The USA and Europe are the leading importers of the fruit, and India is the lead exporter (United States Department of Agriculture, 2019).

Global production of mango, mangosteen, and guavas, reported by FAO by 2021, was around 52 million metric tons. Asian countries (India, China and Indonesia) are leading producers of mangoes, with around 72.4% followed by Africa 15.6%, then America (11.9%) (

Figure 1,Figure 2) (Food and Agriculture Organization of the United Nations, 2023).

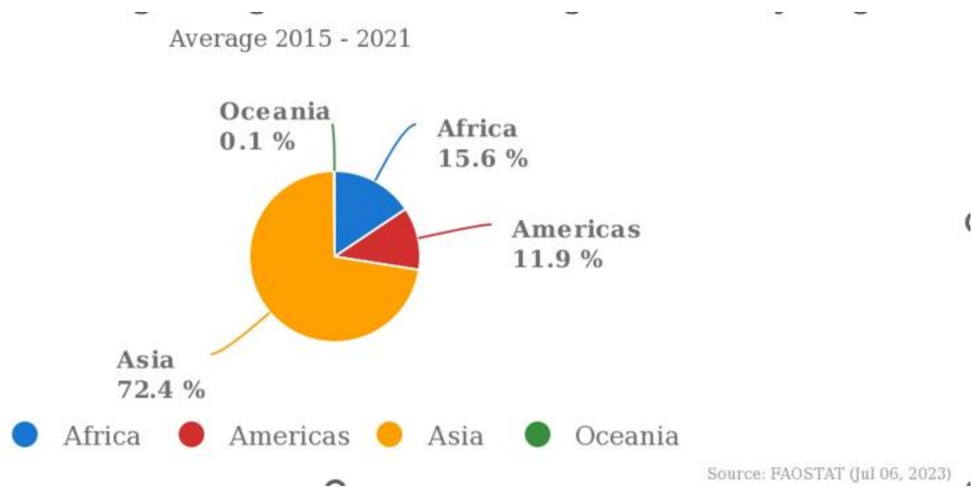

Figure 1: Production share of Mangoes, guavas, and mangosteen by region (Food and Agriculture Organization of the United Nations, 2023b).

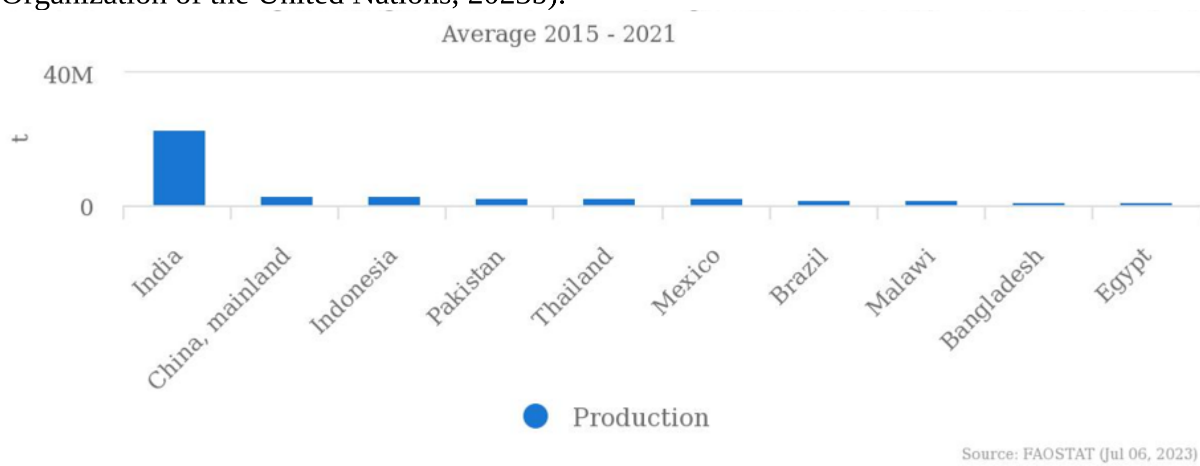

Figure 2: Top 10 producers of Mangoes, guavas, and mangosteen (Food and Agriculture Organization of the United Nations, 2023b).

Mangoes experience approximately 30-80% post-harvest losses in developing countries from harvesting, packing and distribution to markets, as they are perishable and prone to injuries due to their soft tissues (Owino & Ambuko, 2021). Processsing of the mango fruits can promote commercializatiom and consumption of the fruit. There are some processes like drying that can promote the shelf life of mangoes, ensuring that mangoes are available for consumptio all seasons of the year. Developing new mango products and preservation is an important way of creating alternatives for value addition which will help in reducing post harvest losses (Zotarelli et al., 2017).

Mangoes are processed into different products like puree, juices, wine, churtney, leathers, and powder. The processed mangoes can be used to flavor or enrich other products, they can be used as concentrates, juice, puree and ingredients in several products like cereals, baked products, nutrition bars, ice cream, baby foods, and healthy drinks (Izli et al., 2017; Owino & Ambuko, 2021).

Dried mango products like leather and powders are made from ripe mangoes. They are dried using different drying machines like freeze dryers, vacuum-oven dryers and hot air dryers. The dried products are known to have high antioxidants compared to fresh mangoes (Owino & Ambuko, 2021). Dried mango products are made for direct consumption or used to enrich other types of food. Products like dried slices and chips are becoming common snacks in North America and Europe (Siddiq et al., 2017).

2.4.PRODUCTION AND PROCESSING OF ORANGE FLESHED SWEET POTATOES

Roots and tubers are the most used food crops after cereals, they yield starchy roots, tubers, rhizomes, corn, or stems, and are characterized with high moisture content around 62-82% and carbohydrates (16-30%). They are classified into seven primary crops: sweet potatoes, cassava, potato, cocoyam, tayo, yam and others (arrowroot etc.). Sweet potatoes, potatoes, and cassava are among the top ten food crops produced in developing countries (Nabeshima et al., 2020; Sharma, 2016).

Sweet potatoes are considered one of the most produced and consumed root and tuber crops, and they are a dicotyledon plant, considered the third vital food crop in seven central and eastern African countries, fourth priority crop in six South African nations, and eighth in four West African countries. Sweet potatoes have unique attributes like adoptability in wider environments, the ability to grow in harsh circumstances, even in drought conditions, short-term productivity, and balanced nutrition (Neela & Fanta, 2019).

Sweet potatoes are grown in more than 91 countries. The total production of sweet potatoes worldwide according to FAO, the production is around 80,619,618.44 metric tons. Asia grows around 64.8% of the crop with China leading (43,395,110.81 mt), followed 30.1% in Africa with Malawi leading (6,751,500.72 mt) and Tanzania (4,528,540.18 mt) (Food and Agriculture Organization of the United Nations, 2023b).

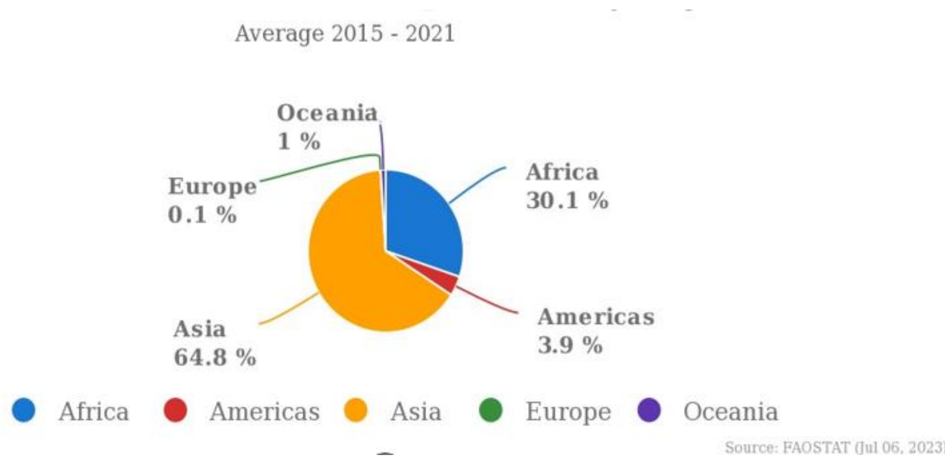

Figure 3: Sweet potatoes production by region (Food and Agriculture Organization of the United Nations, 2023b).

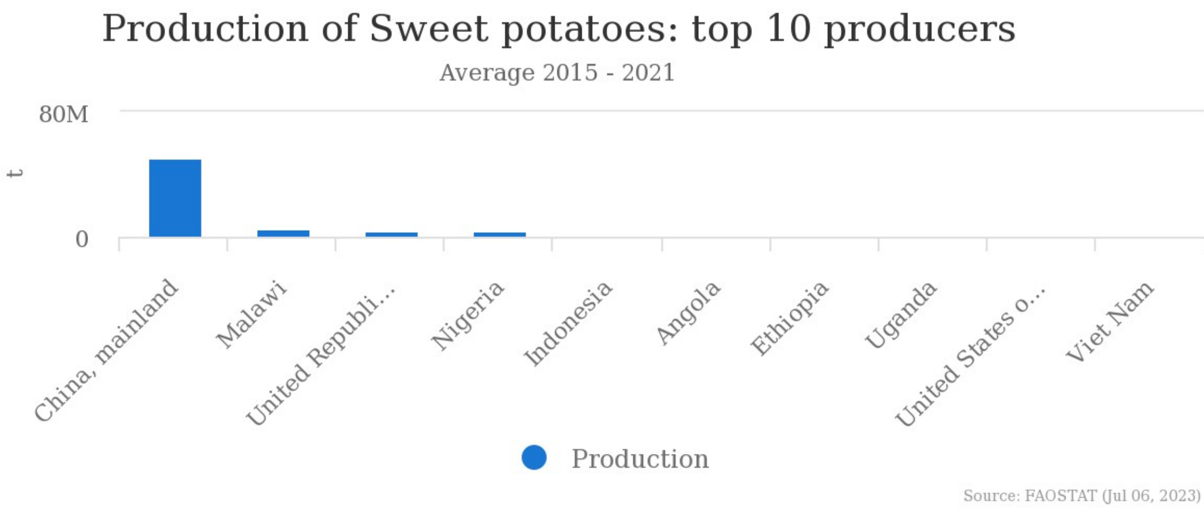

Figure 4: Top 10 producers of sweet potatoes (Food and Agriculture Organization of the United Nations, 2023b).

Sweet potatoes vary in color from white, yellow, purple, and orange, with the colors being connected to nutritional and sensory acceptability. Biofortification programs carried in Sub-Saharan Africa (SSA) like Malawi, Uganda, Ghana, Kenya, Ethiopia, and Mozambique have contributed to the release of new orange, yellow and purple fleshed sweet potatoes (Amagloh et al., 2021).

Purple and orange fleshed sweet potatoes contain more anthocyanins and carotenes than white fleshed potatoes. Orange-fleshed sweet potatoes have drawn the attention of researchers in the food and nutrition fields due to their high level of beta carotene and non-provitamin A carotenoid. It is also considered one of the staple crops that has been a successful food biofortification, which is helping in improving nutrition of low-income groups and vulnerable populations such as under five children (Amagloh et al., 2021; Neela & Fanta, 2019).

There are more than six thousand varieties of OFSP worldwide with USA having more than one hundred varieties which includes Covington, Darby, Jewel and many more (Dyer, 2021). Orange fleshed sweet potato is a reliable source of many nutrients and compounds making it a functional food.

OFSP are a reliable source of vitamin A (beta-carotene), vitamin C, manganese, copper, pantothenic acid, and vitamin B6, they also contain potassium, dietary fiber, niacin, vitamin B1, vitamin B2 and phosphorus, as well as having antioxidant, anti-inflammatory, and disease fighting components. Beta-carotene can be converted to retinol in the body which contributes to health eye vision (Yenumula & Thilakavathy, 2018).

OFSP has around 75% moisture content, making it more perishable, and has a high starch content (65.41%) on a weight basis, which makes it a staple crop since it provides energy from that starch (Neela & Fanta, 2019).

Orange fleshed sweet potato has five carotenoids, containing 364µg/g on dry basis of beta-carotene, and it is used as a food product, which can help reduce vitamin A deficiency. Vitamin C (Ascorbic acid) concentration in OFSP is less compared to other fruits and vegetables (148µg/g db.) (Neela & Fanta, 2019).

OFSP has reported having different moisture content depending on variety and the place they are grown. For a longer shelf life, most OFSP are dried to <11% moisture content, as a study conducted in Brazil on OFSP showed that fresh sweet potato had moisture content levels ranging from 69.4% - 73% which when processed into flour, moisture content reduced to 6.9 to 10.97%, the OFSP flour had 768µg RAE, which is 85% per 50g (1/4 cup) (Rodrigues et al., 2016).

According to a review of the nutritional composition of orange fleshed sweet potatoes from Korea, the total carotene content was found to be 570µg/g. OFSP beta carotene content ranged from 20-364µg/g db. in Uganda, and OFSP from USA varieties ranged from 44.9-226 µg/g fw, indicating a high beta carotene content when compared to carrots (43.5µg/g), mangoes (10.9-12.1µg/g), and tomatoes (2.17-2.83µg/g) (Neela & Fanta, 2019).

In Malawi sweet potato is the second widely grown root crop after cassava, and it is widely grown due to its tolerance to drought and poor soil conditions. Malawi has different varieties which were bred and released in 2011 by the Department of Agriculture Research Services (DARS), Malawi. The names of the varieties were given by local farmers depending on the behavior of the crops, this include Ana akwanile, Chipika, Kadyaubwelele, Kaphulira, and Zondeni, and many more (Chipungu, 2015).

In Sub Saharan Africa countries, including Malawi, both roots and leaves of sweet potatoes are consumed. Traditionally, roots are eaten boiled, steamed, and roasted as a form of breakfast in both rural and urban areas (Kathabwalika et al., 2016). Sweet potatoes can also be processed into different products like canned or dried; the dried potatoes are made into flour, cereals, noodles, and other baked items (Neela & Fanta, 2019).

The flour processed from orange fleshed sweet potato can be used as a micronutrient supplement in porridge, in baking, and by adding the product to other products to add nutritive value. The flour can be used as a substitute for wheat flour, which can help reduce gluten reactions.

2.5.DRYING TECHNIQUES

Drying is the operation where moisture in a product evaporates because of the heat and matter exchange between the product and the working medium. There is a separation of liquid from solid, which is achieved by the evaporation of the liquid, provided there is enough heat supplied to the solid matter (Radojčin et al., 2021).

The heat in drying is supplied in different ways through: (a) convection, where a carrier gas, like air, is supplied directly to food material; or through (b) conduction, where heat is subjected indirectly, and carrier gas is used to remove water; and lastly through (c) radiation, where there is a generation of thermal radiation from emission of electromagnetic waves, which are non-penetrating, like infrared radiation, or penetrating, like radiofrequency and microwaves (Radoiu, 2020).

Fruits and vegetables are perishable due to their high moisture content and tender texture. Drying is one technique that has been used for a long time to preserve products and extend their shelf life by reducing the amount of water to prevent growth and reproduction of micro-organisms. It helps to deactivate moisture mediated in deteriorative reactions (Deng et al., 2017).

There are different drying techniques, which are mainly classified into three methods. The first method is a thermal drying method. In this method, heat or gas medium is used to evaporate water in food, through methods such as air drying, like hot air convective drying, low air environment drying, freeze drying, vacuum-oven drying, and modified atmosphere drying. The second class of drying is osmotic dehydration, where a solution like salt is added to remove water from food. Lastly the third class of drying is mechanical dewatering, where physical force is applied to food to remove water, like drum drying (Rahman & Perera, 2020a).

Drying was used naturally in the past through means of the sun, but it is no longer a preferred method due to its unhygienic processes, the destruction of quality, and its prolonged drying time. With technological advancement, drying is now mostly conducted using methods like freeze drying, hot-air drying, and vacuum-oven drying (Alp & Bulantekin, 2021).

There are a lot of drying techniques in the world, and each drying method has its own effects. Some drying techniques produce poor products, hence there has been development of new improved technologies. Hot air drying is an improved technique from solar or sun drying, as it produces products with high extended shelf life up to a year, but still results in a poor-quality product. Vacuum drying is an improvement over hot air drying, and it is used for high value and heat sensitive products. Freeze drying is then used as one of the best drying methods in industries, it is a gentle method that produces high quality products (Karam et al., 2016).

Drying affects the physical (color) and chemical (nutrients) properties of food, aids in formation of harmful compounds like hydroxy methyl furfural (HMF) and enhances loss of bioactive compounds due to high temperatures (Shende & Datta, 2019). It also has significant effect on the total carotenoid and vitamin C of final product (Siddiq et al., 2017). A lot of changes in products are caused by temperature, pressure, atmosphere of drying, and electro-energy used.

2.5.1. CONVECTIVE HOT AIR DRYING

Convective hot air drying is the most common drying method used in both industries and commercial places, where it involves circulation of hot air in an enclosed chamber with the help of a fan and electric heater. Hot air passes over the product that is on open trays in the chamber, this air is passed at a regulated temperature and humidity through or over the food in the dryer. Heated air thern meets the surface of wet material, which transfers heat into solid by conduction. Then the liquid moves to the materials surface and is transported away by air convection (Karam et al., 2016; Rahman & Perera, 2020a).

Hot air is a conventional drying method, which transfers heat from the drying medium to the product using a conduction heating method. When a product absorbs heat, the moisture from the surface of the product diffuses to the drying medium (external diffusion) and moisture from the products interior diffuses to the products surface (internal diffusion). The process keeps going on until the product drops to a certain point of degree for drying (Food drying oven, 2020).

Hot air drying is a straightforward and inexpensive drying technique since it just needs basic building supplies and equipment, and is simple enough for operators to utilize in both industrial and commercial settings. Unlike other drying procedures, that employ radiant heat or other sources of energy, convective hot air does not use a complex heating mechanism to remove moisture from items (Barbosa et al., 2015).

Hot air drying is a harmless and non-toxic method that produces uniform, hygienic, and rapid dried products that extends its shelf life by at least a year. Hot air drying is efficient in removing free water from the surface or the near surface of the product (Dehghannya et al., 2018).When used under ideal conditions, hot air drying delivers more uniform hot-air and temperature distribution over the product than other conventional drying techniques, which minimizes energy used and the drying time, and also produces a better dried product compared to the other traditional methods (Dehghannya et al., 2018; Onwude et al., 2017).

Hot air drying has high energy consumption and a longer drying time because of its low thermal conductivity of foodstuffs, and requires high drying temperature which causes final products to have tough textures, high shrinkage, a reduced bulk density, and low rehydration capabilities. An increase in drying time changes the taste and fragrance (Dehghannya et al., 2018; Onwude et al., 2016).

The drying conditions of hot air drying; temperature (above 55℃), aerobic conditions, air velocity, relative humidity, and moisture content of food products has an effect on the properties of the food being dried. It causes physical and chemical changes, like oxidation of phenolic compounds, the damaging of vitamins, maillard reactions, change in sensory properties (taste,color,smell), and a reduction of the nutrient composition (Dehghannya et al., 2018; Ngamwonglumlert & Devahastin, 2017).

2.5.2. FREEZE DRYING OR LYOPHILIZATION

Freeze drying is a drying method that uses sublimation; a process where a product transitions from solid directly to a gas without passing through the liquid state. Heat is supplied through conduction or radiation. It is a drying method used in pharmaceuticals, the food industry, and many other companies. It is used to dry products that are thermolabile or those that are unstable in aqueous solutions during a long storage time (Gaidhani et al., 2015). Freeze drying results in a reduction of water activity, and the product being dried gets frozen to then be subjected to vacuum pressure with the sublimation and desorption of water (Silva-Espinoza et al., 2020).

A freeze dryer contains a vacuum chamber, which has shelves to place products on to be cooled and heated through containers and their contents, a vacuum pump, a refrigeration unit, and controls connected to the vacuum chamber. Products are placed in the vacuum chamber and the cooling elements within the shelves freeze the products. When products are frozen, the vacuum pump evacuates the chamber and product is then heated (Shivanand & Mukhopadhayay, 2017).

The process of freeze drying consists of three main stages; the first is the freezing stage, where a sample is completely frozen at -10℃ or lower. The final temperature of a frozen product and its method of freezing can affect the final product. Sample liquid is cooled until it forms pure ice crystals, then the remainder of the sample is then freeze concentrated into a glassy state, where viscosity is very high. Small ice crystals result in products that are difficult to freeze dry, compared to formation of larger ice crystals which form during slower cooling conditions(Chen et al., 2016; Gaidhani et al., 2015).

The second, and most primary stage, is when a vacuum is applied and the pressure inside is lowered below the vapor pressure of ice at the operating temperature, while shelf temperature is raised to start sublimation ,where there is heat and mass transfer process. The heat is gradually supplied by conduction, the temperature of the food is at 2-20℃ and about 95% of the water is removed. When water is removed, heat is no longer needed, and the products temperature increases. Primary drying finishes when there is no longer a frozen layer (Gaidhani et al., 2015).

Lastly, the secondary stage (desoption), where bound water (unfrozen water) in a product is removed. This is carried out under a vacuum at 50℃ or 10-35 ℃ for heat sensitive products (Chen et al., 2016). Secondary stage starts when sublimation is still in process, it starts at a higher temperature to efficiently remove the remaining water (Bhatta et al., 2020). The moisture rate in a completely dried product is 0.5-3%, where the more dry the product is, the longer its shelf life. Drying times range from 4 to 24 hours (Bourdoux et al., 2016).

Freeze drying produces high quality products and it maintains the quality of the product better when compared to other drying methods due to its low pressure, air oxygen, and temperature. There is minimal contact between the food and oxygen and enzymatic activities which inhibit oxidation. This makes it a good method of drying for products that are thermally sensitive and prone to oxidation. Products that are freeze dried have a high porosity, slight shrinkage, good rehydration abilities, high retention of flavors and nutrients, bioactive compounds, texture, and low color degradation (Bhatta et al., 2020; de Ancos et al., 2018; Fan et al., 2018).

Freeze dried products are light weight making them easier to transport and store. This makes freeze dried products a popular choice for backpackers, hikers, campers, astronauts, and military personnel (Shivanand & Mukhopadhayay, 2017).

Fresh fruits with high moisture levels are hard to dehydrate by this type of drying method because their physical attributes are easily damaged. Fresh fruits also have high collapsing levels, and the skin bleeds due to the skin rupturing, producing a low quality final product, but some vegetables, like tomatoes, in the freeze dryier have a high retention of ascorbic acid and antioxidant capacity (Bhatta et al., 2020).

Due to weak sublimation heat conductivity supplied by the heated plate, freeze drying requires a long drying process that uses a lot of energy compared to other drying methods. Freeze drying is an expensive method due to it’s low drying rates offered by the refrigeration and vacuum systems, which raises energy expenditures. The equipment used for freeze drying is also expensive because of ongoing costs involved to maintain the machine and run the machine (Fan et al., 2018; Karam et al., 2016).

The freeze drying process is complicated because it involves many steps such as freezing, sublimation, and all the other processes, making it a method that necessitates special equipment and trained personnel. Freeze dried products must be stored in airtight containers because they are easily rehydrated, and airtight containers prevent moisture from entering the products.

Freeze drying can easily ruin the structure of products that are dried if temperature at the primary drying stage is not kept high, and is at critical process, the critical process temperature collapses temperature for amorphous substance (Gaidhani et al., 2015).

A study conducted to compare the influence of different drying techniques on mangoes showed that freeze drying had the longest drying duration compared to microwave drying, which had the shortest duration (Izli et al., 2017).

2.5.3. VACUUM-OVEN DRYING

Vacuum drying reduces water activity of foods under a reduced pressure environment (sub-atmospheric pressure) that reduces the heat needed for rapid drying. Heat is supplied by passing steam or hot water through hollow shelves. A vacuum replaces the air to remove any moisture of the products. The vacuum reduces vapor pressure saturation at a given temperature, which removes water vapor from the drying vessel (Bourdoux et al., 2016).

Vacuum drying is used to prevent oxidative problems; a lower vacuum pressure allows for drying at a lower temperature, resulting in a lower final moisture content of the product. When combined with other drying methods such as microwave assisted and oven assisted, the vacuum drying method performs nicely (Hasan et al., 2019).

A vacuum-oven is a drying chamber with a metal plate at the bottom heated by electric resistance that gets to the foodstuff. One pump supplies a vacuum to the chamber, a gauge called vacuometer then screens the value of pressure into the chamber. A vacuum oven uses less energy, which decreases the processing costs (Ismail et al., 2021).

The vacuum oven removes moisture from a product by subjecting it to high temperatures and low pressure in the oven. The vacuum oven creates a vacuum in the drying chamber when the product is placed in it, lowering the boiling point of water, or other solvents, in the product being dried, allowing moisture to evaporate more easily and at a lower temperature, reducing the risk of thermal degradation of the substance (Parikh, 2015).

Vacuum oven dryer is a gentle and efficient method for heat sensitive and easily oxidised products. It helps in increasing the rate of drying, which is done at lower temperatures and it is an oxygen deficient processing method, as it inhibits oxidisation by atmospherical oxygen and lets moisture vaporize from the material at reduced temperatures, which protects sensitive components like vitamins from being destroyed. Moisture present in food is removed by creating a vacuum; the vacuum pump lowers the pressure of the product to be dried. When pressure is low, the boiling point of the product decreases, which increases the evaporation of water in the food product (Ismail et al., 2021; Tec2Med, 2021).

When compared to other drying methods, such as hot air drying, vacuum ovens have a faster drying rate, lower temperature, better retention of rehydration capacity, uses less energy, and produces products with better sensory and nutritional properties, as well as the ability to retain more vitamins and bioactive compounds (Hasan et al., 2019; Roratto et al., 2021).

The drying times for a vacuum oven dryer takes a long time (12-48hr) depending on the amount and type of product being dried, since it does not use direct heat like hot-air drying, it operates at low temperatures and pressure (Parikh, 2015). In vacuum oven drying, water molecules diffuse to the surface and evaporate in the vacuum chamber. Heat is supplied by conduction or radiation to the system at a partial vacuum to have the best quality of a product (Karam et al., 2016). When compared to hot air drying, vacuum ovens are more expensive. They also require regular maintenance and frequent part replacement.

The microstructure of food dried under a vacuum have higher porosity compared to hot-air drying, which results in less shrinkage and a higher rehydration and reconstitution capabilities of said product. A study conducted on banana slices showed that bananas dried at vacuum conditions have a higher and larger porosity than those dried through a hot-air dryer, the high porosity improves the texture of the product by making it crispier (Ngamwonglumlert & Devahastin, 2017).

2.6. EFFECTS OF DRYING ON FRUITS AND VEGETABLES

2.6.1. VITAMIN A AND C

Ascorbic acid is mostly found in almost all living tissues, it is best known as L-ascorbic acid, it is an antioxidant, and it removes singlet oxygen, eliminating peroxy radicals formed during lipid peroxidation (Gümüşay et al., 2015).

Vitamin C is an antioxidant that can easily be destroyed during handling, processing, and storage. Processing methods and treatments like pH, temperature, light, time, enzymes, and oxygen play a role in destruction of the vitamin. The loss of vitamin C during drying methods mostly happens due to oxidation of ascorbic acid under high temperature drying conditions. The loss of Vitamin C varies depending on the drying method. In some drying methods, vitamin C is lost more compared to others, due to long exposure of products at high temperatures (Kamiloglu et al., 2016b).

Vitamin C easily oxidizes, so processes that use high temperatures causes the loss of 20-90% of vitamin C depending on the temperature levels, the processing time and the oxygen contact. Vitamin C destruction can cause quality loss and colour formation in products (Mieszczakowska-Fr et al., 2021; Verma et al., 2020).

Beta carotene (pro-vitamin A) provides at least 80% of vitamin A in fruits and vegetables, and the demand of beta carotene is increasing due to its high anti-oxidant activity. However, processes like drying reduce the amount of beta carotene due to the higher temperatures, oxidation reactions, and light (Kamiloglu et al., 2016b).

Oxidation is a major cause of the loss of beta carotene when processing and in storage. It occurs through free radical processes. The free radicals are caused by unpaired electrons, which are unstable, which leads to the destruction of the molecule by a chain reaction (Nicanuru, 2016).

Orange fleshed sweet potatoes dried in a hot-air dryer at 42◦C for 2 hours had a high retention rate of total carotenoids (87%) where the beta-carotene retain was 84%, high, compared to sun drying and solar drying methods. The oven drying method retained 70%-96% of the beta carotene when dried at 65◦C for 12 hours (de Moura et al., 2015).

Mango cubes dried using low pressure superheated steam, vacuum, and hot air drying methods showed changes in colour, ascorbic acid, beta-carotene, total phenol, and total antioxidant activity, where a lot of these changes were seen in hot air drying compared to other techniques. Mango cubes dried under hot air only retained around 36-48% of ascorbic acid and 46-56% of beta carotene. The other drying methods retained more of these compounds (Sehrawat et al., 2018).

L-ascorbic acid of raspberries dried under convective reduced significantly compared to freeze drying due to high exposure of temperature and oxygen. Due to reduced exposure of heat and oxygen freeze drying retaines more L-ascorbic acid compared to convective drying (Stamenkovi´c et al., 2019).

The changes were due to oxygen and longer drying times, which increased browning of the products; higher temperatures cause non-enzymatic maillard browning. The change in colour was also an indication of the reduction in beta-carotene during the drying process (Sehrawat et al., 2018; Stamenkovi´c et al., 2019). Freeze drying retains more due to its low use of temperatures.

Gümüşay et al. (2015), compared effects of different drying methods (freeze drying, vacuum-oven drying, oven drying and sun drying) on ascorbic acid present in tomatoes where freeze drying (-50◦C, 0.133mbar for 24hrs) retained more ascorbic acid in tomatoes, followed by the vacuum oven drying method (60 ◦C, 0.025mbar for 36hrs) (Gümüşay et al., 2015).

Total phenolic, carotenoids and antioxidant properties of Tommy Atkin mango cubes affected by drying techniques were analysed. Freeze dryed (-20◦C and 55◦C) retained more ascorbic acid and carotenoids, followed by hot-air convective drying (60 ± 2◦C) and vacuum drying (60 ± 2◦C). The dried mango powders retained ascorbic acid in a range of 97.59 to 225.38 mg/100g db depending on drying methods. Powders dried in convective drying, infrared drying, and vacuum drying showed lower ascorbic acid compared to freeze drying. Freeze drying and infrared drying had 5.17mg and 3.28mg/100g db total carotenoids, respectively. This showed that drying methods that uses a lot of heat destroy vitamins within mangoes (Sogi et al., 2015).

Vitamin C and total carotene content in bintangor orange puree was reduced when dried into powder under freeze drying, vacuum oven drying, convection oven drying, spray drying and drum drying. Freeze drying retained more vitamin C, with 37.42mg/g before drying, to 28.31mg/g after drying (76% retain), and retained more carotene content,from 122.83µg/g to 91.32µg/g (74% retain). This was followed by the methods of convection oven drying and vacuum oven drying due to lower processing temperature (Phing et al., 2022).

2.6.2. COLOR

Color is an important visual appearance within fruits and vegetables, since consumers make their first judgements from it, hence, it is an important aspect that needs to be maintained when processing. Color is one indication of food quality. Many chemical and biochemical reactions take place during the drying of fruits and vegetables, which makes it hard to maintain the color of a product (Calín-Sánchez et al., 2020; Verma et al., 2020).

Color changes that occur after drying are related to browning reactions, this browning can be a reaction from both enzymatic and non-enzymatic. Enzymatic reactions in fruits and vegetables occur due to phenolic compounds. Non enzymatic is caused by different reactions, like maillard, caramerization, and ascorbic acid oxidation, which is influenced by temperature, water activity, pH, and product composition (Calín-Sánchez et al., 2020).

High temperatures and long drying time reduces the original color of products, this makes convective drying cause more significant colour loss. Minimal exposure of products to heat with a short drying time, and pH adjustments, help in preserving the color of the products, hence industries try to improve on different drying methods and pretreatments to maintain color of final product (Calín-Sánchez et al., 2020; Rahman & Perera, 2020b). When products are exposed to hot air for a long time, maillard reaction and oxidation of ascorbic acid, which forms brown-colored products, may occur (Wojdyło et al., 2020).

The color of a product is measured using colorimeter, by measuring CIE L*, a*, b* color coordinates, where L* stands for whiteness-darkness, a* (green-red) and b* (blue-yellow), as seen in (Calín-Sánchez et al., 2020).

Mango cubes dried using low pressure superheated steam, vacuum, and hot air drying methods showed changes in colour, where a lot of changes were seen in hot air drying compared to the other two techniques. Samples dried using the hot air drying method changed in color, where it had lower values of L* and higher values of a* (Sehrawat et al., 2018).

Raspberries dried under convective drying (60,70 and 80◦C) showed change in color parameters a* and b*, where the products shifted to a maroon colour which showed a decomposition of carotenoid pigments, while raspberries dried under freeze dryer (-20◦C for 48hrs) had the largest color change, where all colour parameters of L*,a* and b* increased, especially a* compared to convective drying. The researchers said the process of replacing free water with air shifted the red color and lightness of the raspberry, due to different diffusion of light passing through the material (Stamenkovi´c et al., 2019).

Different drying techniques including freeze drying, hot air drying, and microwave drying showed a decrease in L* value after drying compared to fresh mangoes. L* value of freeze dryed material was greater than that of hot-air dryed, where there was an increase in a* value of hot air dryed samples. The b* value of the dried mangoes were less than fresh mangoes, but freeze drying had a higher value of the parameter than the other drying methods, meaning freeze drying has a lower value of ΔE (Izli et al., 2017).

Sweet potatoes processed under different conditions including freeze dryer, sun drying, air frying, and baking showed high retaintion of color parameters. In freeze drying, it had high values of L*, a*, and b*, which made the orange sweet potatoes retain its orange color. This happened because freeze drying does not use a high heat processe, which causes browning. Freeze dried potatoes were lighter because freeze drying takes place under vacuum conditions, which then reduce oxidation reactions (Zaizuliana Rois Anwar & Abd Ghani, 2019).

There was a change in color parameters of red fleshed apples in a research that wanted to compare the effect of drying methods on retention of bioactive compounds, antioxidants, and the color of red fleshed apples. In all drying conditions, color parameters were significantly affected, but freeze drying managed to maintain the colour of apples better compared to convective drying, or other drying conditions. The L* and a* parameter of freeze dried apples were higher, which showed the sample was lighter and reddish in colour (Wojdyło et al., 2020).

2.6.3. WATER ACTIVITY

Water activity is an important aspect in all foods, it is ratio the of vapor pressure of water in a system (P_0) and the vapor pressure of pure water (P_1) at the same temperature (Equation 1). It represents water available for microbial spoilage and water mediated degradation of quality in dehydrated foods. Water activity is used as a parameter to examine how stable a dehydrated food product is and the shelf life (Feng et al., 2021).

Equation 1: Water activity

$$\mathrm{aw} = \frac{\text{vapor Pressure of Water in Food}}{\text{Vapor pressure of Pure Water}}$$

Water activity is a reliable indication of microbial growth, enzymatic activity, preservation, and quality of food. Microbial growth at low water conditions depends on several factors including temperature and exposure time, strains used, the medium composition, and the nature of solutes present in the food matrix. To have low water activity, it is important to know the interactions between intrinsic factors (water content, water activity and food composition) and extrinsic factors (relative humidity, treatment time and temperature) (Dhaliwal et al., 2021).

Water activity helps in dictating shelf-life stability of food. Water activity is the amount of free water in food used for chemical, physical, enzymatic, and microbiological reactions in food. Micro-organism water activity varies from 0.60 to 1.00 $_{a}$w. Some microorganisms require high amounts of water, while others survive in low water activity. For instance, spoilage bacteria grow at above 0.90 water activity. Fresh fruits and vegetables have a water activity of 0.97 to 0.99, which shows how susceptible they are to bacteria. Drying reduces water activity to less than 0.60 (Sandman, 2021).

Lowering water activity reduces the growth of most bacteria, yeasts, and molds, which do not grow below 0.87,0.88 and 0.80, respectively. Removing water reduces the weight of products, which facilitates economical storage and transport, low water activity also inhibits oxidative and enzymatic reactions, which then improves the shelf life of products (Bourdoux et al., 2016).

CHAPTER 3: MATERIALS AND METHODS

The study was divided into two parts: the product development stage, in which the products were dried in various drying machines, and the analysis of products.

3.1. MANGO AND ORANGE FLESHED SWEET POTATO SAMPLES

Tommy Atkins stage 4 (ripe) mangoes (National Mango Board, 2017), were purchased from Stan Setas produce (Lansing, MI), were sorted, cleaned, and peeled with a knife, and then sliced into 7-8 mm thick chips and placed drying machines.

Covington orange-fleshed sweet potatoes (Covington variety) were purchased from the Horticultural Sciences department at North Carolina State University (Raleigh, NC). The potatoes were sorted and peeled using an electric peeler (Hobart Corporation; Troy, OH). They were then grated using a box grater (OXO kitchen utensils brand, NY) using a medium grate size and placed in the respective drying machines.

3.2. DRYING METHODS

The mango and OFSP samples were dried using three drying methods – hot air drying, freeze drying, and vacuum oven drying. The drying procedures for both substrates were repeated in triplicate.

The mango and OFSP samples were hot air dried for 10 hours at 140 °F (60 °C) in a D-14 digital touch screen food dehydrator with stainless steel shelves at a high fan speed (TSM products, Buffalo, NY). The relative humidity of the machine was at 5% at start and when drying was complete humidity was at 35%.

The samples were freeze dried for 24 hours at -20 °F (-28.9 °C) in an HRC-7-115 Harvest Right scientific model freeze dryer (Harvest Right; Salt Lake City, UT). Samples were freeze dried on stainless-steel trays using the freeze drying profile that listed in Table 1.

Lastly, the samples were placed on stainless steel trays and dried in a CV-10 vacuum oven dryer at 140 °F (60 °C) for 10 hours (Cascade Sciences, Hillsboro, OR). After drying all the samples were stored in vacuum bags at room temperature.

Vacuum 1	500
Vacuum 2	600
Ramp rate	5°F
Freeze temperature	20°F
Temperature 1	30°F
Temperature 2	120°F
Temperature 3 to 5	2°F
Freeze hour	2
Hour 1	2
Hour 2	10
Hour 3 to 5	2
Freeze Minutes (1 to 2)	0
Minutes 3 to 5	2

Table 1: Freeze dryer profile

3.3.PHYSICAL PROPERTIES ANALYSIS

Color was measured in all samples before and after drying with a chroma meter CR-400 (Konica Minolta, Inc, Japan) and a color flex EZ spectrophotometer (Hunter Associates Laboratory, Inc; Reston, VA), referring to color space CIE L*, a*, and b*.

Water activity of samples before and after drying procedures was measured using an Aqualab TDL 2 water activity meter (METER Group, Inc. USA; Pullman, WA).

Dry matter was determined by drying duplicate one-gram quantities of each sample overnight at 100 °C in a digital multiprocessor oven (Quincy Laboratory, Inc; Burr Ridge, IL).

Ash content was determined in duplicate one-gram quantities of each sample using a Thermolyne muffle furnace (Thermo scientific) by following the AOAC-2000 official method 942.05.

Prior to further analysis for proximate composition and vitamin contents, samples were ground to fine powders using a SPEX model 6875 freezer mill high-capacity cryogenic grinder (SPEX

Industries; Metuchen, NJ). In the cryo-mill samples were precooled in liquid nitrogen for 10 minutes and then ground using three sequential one-minute cycles.

3.4. VITAMIN A

Individual carotenoids content was analyzed at Eurofins SF analytical DBA craft technologies (Wilson, NC) using a reverse phase HPLC method. A high efficiency C18 column selective for xanthophylls was used to separate carotenoids. Acetonitrile, p-dioxane, methanol, isopropanol, triethylamine, and ammonium acetate were mixed for mobile phase. Separated compounds were identified and quantified using both a diode array detector and visible detector. Carotenoids were detected at 450 nm in the visible spectrum with a quantification limit of 0.03µg/g.

3.5. VITAMIN C

Ascorbic acid was analyzed using two methods; the first method was conducted at Eurofins SF analytical DBA craft technologies (Wilson, NC) using a reverse phase HPLC method with ultraviolet detection. Vitamin C was measured using UV at 245nm and 600 mV with a limit quantification of 0.03µg/g. Samples were separated using C18 column without ion-pairing and the method was based upon reduction with TCEP in an aqueous buffer followed by acidic extraction. The second analysis method was done using the 2,6-dichloroindophenol titration method (AOAC, 1990). Metaphosphoric acid and acetic acid solution (HPO_3-HOAc) was used for extraction.

3.6. STATISTICAL ANALYSIS

Statistical analyses were completed using Statistical Analysis Software version 9.4 (SAS Institute Inc.; Cary, NC). The general linear model's procedure of SAS was used to conduct analyses of variance of the measured parameters using a completely randomized design with a two X three factorial arrangement of treatments (two substrates and three drying methods). Effects were considered significant using $\alpha \leq 0.05$, and least square means were used to compare main effect and treatment means using Fisher's f-test protected least significant difference method. Data are presented as least squares means ± standard errors of the mean.

CHAPTER 4: RESULTS

4.1.COLOR

The color of products is affected after drying due to various reactions that occur during the process. L*, a*, and b* parameters were used to analyze the color of the products before and after drying the samples.

There was a significant effect of drying method on the L* value in products being dried ($P \leq 0.05$). The freeze-dried product had the highest value of L* in both mangoes and OFSP, with a significant difference in some of the drying methods (Figure 5).

The L* value of orange fleshed sweet potatoes ranged from 76.3 to 79.5, and the L* value of mangoes ranged from 72.3 to 84.2. In mangoes, freeze drying had the highest L* value, followed by vacuum oven drying then lastly hot air drying. In OFSP, freeze drying had the numerically highest L*, followed by hot air drying, and lastly vacuum oven drying. However, these values were not statistically significant in dried OFSP.

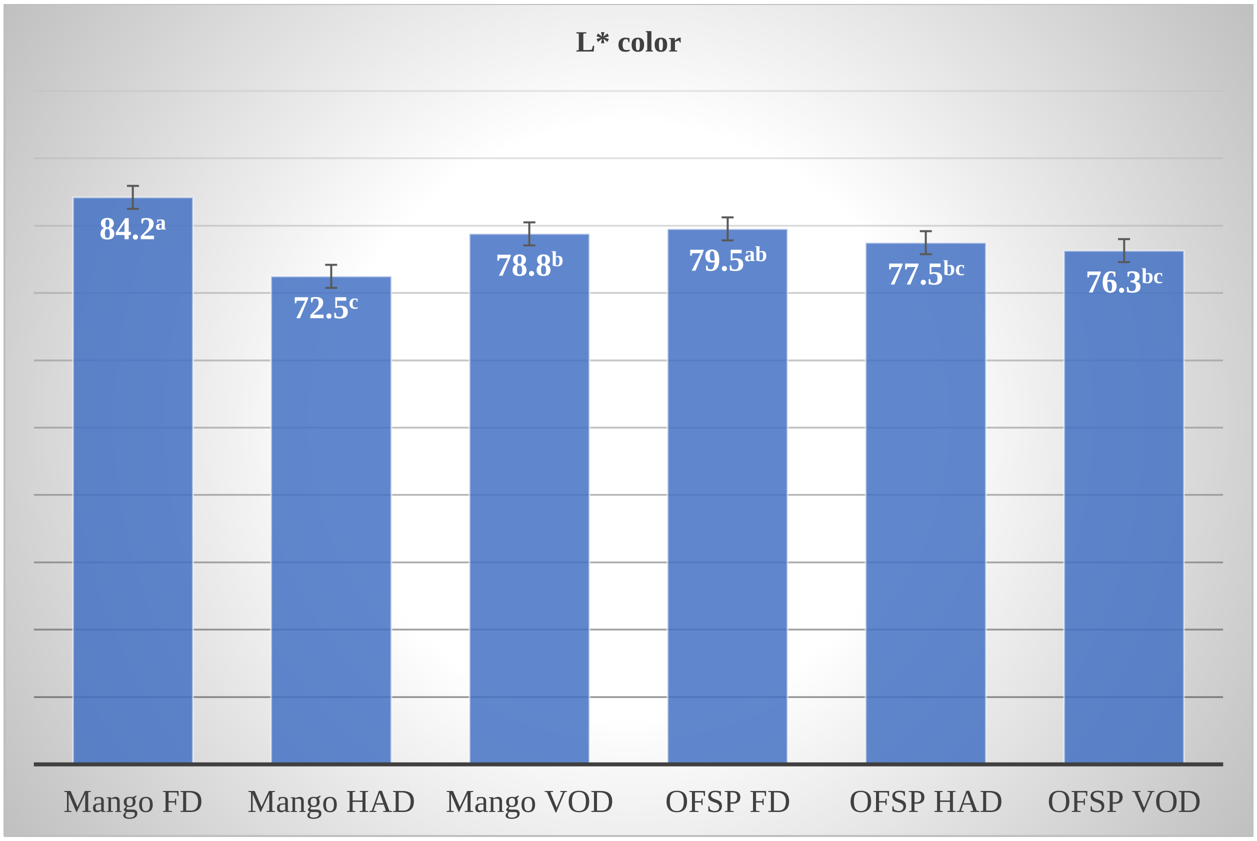

Figure 5: L* color values of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

[abc] Means not sharing a common superscript are different ($P \leq 0.05$).

There was a significant difference in a* mean values among products and drying methods ($P \leq 0.05$). All the products had a different value in the a* of all samples. Mango freeze dried sample was different from all the other samples except from mango vacuum oven dried (Figure 6).

In mangoes, a* ranged from 3.7 to 8.6, where the hot air drying resulted in the highest value of a*, and the freeze drying had the lowest value of a*. In OFSP, a* ranged from 8.2 to 11.1, where freeze drying resulted in the highest a* value, and vacuum oven drying led to the lowest value of a*.

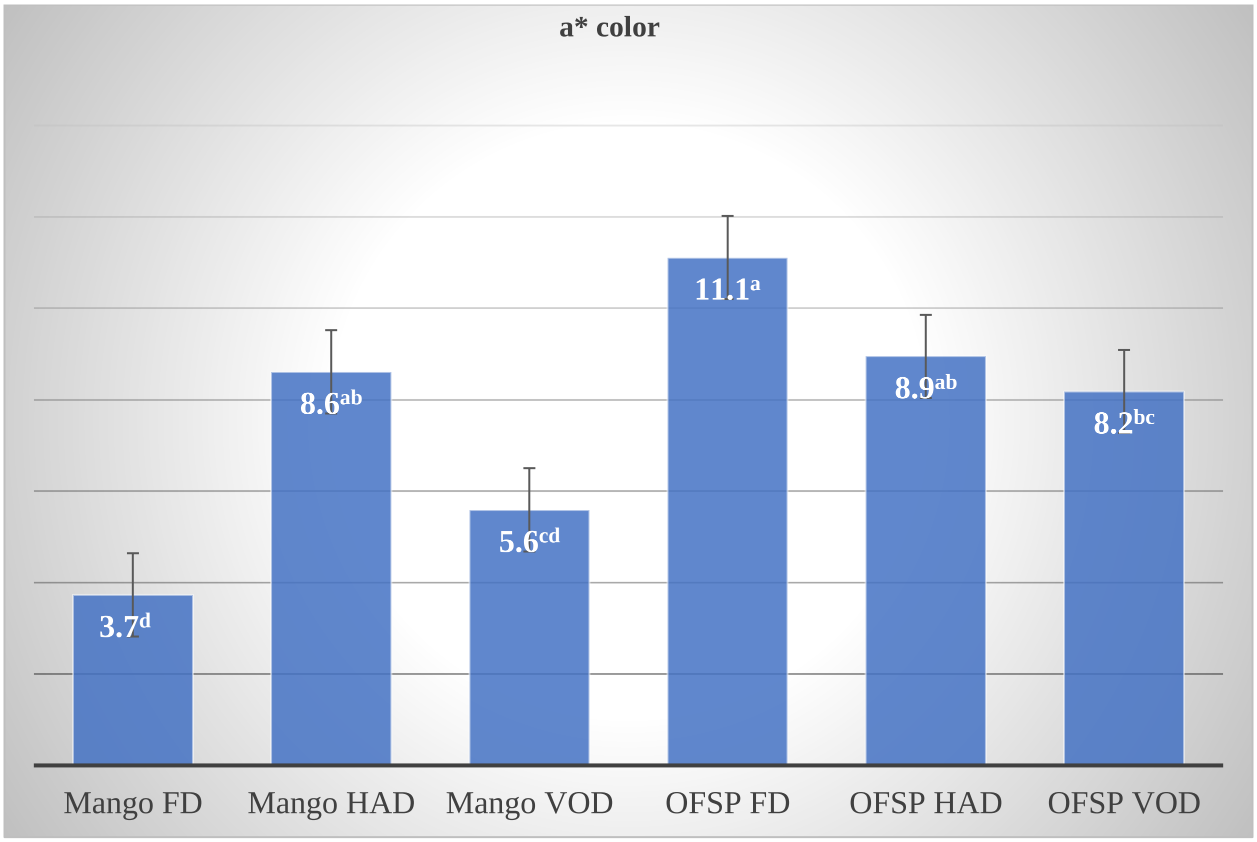

Figure 6: a* color values of mango and orange fleshed sweet potatoes subjected to freeze drying, hot-air drying, and vacuum oven drying methods.

[abc] Means not sharing a common superscript are different ($P \leq 0.05$).

Drying method did not significantly influence the b* value of products ($P \geq 0.05$). Averaged across all drying treatments, mango had significantly higher b* values compared to OFSP ($P \leq 0.05$). The b* value of mangoes ranged from 34.6 to 40.1 and the OFSP value ranged from 24.6 to 30.2 (Figure 7).

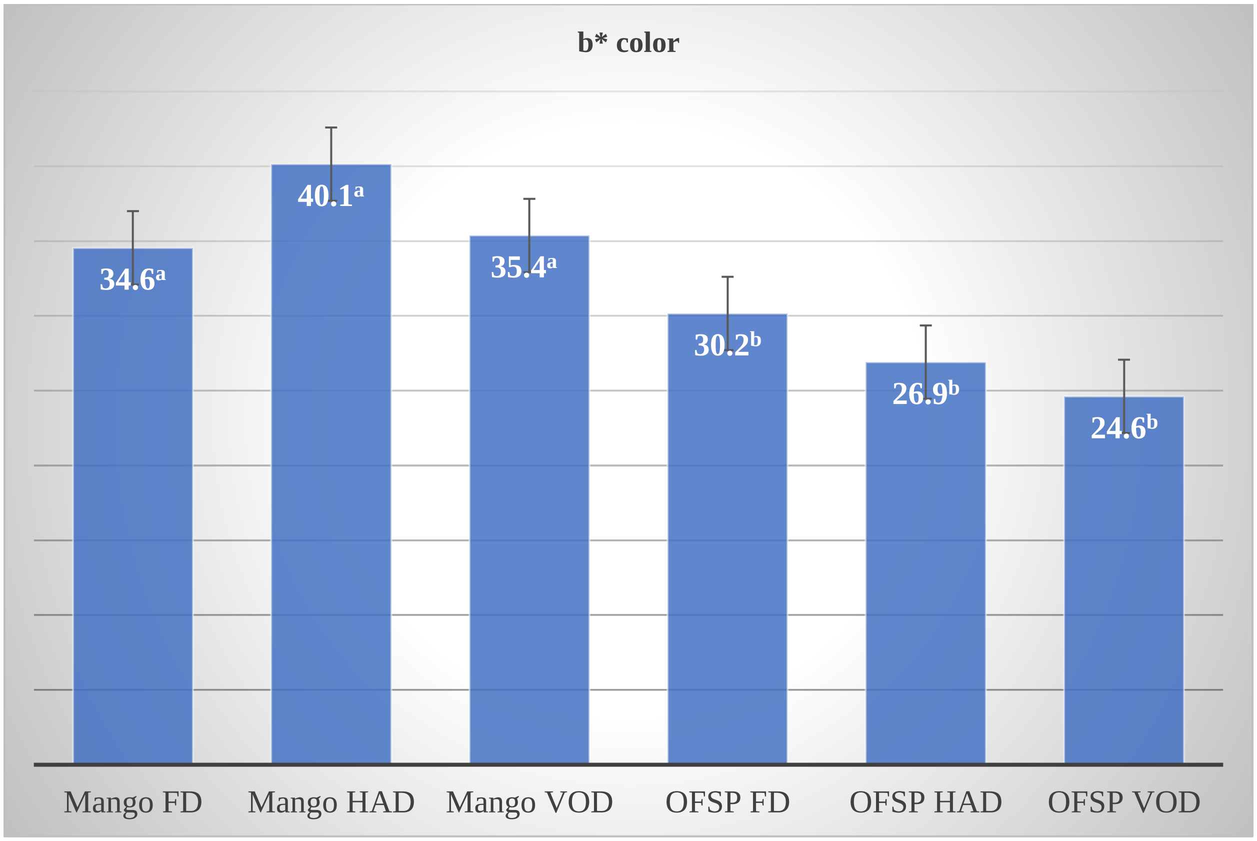

Figure 7: b* color values of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

[ab] Significant substrate effect ($P \leq 0.05$). Means not sharing a common superscript are different.

4.2.WATER ACTIVITY

The water activity of products is reduced during the drying process, which serves to reduce or prevent the growth of microorganisms that can spoil food.

There was no significant difference between the products and drying methods in the least square means of water activity ($P \geq 0.05$). All the drying methods were able to reduce the water activity below 0.60, where the water activity ranged from 0.23 to 0.35 (Figure 8).

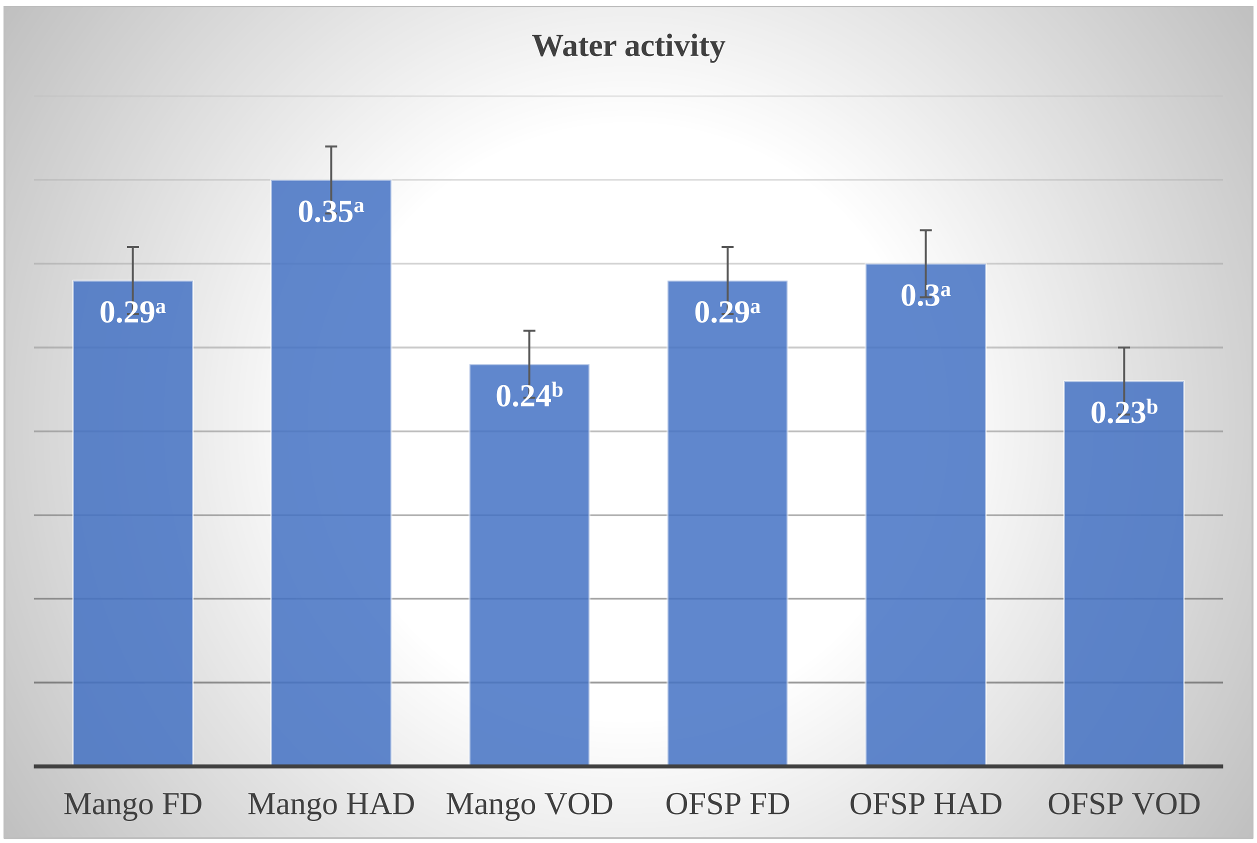

Figure 8: Water activity content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

[ab] Significant substrate effect ($P \leq 0.05$). Means not sharing a common superscript are different.

4.3. DRY MATTER

Dry matter is the portion of material that remains when all water has been removed after drying a product. Analytically, the procedure is conducted by drying products in a forced air oven at 105◦C for 24 hours and quantifying weight loss during the drying process.

There was significant difference between the products and the drying methods in least square means of dry matter ($P \geq 0.05$) (Figure 9), with vacuum oven-dried OFSP having the highest dry matter content (94.7%), hot air dried mango having the lowest (91.4%), and the other product and treatment combinations being intermediate.

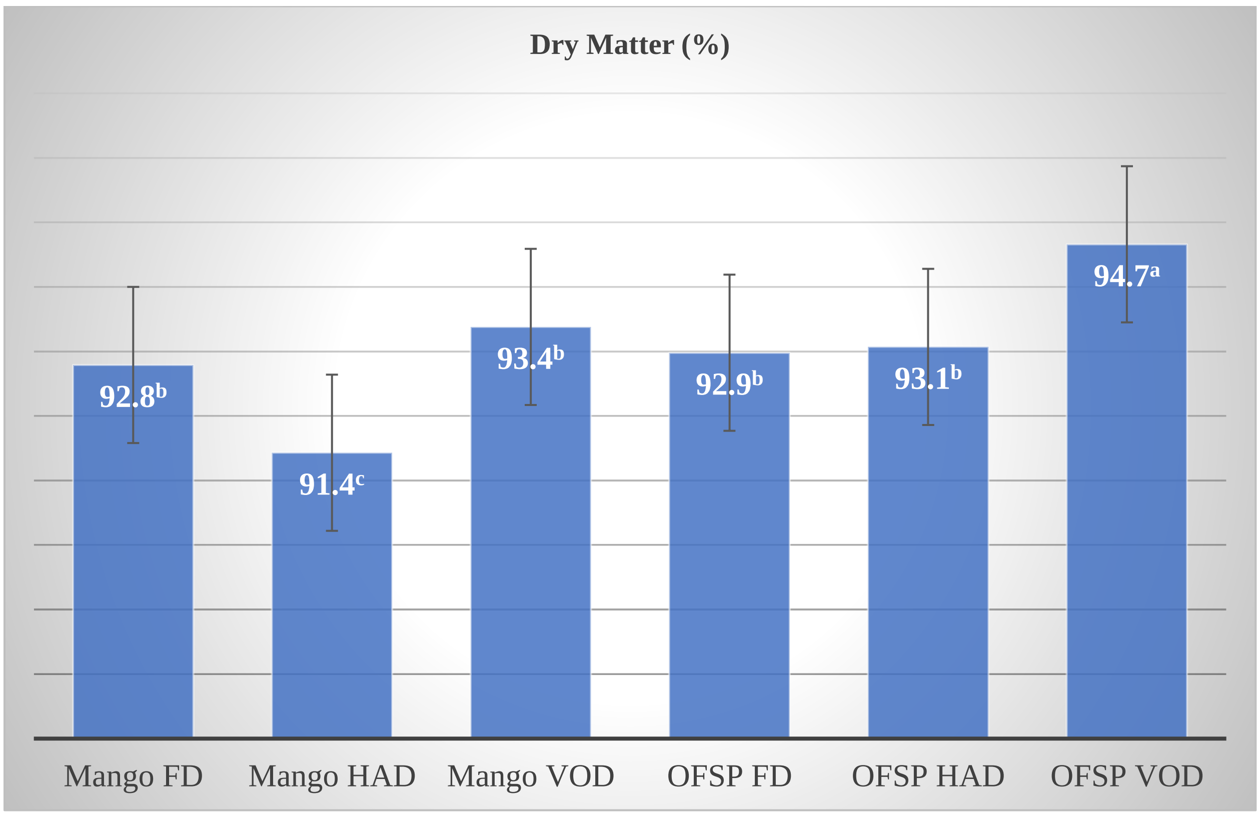

Figure 9: Dry matter content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

^{abc} Means not sharing a common superscript are different ($P \leq 0.05$).

4.4.ASH CONTENT

Ash content includes minerals and inorganics left after the food sample has been ignited in a muffle furnace at high temperatures, removing moisture, volatiles, and organics.

Drying methods did not significantly influence ash content of substrates (P ≥ 0.05). Substrates differed significantly in ash content, with OFSP having higher ash content compared to mangoes (Figure 10).

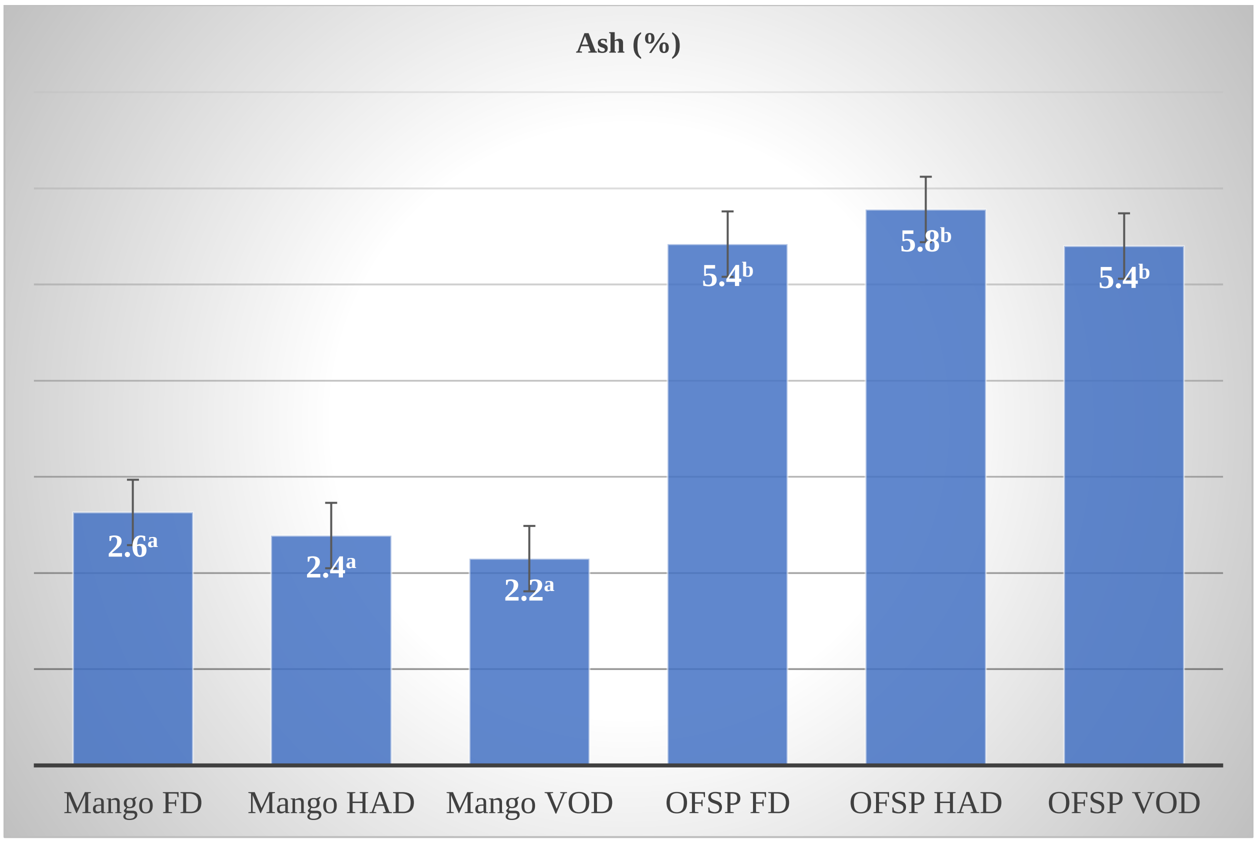

Figure 10: Ash content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

[abc] Means not sharing a common superscript are different ($P \leq 0.05$).

4.5.VITAMIN A (CAROTENOIDS) CONTENT

There was a significant difference in the carotenoids that were present in both mangoes and OFSP between products and drying methods ($P \leq 0.05$).

Figure 11 shows that OFSP had greater carotenoid concentrations compared to mango. Carotenoids in freeze dried OFSP products were significantly greater compared to that in OFSP dried by other methods. Freeze dried OFSP had the highest retention of carotenes that are present in both products and the greatest total beta carotene concentration (37.39 µg/g).

The retention of carotenoids in OFSP did not vary significantly between the vacuum oven dryer and the hot air dryer. Mangoes retained a high amount of the carotenes, including beta carotene, in hot air dried products (10µg/g), followed by freeze dried mango (6.2µg/g), and the vacuum oven dried mangoes had the lowest carotenoid concentrations.

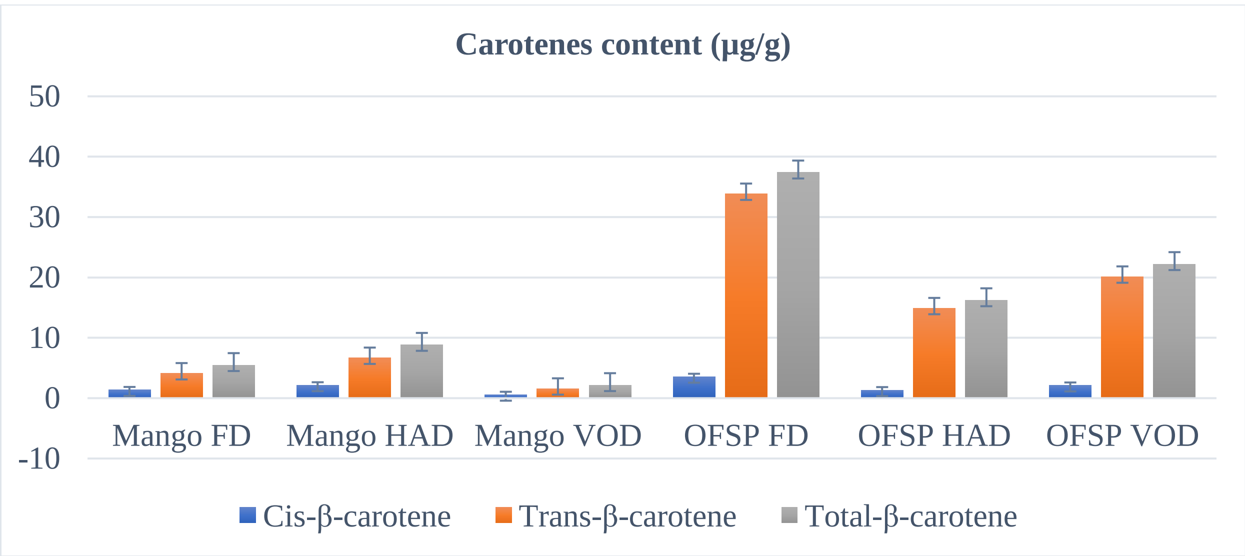

Figure 11: Carotenoids content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying and vacuum oven drying methods.

[abc] Means not sharing a common superscript are different ($P \leq 0.05$).

There was a significant substrate by drying method interaction ($P \leq 0.05$) for all-E-β-cryptoxanthin content of products.

Freeze dried OFSP had the highest concentration of all-E-β-cryptoxanthin (1.9µg/g) whereas OFSP dried by other methods had significantly lower concentrations. Mango contained relatively low concentrations of this carotenoid, and its concentration was not significantly influenced by drying method.

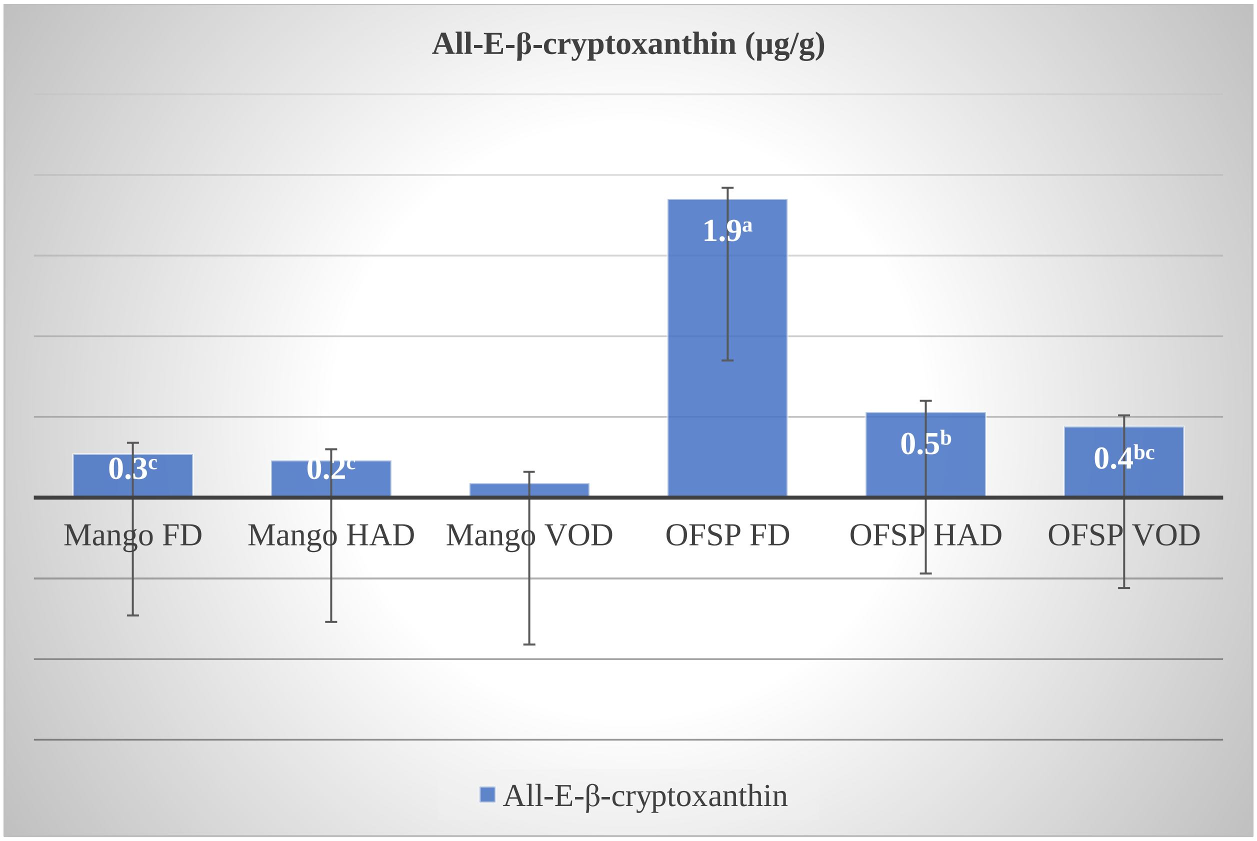

Figure 12: All-E-β-cryptoxanthin content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying and vacuum oven drying methods.

[abc] Means not sharing a common superscript are different ($P \leq 0.05$).

Lutein and zeaxanthin are carotenoids that were only detected in mangoes in this study. There was no statistically significant difference in the amount of lutein present in mangoes dried by different methods (P ≥ 0.05), while there was a significant difference in the amount of zeaxanthin present in products dried by different methods. Hot air-dried mangoes retained a high amount of lutein and zeaxanthin (0.4 µg/g and 0.5 µg/g respectively), followed by freeze dried mangoes (Figure 13).

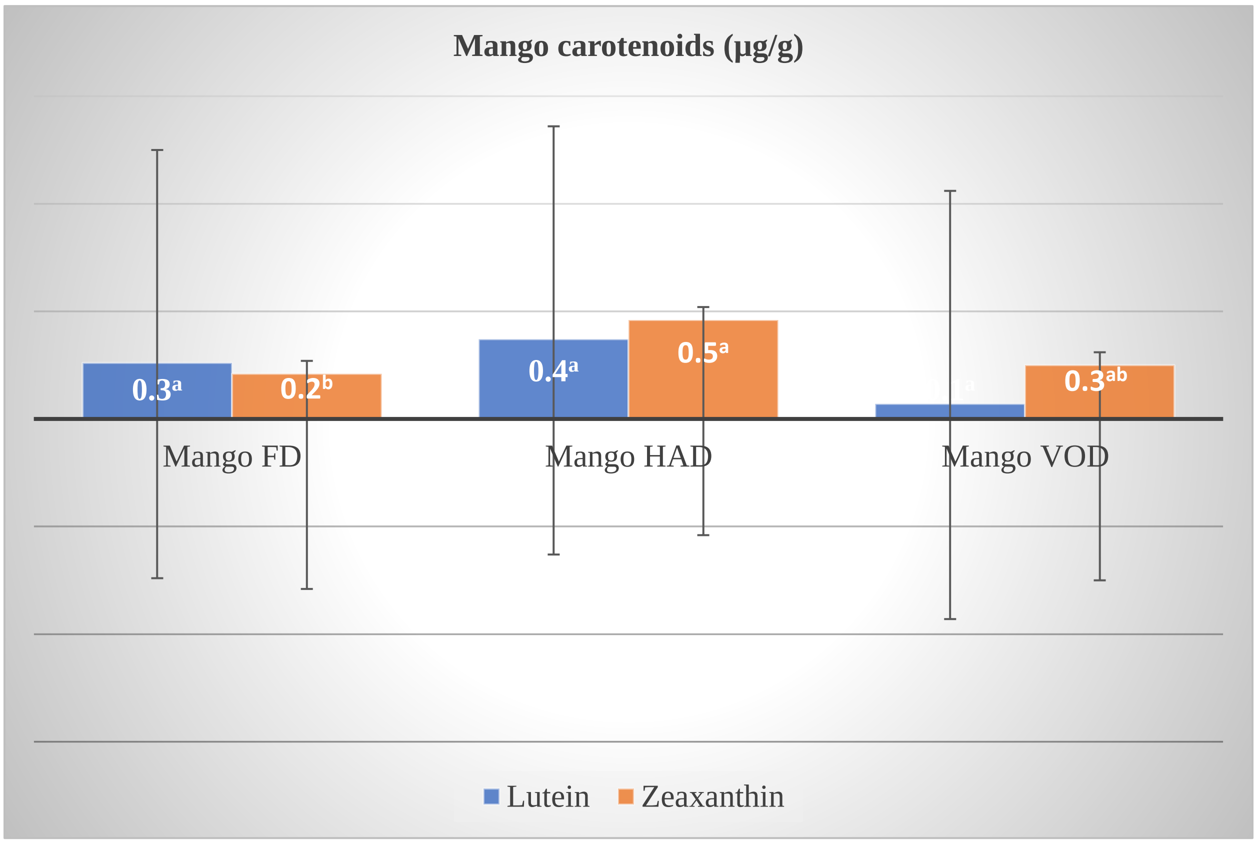

Figure 13: Carotenoid content of mangoes only subjected to freeze drying, hot air drying, and vacuum oven drying methods.

[abc] Means not sharing a common superscript are different (P < 0.05).

Lycopene is a carotenoid that was only detected in OFSP. There was a significant difference in the total lycopene content of OFSP dried using different methods. OFSP freeze dried products contained the highest concentration of total lycopene (3.9 µg/g), with OFSP vacuum oven dried products (1.9 µg/g) and OFSP hot-air dried products (1.7µg/g) containing lower total lycopene concentrations (Figure 14).

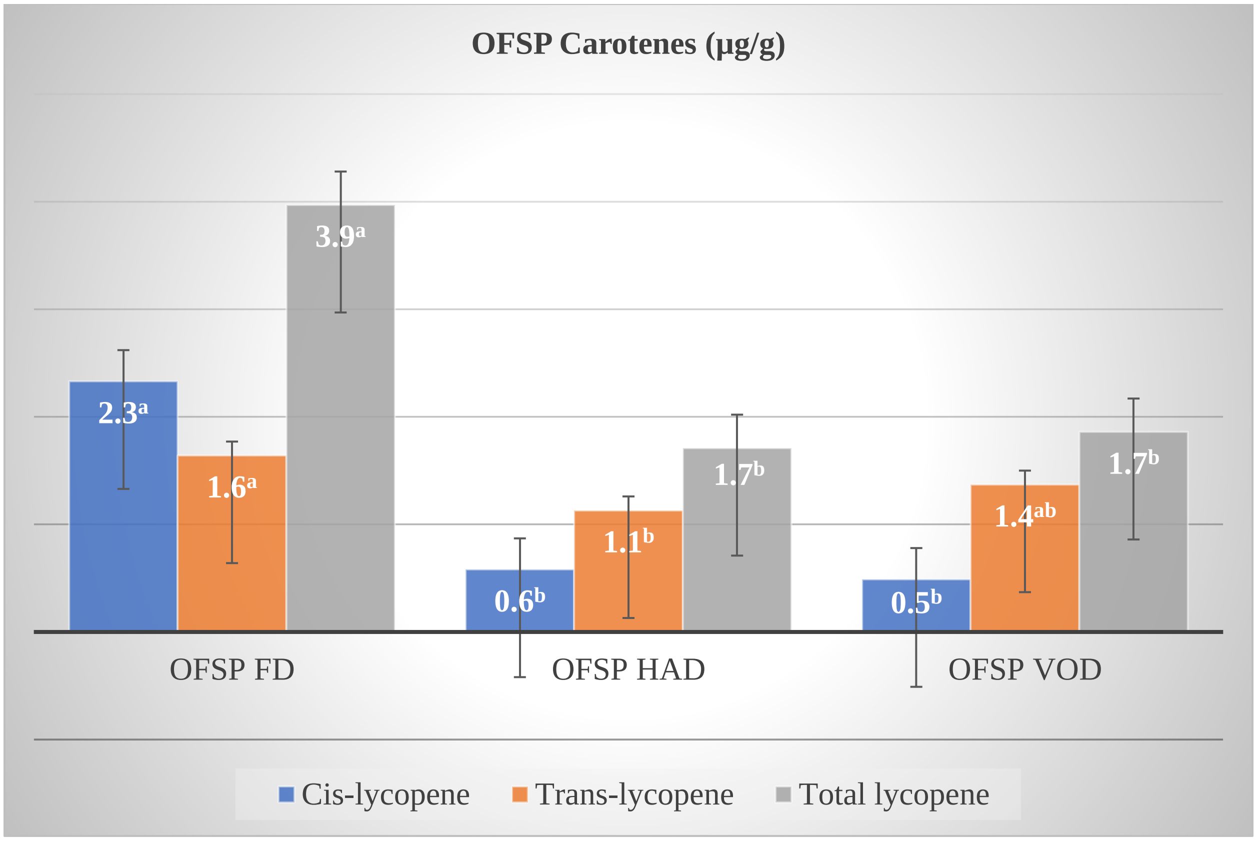

Figure 14: Carotenoids content of orange fleshed sweet potatoes only, subjected to freeze drying, hot air drying, and vacuum oven drying methods.

[ab] Means for bars of the same color not sharing a common superscript are different ($P < 0.05$).

Total carotenoids contents in mangoes and OFSP dried by different methods are presented in Figure 15. A significant substrate by drying method interaction was observed for total carotenoids content ($p \leq 0.05$), with drying methods having a considerable impact on the total carotenoids present in mangoes and OFSP.

Freeze dried OFSP contained the highest amount of total carotenoids (44.1 µg/g) followed by vacuum oven dried (24.6 µg/g) and hot air dried (18.9 µg/g) OFSP. Mangoes had lower total carotenoid concentrations compared to OFSP, with hot air dried mangoes (10.0 µg/g) having significantly greater total carotenoid concentrations compared to vacuum oven dried mangoes (2.6 µg/g) (Figure 15).

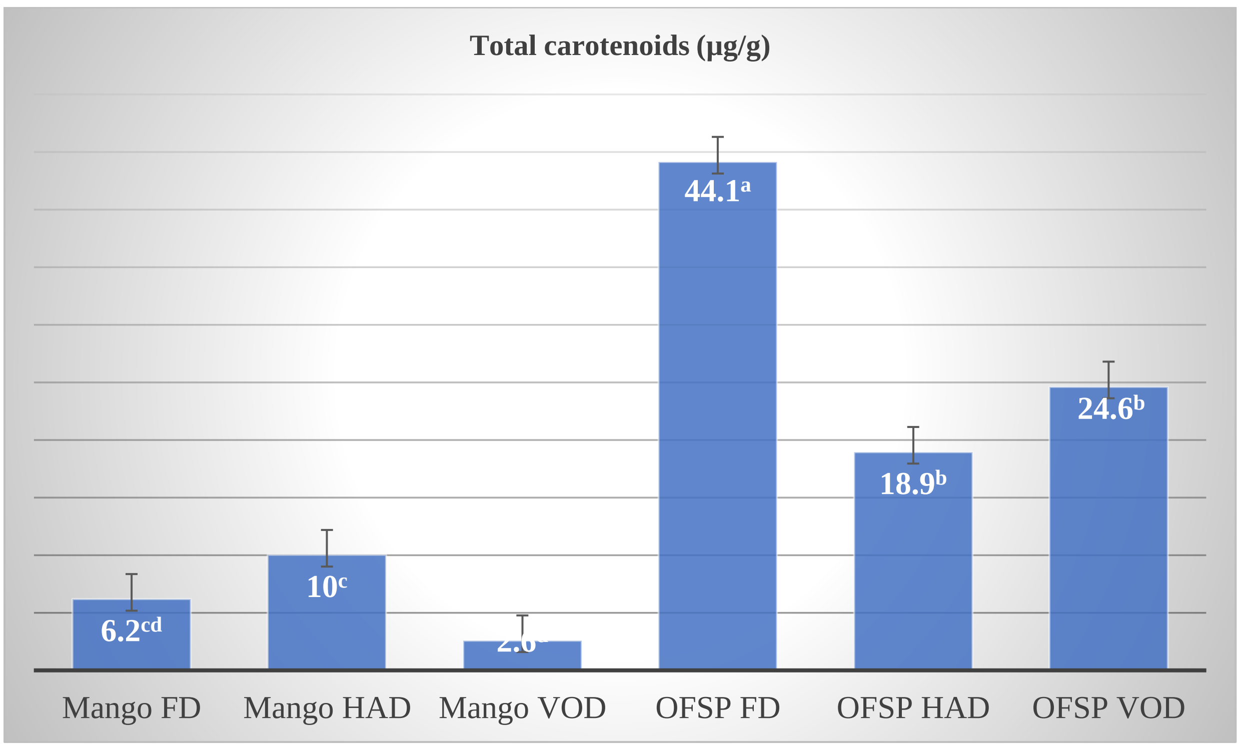

Figure 15: Total carotenoids content of mangoes and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

abcd Means not sharing a common superscript are different ($P \leq 0.05$).

4.6. ASCORBIC ACID

Ascorbic acid was measure using two methods in this study and the results are presented in Figure 16 and Figure 17. Drying method did not significantly influence ascorbic acid concentration for either substrate as measured by the titration method or the HPLC method (Figure 16; Figure 17). There was a significant difference in ascorbic acid concentration in the substrates, with mango containing more ascorbic acid than OFSP.

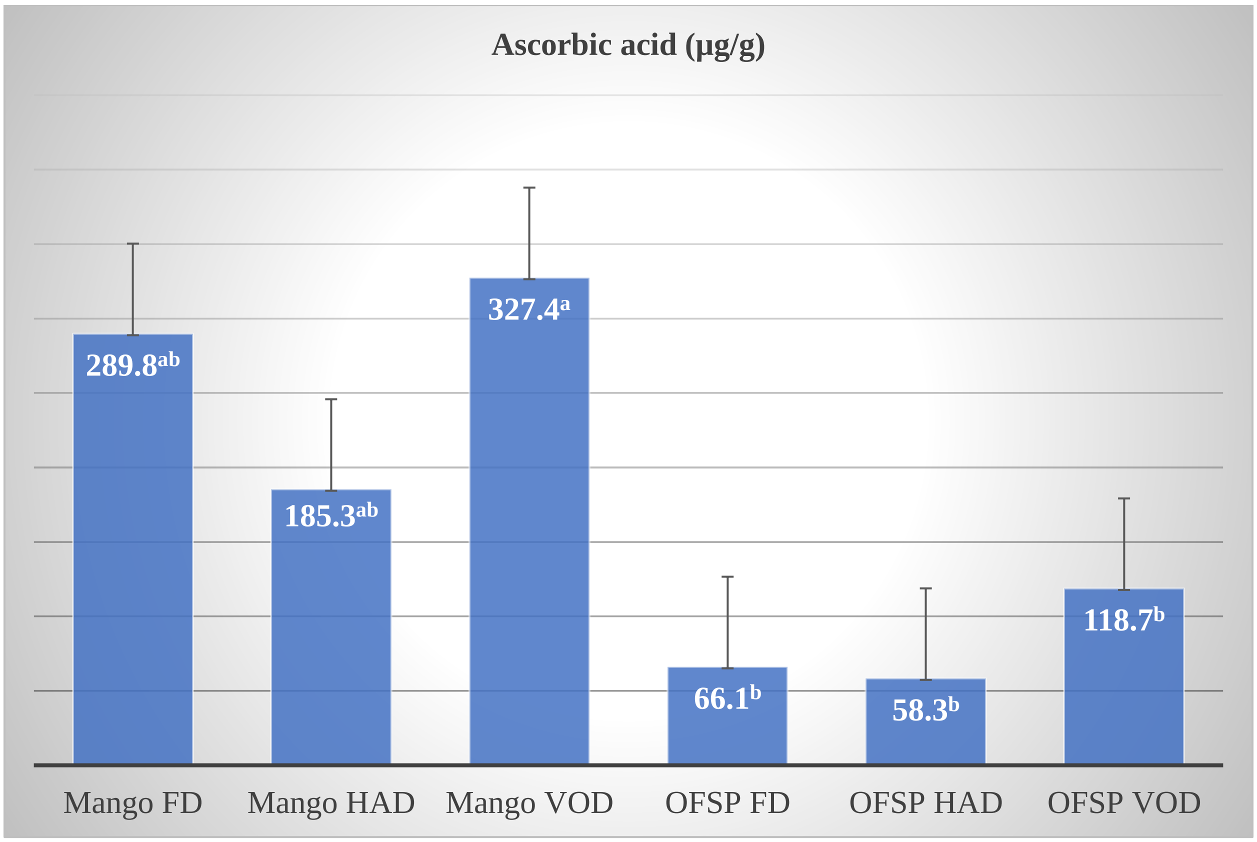

Figure 16: Ascorbic acid content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

[ab] Significant substrate effect ($P \leq 0.05$). Means not sharing a common superscript are different.

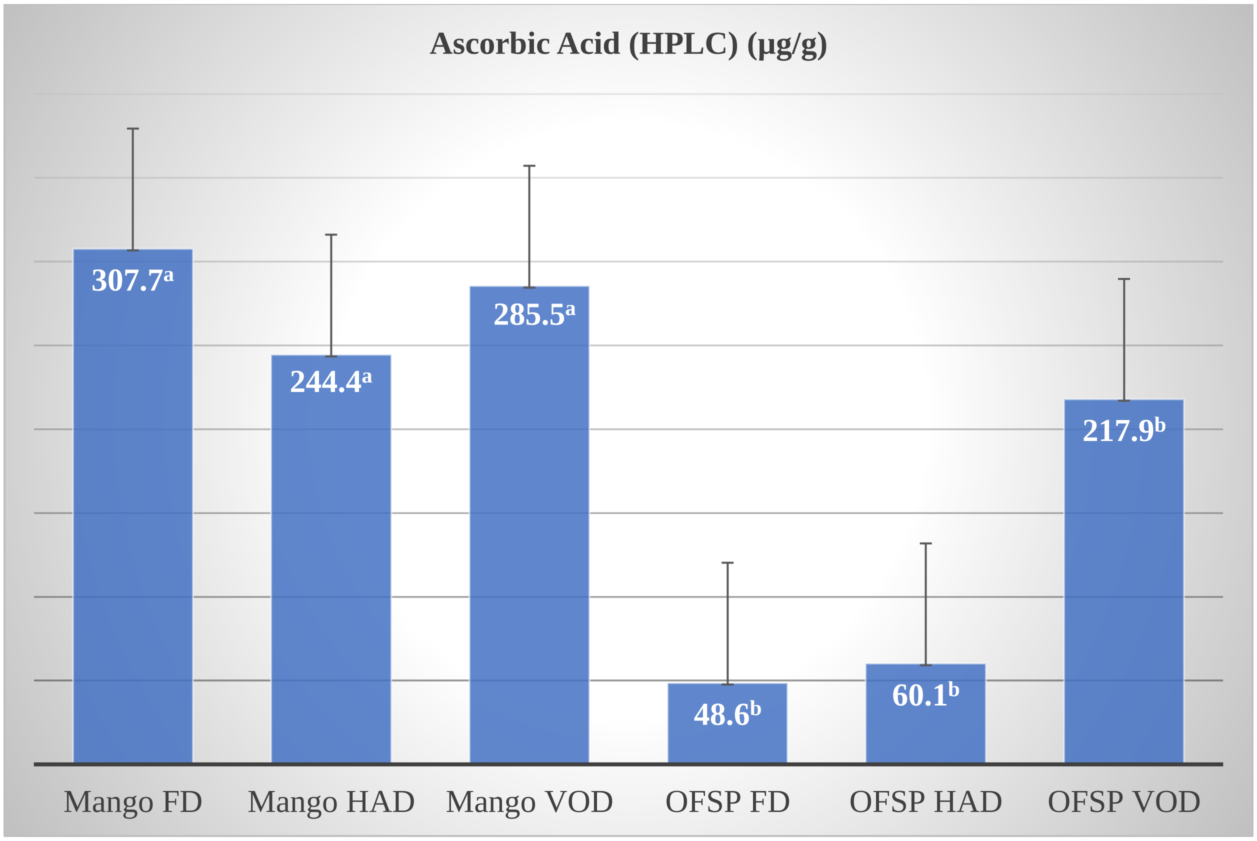

Figure 17: Ascorbic acid content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

[ab] Significant substrate effect ($P \leq 0.05$). Means not sharing a common superscript are different.

CHAPTER 5: DISCUSSION

The extent of quality change during drying of food products depends on the type of product being dried, the drying methods used, and any pretreatments used. The quality changes during food product drying commonly include commonly include color, water activity levels, nutrient concentrations, and many other factors.

Because the objective of this research was to determine the changes that occur to selected fresh produce during drying, no pretreatments to the substrates such as cooking were used prior to the drying processes in this study. Some pretreatments have effects on the changes that occur during the drying process, which could have confounded the results of this research.

5.1.COLOR

Color is an important attribute that influences consumer acceptability of foods and helps consumers when making food choices; most consumers choose processed fruits and vegetables that look like fresh products in color. Therefore, color retention should be a consideration when drying products (Huang & Zhang, 2016).

Fruits and vegetables become darker and more concentrated in color when dried for a variety of reasons including a decrease in the moisture content, and increased concentration of pigments that give the products color. Color changes during drying are primarily determined by browning reactions, which can be caused by both enzymatic and non-enzymatic processes (Calín-Sánchez et al., 2020).

Browning occurs in fruits and vegetables due to high carotenes, which are thermosensitive, and due to an abundance of sugars such as glucose and fructose, which interact with amino groups in proteins and initiate the Maillard reaction during exposure to air and high temperatures, long drying times, and an abundance of water (Calín-Sánchez et al., 2020).

L*, a*, b* color is a three-dimensional color space with three components that is used to describe colors in the visible spectrum. L* represents lightness on a scale of 0 to 100, with 0 representing black and 100 representing white; the higher the L* value, the lighter the color of the product. a* represents the colors red (+) to green (-), the stronger the red pigment, the higher the positive a* value. Blue (-) to yellow (+) color is represented by b*; the higher the positive b* value, the stronger the yellow pigment in the products (Zaizuliana Rois Anwar & Abd Ghani, 2019).

The results of this research have shown how color is affected differently when fruits and vegetables are being dried, and it all depends on different factors like the type of product, drying machine, and drying temperature. Different fruits and vegetables have different color outcomes after drying. As seen from the results, all drying methods affected the color of the products. There was a change of color in both the L*(lightness), a*(redness), and b* (yellowness) of mangoes and orange fleshed sweet potatoes. L* and a* showed a significant difference between the products and drying methods, whereas b* did not show a significant difference.

In mangoes, the freeze dried products had the highest L* (84.2) which showed that it had the brightest color of the mango, followed by vacuum oven dried mangoes (78.8), with hot air dried mangoes having the lowest L* (72.5) (Figure 5). Hot air dried mangoes had the highest a* values, followed by vacuum oven dried sample, and then the freeze dried samples (Figure 6). The b* values of mangoes dried using the different methods were not statistically different, although the hot air dried mangoes had the greatest numerical value for b* (Figure 7).

The findings in this study are in line with Zhang et al., 2018, in which a Japanese herb called Ashitaba (Angelica keiskei) had high L* and less a* after freeze drying. They found high a* (redness) in products after using thermal processing drying methods (vacuum oven and convective hot air drying), confirming that the product dried using the freeze dryer was lighter in color. When products are exposed to high temperatures, enzymatic and non-enzymatic browning reactions cause the degradation of L* color (Jia et al., 2019; Zhang et al., 2018).

According to a study on the effect of drying on pomegranate peel, freeze dried pomegranates had a lower a* value, which reduced the color intensity of the product when compared to vacuum oven dried pomegranate. Freeze dried pomegranates were slightly bleached, but they had a high L* value (Mphahlele et al., 2016).

Freeze dried OFSP had numerically the highest L* (79.5), a* (11.1), and b* (30.2) values, followed by hot-air dried and vacuum oven dried samples. However, only the differences a* values were statistically significant for OFSP dried using the different methods (Figure 6). The changes in the color parameters after using the other drying methods indicates that the drying conditions caused enzymatic and non-enzymatic browning reactions (Jia et al., 2019)

Like in this research, vacuum oven drying in chokeberry showed lower L* value, which resulted in darker chokeberries compared to other drying methods (freeze and convective drying) (Samoticha et al., 2016).

Freeze dried mango and OFSP had highest levels of L* (84.2 and 79.5, respectively), indicating that freeze drying produced lighter products when compared to the other drying methods (Figure 5). Freeze drying employs the sublimation technique and the low temperature reduces the ongoing chemical and microbiological processes, assisting in the preservation of product color (Hasan et al., 2019a).

According to a study conducted by Izli et al., 2017, on the influence of drying techniques in mangoes, freeze dried mangoes had higher values of L* and b* compared to hot air dried mangoes and other methods, but there was an increase in a* value of hot air dried mango samples, which was due to the high temperatures in hot air drying, which caused non-enzymatic browning reaction (Izli et al., 2017).

Another study on the effect of sweet potato processing methods found that freeze dried sweet potatoes had a higher L* value than other processing techniques. The lightness of the product in the freeze dried samples resulted from the use of a vacuum in drying samples, which reduces oxidation reactions (Zaizuliana Rois Anwar & Abd Ghani, 2019).

According to Sehrawat et al., 2018, mango cubes dried using a hot-air dryer had low L* values due to enzymatic browning due to the presence of oxygen but had increased a*. High yellow orange is indicative a good amount of β-carotene in fruits and vegetables, and a reduction of the carotene concentration reduces the intensity of said color (Sehrawat et al., 2018).

Phing et al., 2022, discovered that bintangor puree dried in freeze dryers and vacuum oven dryers had positive a* values, resulting in products with colors similar to fresh products. These results showed that freeze dryers had the highest a*, which is consistent with the results of the present study for OFSP freeze dried samples; the low processing temperature in freeze dryers helps in retaining high pigments of vitamin C, which protects molecules responsible for red color (Phing et al., 2022).

Hawthorn fruit dried under different drying methods had high L* when freeze dried, the product was even lighter compared to the fresh product, but the freeze dryer had the lowest a* value, as found in the mangoes dried under freeze dryer from this research. In contrast, the freeze dried orange fleshed sweet potatoes had a high value of L* and a* (Coklar et al., 2018).

In the current study, all products had positive b* values and drying did not affect the yellowish color of the products in a statistically significant manner, indicating that the yellowish color in the dried products was close to the original color of the fresh products. Mangoes are yellow in color when ripe compared to OFSP, hence it had the higher b* value among the substrates used in this research (Figure 7).

Kiwi fruit dried under different conditions showed higher values of a* and b* in hot air and vacuum oven drying, respectively, with similar L* values. Freeze dried kiwi fruit showed a decrease in a* values but had an increase in L* value which resulted in a lighter kiwi product. There was no significant difference in the b*, all the drying methods had the same b* value (Akar & Barutçu Mazı, 2019).

When compared to other drying methods, freeze drying is known to preserve the color of dried fruits and vegetables, where rapid freeze drying produces more intense white or light products, with a high L*. It suppresses enzymatic browning reactions by using low temperatures, little oxygen, and the sublimation of ice to remove water, resulting in an increase in L* value when drying products (Valentina et al., 2016).

A change in color in the products dried is related to pigment degradation, the degradation of carotenoids, and the formation of brown pigments by enzymatic and non-enzymatic (Maillard) browning (Izli et al., 2017). When fruits and vegetables are being heated during the drying process, enzymatic and non-enzymatic browning reactions occur, which darkens the surface color of products and destroys the natural color (Wang et al., 2021).

5.2.WATER ACTIVITY

Water activity is useful in indicating the potential for microbial growth and other chemical reactions in food (Wojdyło et al., 2020). The range of water activity values permissive for growth of microorganisms ranges from 0.60 to 1.00 $_{a}$w. Some bacteria require high water activity to survive and proliferate, whereas others do not. For example, spoilage bacteria generally grow well at water activity levels greater than 0.90. Fresh fruits and vegetables typically have a water activity of 0.97 to 0.99, making them susceptible to microbial colonization and growth. Lowering the water activity to 0.60 aids in the preservation of fruits and vegetables (Sandman, 2021).

For the current research, all drying methods reduced the water activity of the products to less than 0.60, ranging from 0.2 to 0.4. There were no significant differences in water activity least square means between products ($P \geq 0.05$), but drying procedures had a significant effect with vacuum dried products having water activity less than that of products dried by the other methods (Figure 8). The results of this research shows that all the drying methods (freeze, vacuum oven, and hot air dryer) can reduce the growth and multiplication of microorganisms and reduce chemical reactions which will improve the shelf life of the products.

According to literature, freeze dryer, vacuum oven dryer and hot air dryer reduces water activity levels to less than 0.60 which is below the safe limit for oxidation, enzyme activities and microbial activities. Banana peels water activity level was reduced to a range of 0.39 to 0.44 (Vu et al., 2017). Chokeberry water activity level reduced in ranges 0.13 to 0.55 in all the drying methods and Gac peels water activity ranged from 0.30 to 0.55 (Chuyen et al., 2017; Samoticha et al., 2016).

5.3.DRY MATTER

Dry matter is the portion of a material that remains when all water has been removed after drying a product. High dry matter increases the shelf life of products by reducing the amount of water available for microbial growth and chemical reactions, and it also makes a product more concentrated, which can be desirable during food processing and gives high yield when processing. It allows fruit to taste good with better transportation and good keeping quality; but sometimes high dry matter makes products dryer for consumption and processing, hence it is good ensure that the dry matter is balanced (Kurina et al., 2021).

There was a significant difference in the resulting dry matter content of products dried by different methods in this study. Vacuum dried OFSP had the highest dry matter content compared to other OFSP and mango products dried using other methods, with hot air dried mangoes having the lowest dry matter content (Figure 9). These results are consistent with the observations for water activity; the less the water activity the higher the dry matter content.

Other researchers have reported there is an inverse correlation between total carotenoids and dry matter content of fruits and vegetables. Doubling carotenoid content results in a decrease of about 1.2% in dry matter content of different sweet potato varieties (Truong et al., 2018). Japanese quince dried under different conditions showed lower values of dry matter in the freeze dryer compared to the vacuum oven and other drying methods (Çakmakçı & Çakmakçı, 2023).

5.4. ASH CONTENT

Ash analysis is performed as part of nutrition analysis; ash is an inorganic residue (which includes minerals in food) that remains after organic matter has been burned off. It is calculated as a percentage of the initial dry weight of a material. Drying affects the ash content of products, particularly food and agricultural products. After drying, the water content of the material decreases, causing the ash content to become more concentrated; the level of the concentration varies on the type of product being dried, the drying conditions, and the materials used (Ismail, 2017).

Ash content includes small elements of minerals and inorganics like calcium, magnesium, potassium, zinc, iron, and sodium. Food products typically have around 7% ash content, but it varies (Precisa, 2023).

In this study, OFSP had significantly higher ash content, ranging from 5.4 to 5.78%, compared to mangoes that ranged from 2.15 to 2.63%. Hot air dried OFSP had numerically the highest ash content (5.78%) followed by freeze dried OFSP. Mango vacuum-oven dried had the lowest value of ash content (2.51%). Drying methods did not significantly influence the ash content of mango or OFSP.

Dried vegetables like sweet potatoes have total ash content around 5% depending on the type of vegetable, drying materials, and time of drying (Kenya Bureau of Standards, 2018). This is consistent with the findings of this research.

The results of this research are in contrary with Truong et al., 2018, where they wrote that sweet potatoes have an ash content of 3% on dry basis and another study showed that OFSP flour ash content was 2.11% (Rodrigues et al., 2016). Sweet potatoes used in this research had a mean ash content in excess of 5% of dry matter.

5.5.VITAMIN A (CAROTENOIDS)

Carotenoids are plant pigments that are partially responsible for the red, yellow, and orange colors in plants. The main compounds that make up total carotenoids in fruits and vegetables are alpha-carotene, beta-carotene, cryptoxanthin, lutein, zeaxanthin, and lycopene (Kamiloglu et al., 2016). In this study, there was a significant difference in the total carotenoids content present in mangoes and OFSP ($P \leq 0.05$). Mangoes and OFSP contain different types of carotenoids, with OFSP containing high concentrations of beta-carotenes, which makes them a potential food product to deal with vitamin A deficiencies (Neela & Fanta, 2019). Lutein and zeaxanthin were only detected in mangoes while lycopene was only found in OFSP, as shown in Figure 13 and Figure 14.

Lutein and zeaxanthin are a type of carotenoids (xanthophylls) that give fruits and vegetables yellow color. In this research they were detected in mangoes only. Mango hot-air dried sample retained high amount of both lutein and zeaxanthin (0.4 µg/g and 0.5 µg/g respectively). There was no significant difference in the amount of lutein that was retained for the different drying methods, all the drying methods retained the same range of lutein.

Lycopene was only detected in OFSP in this study. Freeze dried OFSP samples retained high amounts of total lycopene (a combination of cis and trans lycopene), followed by vacuum oven dried samples.

Total carotenoids were present in high concentrations within the freeze dried OFSP (44.1µg/g), the vacuum oven dried OFSP (24.6 µg/g), and the hot air dried OFSP (18.9 µg/g) (Figure 15). Among the carotenoids assessed in this study, OFSP had the highest level of beta carotene (a combination of cis and trans beta carotene), while the other carotenoids were present in lesser amounts. Freeze dried OFSP had a total beta carotene level of 37.4 µg/g, while vacuum oven dried OFSP had a concentration of 16.2 µg/g (Figure 11).

Hot air drying retained high concentrations of total carotenoids in mangoes (10 µg/g), followed by freeze drying (6.2 µg/g). Like sweet potatoes, mangoes contained high concentrations of beta carotene, where hot air-dried mangoes had 8.9 µg/g followed by freeze dried mangoes, which had 5.5 µg/g, and lastly, freeze dried mango with 2.2 µg/g.

According to United States Department of Agriculture, 2022, raw mangoes contain 640 µg/100g of beta carotene. According to Neela & Fanta, 2019, the beta carotene of OFSP ranges from 200 to 36,400µg/100g on dry basis. After drying in this study, mangoes had beta carotene levels ranging from 2.17 to 8.84 µg/g (217 to 884 µg/100g), while OFSP had a beta carotene content ranging from 16.23 to 37.39 µg/g (1,623 to 37,390 µg/100g).

In this study, there was a significant difference in total carotenoids of OFSP dried using different methods (Figure 15). freeze dried OFSP contained 44.1 µg/g which dropped significantly in OFSP dried by the other methods. This shows that in this study hot air and vacuum oven dryer had a high impact on the carotenoids that were present especially in OFSP. The higher retention of total carotenoids in freeze dried OFSP may be due to the use of low temperatures during the drying process and lack of oxygen which prevented reactions that cause carotenoids loss (Jia et al., 2019). A prior study on the effect of different drying methods on total carotenoids in Tommy Atkin mangoes was supported by with results found in this research on OFSP, where freeze dried mangoes retained high values of total carotenoids (5.17mg/100g) compared to convective hot-air dried and vacuum oven dried mangoes (Sogi et al., 2015).

A study on dried peppers showed a high degradation of beta-carotene after drying, with the beta carotene content ranging from 0.075 to 0.239g/kg, with freeze dried peppers having the highest value of beta carotene, due to lower temperatures than the other drying methods, and hot air drying did not retain much of the beta-carotene due to high oxidation exposure (Maurya et al., 2018).

Due to the moderate to low drying temperatures, bintangor oranges retained 74% of total carotenoids when freeze dried, followed by convection hot air drying and vacuum oven drying (Phing et al., 2022).

In contrast to these studies, a study on the impact of drying methods on the carotenoid content of Ataulfo mango byproducts was conducted; hot air drying preserved more total carotenoids in mango peels (67.82g/kg), while freeze drying retained the least (51.14 g/kg), and freeze drying preserved more carotenoids in mango paste (50.94 g/kg), whereas hot air drying reduced the amount of total carotenoids (29.57 g/kg) in mango paste. The researchers concluded that hot air drying was the more suitable method for preserving mango peels, whereas the freeze drying was more suitable for preserving mango paste (de Ancos et al., 2018).

In this study, the total carotenoids content of products varied based on the drying process and products used. According to this research, mangoes preserved most of their carotenoids when hot air dried, but OFSP retained most of its carotenoids when freeze dried. According to de Ancos et al., 2018, preservation of compounds in food depends on the food matrix, and the retention of compounds depends on the type of food and drying parameters. This might have caused a more retention of carotenoids in hot air dried mangoes compared to freeze and vacuum oven dried mangoes.

Carotenoids are lost during oxidation reactions; however, additional processing techniques, such as drying, contribute to carotenoids loss due to an increase in product porosity. The inside of the products become concentrated during drying, making them subject to the effects of the processing conditions, such as high oxygen, tension, and heat. Because of oxidation and the breakdown of conjugated double bonds in carotenoid molecules, the products are highly vulnerable and end up losing more carotenoids. Light and heat stimulate the enzymes present in the products, thereby increasing carotenoids oxidation (Kamiloglu et al., 2016).

According to the National Institutes of Health, 2022, the recommended daily intake of vitamin A is between 300 to 1700 µg/day depending on age, sex, and health condition. In this study mangoes contained between 2.59 to 10.01µg/g of total carotenoids and OFSP contained between 18.95 to 44.13µg/g. Based on these concentrations, with a 50 g serving mangoes can supply around 148 to 500 µg total carotenoids when consumed and OFSP can supply 947 to 2,206 µg. Thes results show that a 50g/db. serving size can at least meet the recommended daily allowance especially for the OFSP which is high in carotenoids especially β-carotene.

5.6.VITAMIN C (ASCORBIC ACID)

Drying can cause a significant loss of vitamin C content in fruits and vegetables. Vitamin C is a water-soluble vitamin that can be damaged by heat and oxygen during the drying process. The amount of vitamin C lost during drying may vary depending on the drying process and the type of food being dried. According to the literature, different drying processes significantly reduce ascorbic acid retention in fruits and vegetables (Kamiloglu et al., 2016).

According to the United States Department of Agriculture, 2022, orange fleshed sweet potatoes contain 148µg/g of ascorbic acid, while fresh mangoes contain 364µg/g, depending on the variety. Ascorbic acid content is used as an indicator for preservation of nutrients in dried food items because it is sensitive to heat and evaporates easily due to it being a water-soluble vitamin, when vitamin C is maintained, it indicates that other nutrients are also preserved. Presence of oxygen and heat supply causes the reduction of ascorbic acid (Ali et al., 2016).

In this study, there was no significant effect of drying methods on vitamin C concentration in either mangoes or OFSP. This was confirmed by conducting vitamin C quantification using two methods- the AOAC titration method and by HPLC analysis conducted by Eurofins.

There was a significant difference in vitamin C concentration in the two substrates, where mangoes had a high amount of ascorbic acid compared to OFSP (Figure 16 and Figure 17).

Most published research indicates that freeze drying retains more ascorbic acid compared to vacuum oven and hot air drying.

According to a study that examined the effects of drying on ascorbic acid in ginger and tomatoes, freeze dried tomatoes retained more ascorbic acid (65.47mg/100g) than vacuum-oven dried tomatoes. Ginger lost all its ascorbic acid during all the drying techniques because it already had the least quantity of ascorbic acid when fresh. When compared to the freeze dryer, which uses low-temperature thermal drying methods destroyed a lot of ascorbic acid (Gümüşay et al., 2015).

According to Akar & Barutçu Mazı, 2019, a significant amount of ascorbic acid was lost in dried kiwi fruit regardless of the drying method including hot air drying, vacuum oven drying and freeze drying. There was no significant difference between vacuum oven drying and hot air drying but vacuum oven dried products contained numerically more ascorbic acid (61.27 mg/100g); the greatest reduction was seen in hot-air dried kiwi fruit with a loss of 77.52% (56.01 mg/100g). Freeze drying had the highest retention of ascorbic acid (175.30 mg/100g) (Akar & Barutçu Mazı, 2019).

Green tea leaves dried under different conditions had the highest retention of vitamin C when freeze dried (16.36 mg/100g DM) but hot air dried had the least amount of vitamin C retained (Roshanak et al., 2016). Depending on the drying method, different dried pepper cultivars retained ascorbic acid differently; the retention ranged from 0.149 to 0.373 g/kg. Freeze dried peppers retained the greatest amount of ascorbic acid (0.373 g/kg) and hot air drying retained the least amount of ascorbic acid (Maurya et al., 2018).

Jujube fruits are high in vitamin C, but when dried under different conditions, the amount of vitamin C present in it decreased; freeze drying had the least loss of vitamin C, with a 22% loss, while hot air drying caused jujube fruits to lose around 87% of the vitamin C present in fresh jujube (Wang et al., 2021).

Bintagor oranges dried under different drying methods had a reduction in ascorbic acid, with freeze dried oranges retaining around 78.5% of ascorbic acid (28.31mg/g), which was greater than vacuum oven dried oranges, which retained around 18.10mg/g. The low processing temperature was responsible for the increased retention in the freeze dryer (Phing et al., 2022).

Mangoes dried under various drying conditions had lower ascorbic acid levels (ranging from 92.59 to 225.38mg/100g). Heat damage had a significant negative impact, with decreased ascorbic acid levels detected in convective hot air dryers and vacuum oven dryers. When compared to other drying processes, freeze dried mangoes had a greater ascorbic acid content (Sogi et al., 2015).

The loss of vitamin C in most drying methods is caused by oxidation of ascorbic acid under high temperatures and depletion of the compound due to its utilization for protecting oxidation of polyphenols during drying (Kamiloglu et al., 2016).

Freeze drying uses low temperature, which is why it typically has a high retention of ascorbic acid. There is an inactivation of ascorbic acid oxidase which leads to protection of ascorbic acid against enzymatic oxidation. Hence freeze drying is generally considered as one of the most effective methods used in preserving fruits and vegetables but it is mostly used as a reference method due to its high operational cost. Thermal drying methods like hot air drying has an adverse effect on ascorbic acid due to its high temperatures which causes leaching and oxidation of products (Ali et al., 2016; Kamiloglu et al., 2016; Maurya et al., 2018).

The recommended daily allowance of vitamin C is between 15 to 120 mg/g (15,000 to 120,000 µg/g) (National Institutes of Health, 2021), In this research, mangoes had a range of 185.34 to 327.41 µg/g and OFSP had a range of 58.25 to 118.72 µg/g. Mangoes with a 50g/db. serving supplies 9,267 to 16,370.5 µg/50g while OFSP supplies 2,912.5 to 5,936 µg/50g, from the daily allowance mangoes meet the requirement slightly, this means there is need to consume at least more than 50g of the products to meet the daily requirement.

CHAPTER 6: CONCLUSION

Drying methods have significant impacts on the quality and nutritional value of fruits and vegetables. Each type of drying method like freeze drying, vacuum oven drying, and hot air drying has a different outcome of the product. The food matrix influences how the components of food react with the drying method to produce a quality outcome. Based on this research, freeze and hot air drying had a high retention of vitamin A compared to vacuum oven drying. All drying methods tested did not significantly impact on vitamin C content of mango and OFSP in this study; freeze, hot air and vacuum oven drying under the specific conditions used in this study resulted in similar retention of the vitamin.

Each drying technique has its advantages and disadvantages. When processing a product, it is important to consider all those factors before deciding which method to use. According to the findings of this study, freeze drying produces high quality products since it resulted in minimal changes to the products. However, vacuum-oven and hot air drying under the conditions of this study also retained some of the properties of the products. This demonstrates that any drying method can produce quality products depending on the type of product being dried, the specific conditions used, and the properties being preserved.

Freeze drying is known for producing high-quality products; it retains product quality better than other conventional drying processes due to low pressure, low oxygen, and low temperature conditions used during the process. Food has minimal contact with oxygen and enzymatic processes, which reduces oxidation.

Dried mango and OFSP can be used to prepare healthy and nutritious food products, they can be processed into snacks, the products can be milled into powder and be added to different food products to produce a functional food or beverage. Therefore, these preserved products can be used to enrich different food products. To achieve the benefits of these products, there is need to use processing methods that have minimal effects on the nutrients present in the products and methods that will be able to minimize damage by reducing exposure of fruits to light, oxidation and heat.

CHAPTER 7: FUTURE RESEARCH

To determine the ideal drying conditions to preserve bioactive compounds in the products, future research should compare the effects of drying methods on OFSP and mangoes using various drying temperatures and duration of the drying processes. Drying time and temperature are two key factors that influence the quality and nutritional profile of the dried products.

All carotenoids present in the products must be properly studied; this study focused primarily on beta carotene because beta carotene is present in high concentrations in these products and is a critically important pro-vitamin A source. However, this study also demonstrated that mango and OFSP contain some other important carotenoids that can be studied and must be preserved during processing.

For future research, it would be appropriate to compare the effects of drying methods and pretreatments on ascorbic acid and carotenoids to determine which is a better way to preserve the physical and chemical properties of the products. In this study, no pretreatments (e.g., cooking) were used to prevent some of the results from being confounded by substrate preparation procedures.

BIBLIOGRAPHY

Abdullah, M., Jamil, R., & Attia, F. (2022, October 25). *Vitamin C (Ascorbic acid)*. StatPearls.

Adeyeye, S. A. O. (2017). The role of food processing and appropriate storage technologies in ensuring food security and food availability in Africa. In *Nutrition and Food Science* (Vol. 47, Issue 1, pp. 122–139). Emerald Group Publishing Ltd. https://doi.org/10.1108/NFS-03-2016-0037.

Akar, G., & Barutçu Mazı, I. (2019). Color change, ascorbic acid degradation kinetics, and rehydration behavior of kiwifruit as affected by different drying methods. *Journal of Food Process Engineering*, *42*(3). https://doi.org/10.1111/jfpe.13011.

Ali, S., Zahid, N., Nawaz, A., Naz, S., Ejaz, S., Ullah, S., & Siddiq, B. (2022). Tragacanth gum coating suppresses the disassembly of cell wall polysaccharides and delays softening of harvested mango (Mangifera indica L.) fruit. *International Journal of Biological Macromolecules*, *222*, 521–532. https://doi.org/10.1016/j.ijbiomac.2022.09.159.

Ali Sheraz, M., Fatima Khan, M., & Ahmed, S. (2015). *Stability and Stabilization of Ascorbic Acid*. https://www.researchgate.net/publication/321148774.

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

Alissa, E. M., & Ferns, G. A. (2017). Dietary fruits and vegetables and cardiovascular diseases risk. *Critical Reviews in Food Science and Nutrition*, *57*(9), 1950–1962. https://doi.org/10.1080/10408398.2015.1040487.

Alp, D., & Bulantekin, Ö. (2021). The microbiological quality of various foods dried by applying different drying methods: a review. In *European Food Research and Technology* (Vol. 247, Issue 6, pp. 1333–1343). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s00217-021-03731-z.

Amagloh, F. C., Yada, B., Tumuhimbise, G. A., Amagloh, F. K., & Kaaya, A. N. (2021). The potential of sweetpotato as a functional food in Sub-Saharan Africa and its implications for health: A review. In *Molecules* (Vol. 26, Issue 10). MDPI AG. https://doi.org/10.3390/molecules26102971.

Ambler, K., & De Brauw, A. (2017). *Measuring Postharvest Losses at the Farm Level in Malawi*.

Babu, Haggblade, S., Mkandawire, E., Nankhuni, F., & Hendriks, S. (2016). *Micronutrient Policy Process in Malawi*.

Bae, M., & Kim, H. (2020). The Role of Vitamin C, Vitamin D, and Selenium in Immune System against COVID-19. In *Molecules* (Vol. 25, Issue 22). MDPI. https://doi.org/10.3390/MOLECULES25225346.

Barbosa, J., Borges, S., Amorim, M., Pereira, M. J., Oliveira, A., Pintado, M. E., & Teixeira, P. (2015). Comparison of spray drying, freeze drying and convective hot air drying for the production of a probiotic orange powder. *Journal of Functional Foods*, *17*, 340–351. https://doi.org/10.1016/j.jff.2015.06.001.

Bechoff, A., de Bruyn, J., Alpha, A., Wieringa, F., & Greffeuille, V. (2023). Exploring the Complementarity of Fortification and Dietary Diversification to Combat Micronutrient Deficiencies: A Scoping Review. *Current Developments in Nutrition*, *7*(2), 100033. https://doi.org/10.1016/j.cdnut.2023.100033.

Bhatta, S., Janezic, T. S., & Ratti, C. (2020). Freeze-drying of plant-based foods. In *Foods* (Vol. 9, Issue 1). MDPI Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/foods9010087.

Bourdoux, S., Li, D., Rajkovic, A., Devlieghere, F., & Uyttendaele, M. (2016). Performance of Drying Technologies to Ensure Microbial Safety of Dried Fruits and Vegetables. *Comprehensive Reviews in Food Science and Food Safety*, *15*, 1056–1063. https://doi.org/10.1111/1541-4337.12224.

Bouzari, A., Holstege, D., & Barrett, D. M. (2015). Vitamin retention in eight fruits and vegetables: A comparison of refrigerated and frozen storage. *Journal of Agricultural and Food Chemistry*, *63*(3), 957–962. https://doi.org/10.1021/jf5058793.

Braga, T. R., Silva, E. O., Rodrigues, S., & Fernandes, F. A. N. (2019). Drying of mangoes (Mangifera indica L.) applying pulsed UV light as pretreatment. *Food and Bioproducts Processing*, *114*, 95–102. https://doi.org/10.1016/j.fbp.2018.11.013.

Burton, G. W., Mogg, T. J., Riley, W. W., & Nickerson, J. G. (2021). β-Carotene oxidation products - Function and safety. *Food and Chemical Toxicology, 152*. https://doi.org/10.1016/j.fct.2021.112207.

Burton-Freeman, B. M., Sandhu, A. K., & Edirisinghe, I. (2017). Mangos and their bioactive components: Adding variety to the fruit plate for health. In *Food and Function* (Vol. 8, Issue 9, pp. 3010–3032). Royal Society of Chemistry. https://doi.org/10.1039/c7fo00190h.

Çakmakçı, S., & Çakmakçı, R. (2023). Quality and Nutritional Parameters of Food in Agri-Food Production Systems. In *Foods* (Vol. 12, Issue 2). MDPI. https://doi.org/10.3390/foods12020351.

Calín-Sánchez, Á., Lipan, L., Cano-Lamadrid, M., Kharaghani, A., Masztalerz, K., Carbonell-Barrachina, Á. A., & Figiel, A. (2020). Comparison of Traditional and

Novel Drying Techniques and Its Effect on Quality of Fruits, Vegetables and Aromatic Herbs. *Food*, 2–27. https://doi.org/10.3390/foods9091261.

Carr, A. C., & Maggini, S. (2017). Vitamin C and Immune Function. *Nutrients*. https://doi.org/10.3390/nu9111211.

Carr, A. C., & Rowe, S. (2020). Factors affecting vitamin C status and prevalence of deficiency: A global health perspective. In *Nutrients* (Vol. 12, Issue 7, pp. 1–19). MDPI AG. https://doi.org/10.3390/nu12071963.

Chen, C.-C., Hsieh, J.-F., & Jen, F. (2016). Sensorial Characterization of Foods Before and After Freeze-drying Rhodiola crenulata View project. In *Austin Food Sci* (Vol. 1, Issue 6). www.austinpublishinggroup.com.

Chipungu, F. P. (2015). *Orange Fleshed Sweet Potato Varieties for Malawi*.

Chuyen, H. V., Roach, P. D., Golding, J. B., Parks, S. E., & Nguyen, M. H. (2017). Effects of four different drying methods on the carotenoid composition and antioxidant capacity of dried Gac peel. *Journal of the Science of Food and Agriculture*, *97*(5), 1656–1662. https://doi.org/10.1002/JSFA.7918.

Coklar, H., Akbulut, M., Kilinc, S., Yildirim, A., & Alhassan, I. (2018, February 12). *Effect of Freeze, Oven and Microwave Pretreated Oven Drying on Color, Browning Index, Phenolic Compounds and Antioxidant Activity of Hawthorn (Crataegus orientalis) Fruit*. AcademiPres. https://notulaebotanicae.ro/index.php/nbha/article/view/11027/8118.

de Ancos, B., Sánchez-Moreno, C., Zacarías, L., Rodrigo, M. J., Sáyago Ayerdí, S., Blancas Benítez, F. J., Domínguez Avila, J. A., & González-Aguilar, G. A. (2018). Effects of two different drying methods (freeze-drying and hot air-drying) on the phenolic and carotenoid profile of 'Ataulfo' mango by-products. *Journal of Food Measurement and Characterization*, *12*(3), 2145–2157. https://doi.org/10.1007/s11694-018-9830-4.

de Moura, F. F., Miloff, A., & Boy, E. (2015). Retention of Provitamin A Carotenoids in Staple Crops Targeted for Biofortification in Africa: Cassava, Maize, and Sweet Potato. *Critical Reviews in Food Science and Nutrition*, *55*(9), 1246–1269. https://doi.org/10.1080/10408398.2012.724477.

Deeksha, K., & Sunita, M. (2018). *Utilization of mango and its by-products by different processing methods*. http://www.journalajst.com.

Dehghannya, J., Hosseinlar, S. H., & Heshmati, M. K. (2018). Multi-stage continuous and intermittent microwave drying of quince fruit coupled with osmotic dehydration and low temperature hot air drying. *Innovative Food Science and Emerging Technologies*, *45*, 132–151. https://doi.org/10.1016/j.ifset.2017.10.007.

Dekker vacuum technologies. (2020). *Vacuum solutions for dehydration and freeze drying*. https://www.dekkervacuum.com/freeze-drying/.

Deng, L. Z., Mujumdar, A. S., Zhang, Q., Yang, X. H., Wang, J., Zheng, Z. A., Gao, Z. J., & Xiao, H. W. (2017). Chemical and physical pretreatments of fruits and vegetables: Effects on drying characteristics and quality attributes – a comprehensive review. *Https://Doi.Org/10.1080/10408398.2017.1409192*, *59*(9), 1408–1432. https://doi.org/10.1080/10408398.2017.1409192.

Dhaliwal, H. K., Gänzle, M., & Roopesh, M. S. (2021). Influence of drying conditions, food composition, and water activity on the thermal resistance of Salmonella enterica. *Food Research International*, *147*. https://doi.org/10.1016/J.FOODRES.2021.110548.

Duerbeck, N. B., Dowling, D. D., & Duerbeck, J. M. (2016). *Vitamin C: Promises Not Kept*. www.specialtyobstetrics.com.

Dyer, M. (2021, February 15). *Sweet Potato Types - Growing Different Varieties of Sweet Potatoes*. Gardening Know How. https://www.gardeningknowhow.com/edible/vegetables/sweet-potato/sweet-potato-varieties.htm.

Evans, E. A., Ballen, F. H., & Siddiq, M. (2017). Mango Production, Global Trade, consumption Trends, and Postharvest Processing. In M. Siddiq, J. K. Brecht, & J. S. Sidhu (Eds.), *Handbook of Mango* (pp. 1–14). John Wiley & Sons Ltd.

Fan, K., Zhang, M., & Mujumdar, A. S. (2018). Recent developments in high efficient freeze-drying of fruits and vegetables assisted by microwave: A review. *Https://Doi.Org/10.1080/10408398.2017.1420624*, *59*(8), 1357–1366. https://doi.org/10.1080/10408398.2017.1420624,

Feng, Y., Xu, B., ElGasim A. Yagoub, A., Ma, H., Sun, Y., Xu, X., Yu, X., & Zhou, C. (2021). Role of drying techniques on physical, rehydration, flavor, bioactive compounds, and antioxidant characteristics of garlic. *Food Chemistry*, *343*. https://doi.org/10.1016/J.FOODCHEM.2020.128404.

Food and Agriculture Organization of the United Nations. (2011). *Global food losses and food waste: extent, causes and prevention: study conducted for the International Congress "Save Food!" at Interpack 2011 Düsseldorf, Germany*. Food and Agriculture organization of the United Nations.

Food and Agriculture Organization of the United Nations. (2019). *The state of food and agriculture. 2019, Moving forward on food loss and waste reduction*. Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization of the United Nations. (2023a). *The scourge of food loss and waste needs to be urgently tackled to achieve the world's 2030 target*.

Food and Agriculture Organization of the United Nations. (2023b, March 24). *Crops and livestock products*. FAOSTAT.

Food drying oven. (2020, May 11). *Fruits and Vegetables Hot Air Drying Processes Research*. https://fooddryingoven.com/drying-ideas/fruits-vegetables-hot-air-drying-process.html.

Gaidhani, K. A., Harwalkar, M., Bhambere, D., & Nirgude, P. S. (2015). Lyophilization/Freeze Drying- A review. *Kunal et al. World Journal of Pharmaceutical Research World Journal of Pharmaceutical Research SJIF Impact Factor 5*, *4*(8), 517. www.wjpr.net.

Gonçalves, A., Estevinho, B. N., & Rocha, F. (2016). Microencapsulation of vitamin A: A review. In *Trends in Food Science and Technology* (Vol. 51, pp. 76–87). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2016.03.001.

Gonuldas, F., Yilmaz, K., & Ozturk, C. (2014). The effect of repeated firings on the color change and surface roughness of dental ceramics. *Journal of Advanced Prosthodontics*, *6*(4), 309–316. https://doi.org/10.4047/JAP.2014.6.4.309.

Government of Malawi. (2017). *The Malawi Growth and Development Strategy (MGDS) III (2017-2022). III*.

Guiné, R. P. F. (2018). The Drying of Foods and Its Effect on the Physical-Chemical, Sensorial and Nutritional Properties. *ETP International Journal of Food Engineering*, 93–100. https://doi.org/10.18178/IJFE.4.2.93-100.

Gümüşay, Ö. A., Borazan, A. A., Ercal, N., & Demirkol, O. (2015). Drying effects on the antioxidant properties of tomatoes and ginger. *Food Chemistry*, *173*, 156–162. https://doi.org/10.1016/j.foodchem.2014.09.162.

Hasan, M. U., Malik, A. U., Ali, S., Imtiaz, A., Munir, A., Amjad, W., & Anwar, R. (2019a). Modern drying techniques in fruits and vegetables to overcome postharvest losses: A review. *Journal of Food Processing and Preservation*, *43*(12), e14280. https://doi.org/10.1111/JFPP.14280.

Hasan, M. U., Malik, A. U., Ali, S., Imtiaz, A., Munir, A., Amjad, W., & Anwar, R. (2019b). Modern drying techniques in fruits and vegetables to overcome postharvest losses: A review. In *Journal of Food Processing and Preservation* (Vol. 43, Issue 12). Blackwell Publishing Ltd. https://doi.org/10.1111/jfpp.14280.

Huang, J., & Zhang, M. (2016). Effect of three drying methods on the drying characteristics and quality of okra. *Drying Technology*, *34*(8), 900–911. https://doi.org/10.1080/07373937.2015.1086367.

Hummel, M., Talsma, E. F., Van Der Honing, A., Gama, A. C., Van Vugt, D., Brouwer, I. D., & Spillane, C. (2018). Sensory and cultural acceptability tradeoffs with nutritional content of biofortified orange-fleshed sweet potato among households with children in Malawi. *PLoS ONE*, *13*(10). https://doi.org/10.1371/journal.pone.0204754.

Indico. (2020, December 16). *Orange-Fleshed Sweet Potato – A Factory of Vitamin A | Revista Índico*. https://www.indico-lam.com/en/2020/12/16/orange-fleshed-sweet-potato-a-factory-of-vitamin-a/.

Ismail. (2017). Ash Content Determination. In S. Nielsen (Ed.), *Food Analysis Laboratory Manual* (3rd ed., Vol. 3, Issue 1, pp. 117–119). Springer, Cham. https://doi.org/10.1007/978-3-319-44127-6_11.

Ismail, O. _, Ozlem, €, & Okçe Kocabay, G. (2021). Vacuum oven drying of mussels: mathematical modeling, drying characteristics, and kinetics study. *British Food Journal*, *124*(4), 1238–1239. https://doi.org/10.1108/BFJ-05-2021-0486.

Izli, N., Izli, G., & Taskin, O. (2017). Influence of different drying techniques on drying parameters of mango. *Food Science and Technology*, *37*(4), 604–612. https://doi.org/10.1590/1678-457X.28316.

Jia, Khalifa, I., Hu, L., Zhu, W., Li, J., Li, K., & Li, C. (2019). Influence of three different drying techniques on persimmon chips' characteristics: A comparison study among hot-air, combined hot-air-microwave, and vacuum-freeze drying techniques. *Food and Bioproducts Processing*, *118*, 67–76. https://doi.org/10.1016/J.FBP.2019.08.018.

Jia, X., Wang, Z., Zhang, B., Su, C., Du, W., Zhang, J., Zhang, J., Jiang, H., Huang, F., Ouyang, Y., Wang, Y., Li, L., & Wang, H. (2018). Food sources and potential determinants of dietary vitamin C intake in Chinese adults: A cross-sectional study. *Nutrients*, *10*(3). https://doi.org/10.3390/nu10030320.

Kamiloglu, S., Toydemir, G., Boyacioglu, D., Beekwilder, J., Hall, R. D., & Capanoglu, E. (2016). A Review on the Effect of Drying on Antioxidant Potential of Fruits and Vegetables. *Critical Reviews in Food Science and Nutrition*, *56*, S110–S129. https://doi.org/10.1080/10408398.2015.1045969.

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. https://doi.org/10.1016/J.JFOODENG.2016.05.001.

Kathabwalika, D. M., Chilembwe, E. H. C., & Mwale, V. M. (2016). Evaluation of dry matter, starch, and beta-carotene content in orange-fleshed sweet potato (Ipomoea batatas L.) genotypes tested in three agro-ecological zones of Malawi. *African Journal of Food Science*, *10*(11), 320–326. https://doi.org/10.5897/AJFS2016.1471.

Kenya Bureau Of Standards. (2018). Dehydrated vegetables- Specification. *Kenya Standard*. http://www.kebs.org.

Kourouma, V., Mu, T. H., Zhang, M., & Sun, H. N. (2019). Effects of cooking process on carotenoids and antioxidant activity of orange-fleshed sweet potato. *LWT*, *104*, 134–141. https://doi.org/10.1016/j.lwt.2019.01.011.

Kurina, A. B., Solovieva, A. E., Khrapalova, I. A., & Artemyeva, A. M. (2021). Biochemical composition of tomato fruits of various colors. *Vavilovskii Zhurnal Genetiki i Selektsii*, *25*(5), 514–527. https://doi.org/10.18699/VJ21.058.

Lebaka, V. R., Wee, Y. J., Ye, W., & Korivi, M. (2021). Nutritional composition and bioactive compounds in three different parts of mango fruit. In *International Journal of Environmental Research and Public Health* (Vol. 18, Issue 2, pp. 1–20). MDPI AG. https://doi.org/10.3390/ijerph18020741.

Lockyer, S., White, A., & Buttriss, J. L. (2018). Biofortified crops for tackling micronutrient deficiencies – what impact are these having in developing countries and could they be of relevance within Europe? In *Nutrition Bulletin* (Vol. 43, Issue 4, pp. 319–357). Blackwell Publishing Ltd. https://doi.org/10.1111/nbu.12347.

Low, J. W., Ortiz, R., Vandamme, E., Andrade, M., Biazin, B., & Grüneberg, W. J. (2020). Nutrient-Dense Orange-Fleshed Sweetpotato: Advances in Drought-Tolerance Breeding and Understanding of Management Practices for Sustainable Next-Generation Cropping Systems in Sub-Saharan Africa. In *Frontiers in Sustainable Food Systems* (Vol. 4). Frontiers Media S.A. https://doi.org/10.3389/fsufs.2020.00050.

Lowe, N. M. (2021). The global challenge of hidden hunger: Perspectives from the field. *Proceedings of the Nutrition Society*, *80*(3), 283–289. https://doi.org/10.1017/S0029665121000902.

Manusevich Wiseman, E., Bar-El Dadon, S., & Reifen, R. (2017). *The vicious cycle of vitamin a deficiency: A review*. https://doi.org/10.1080/10408398.2016.1160362.

Maurya, V. K., Gothandam, K. M., Ranjan, V., Shakya, A., & Pareek, S. (2018). Effect of drying methods (microwave vacuum, freeze, hot air and sun drying) on physical, chemical and nutritional attributes of five pepper (Capsicum annuum var. annuum) cultivars. *Journal of the Science of Food and Agriculture*, *98*(9), 3492–3500. https://doi.org/10.1002/jsfa.8868.

Maxfield, L., & Crane, J. S. (2022). Vitamin C Deficiency. *The Bioarchaeology of Metabolic Bone Disease*, 41–74. https://doi.org/10.1016/b978-0-12-370486-3.00004-4.

Mieszczakowska-Fr, M., Celejewska, K., & Płocharski, W. (2021). *Impact of Innovative Technologies on the Content of Vitamin C and Its Bioavailability from Processed Fruit and Vegetable Products*. https://doi.org/10.3390/antiox10010054.

Mildon, A., Klaas, N., Leary, M., & Yiannakis, M. (2015). Can fortification be implemented in rural African communities where micronutrient deficiencies are greatest? Lessons from projects in Malawi, Tanzania, and Senegal. *Food and Nutrition Bulletin*, *36*(1).

Moyo, M., Truong, V.-D., Simunovic, J., Pankuku, J., Abong, G. O., Amagloh, F. K., Fuchs, R., Magnaghi, A., Rajendran, S., Grant, F., & Muzhingi, T. (2022). Orange-Fleshed Sweetpotato Puree: A Breakthrough Product for the Bakery Sector in Africa. In *Root, Tuber and Banana Food System Innovations* (pp. 145–172). Springer International Publishing. https://doi.org/10.1007/978-3-030-92022-7_5.

Mphahlele, R. R., Fawole, O. A., Makunga, N. P., & Opara, U. L. (2016). Effect of drying on the bioactive compounds, antioxidant, antibacterial and antityrosinase activities of pomegranate peel. *BMC Complementary and Alternative Medicine*, *16*(1). https://doi.org/10.1186/s12906-016-1132-y.

Nabeshima, E. H., Moro, T. M. A., Campelo, P. H., Sant'Ana, A. S., & Clerici, M. T. P. S. (2020). Tubers and roots as a source of prebiotic fibers. In *Advances in Food and Nutrition Research* (Vol. 94, pp. 267–293). Academic Press Inc. https://doi.org/10.1016/BS.AFNR.2020.06.005.

National Institutes of Health. (2021, March 26). *Vitamin C*. United States Department of Health and Human Services. https://ods.od.nih.gov/factsheets/VitaminC-HealthProfessional/.

National Institutes of Health. (2022, August 12). *Vitamin A and Carotenoids*. United States Department of Health and Human Services.

National Mango Board. (2017). *Mango handling and ripening protocol*. https://www.mango.org/wp-content/uploads/2017/10/Mango_Handling_and_Ripening_Protocol_Eng.pdf.

National Mango Board. (2022). *Mango nutrition*. Mango.Org.

National Statistics Office, Community Health Sciences Unit, Centers for Disease Control and Prevention, & Emory University. (2017). *Malawi Micronutrient Survey 2015-16; Key Indicators Report*.

Neela, S., & Fanta, S. W. (2019). Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. In *Food Science and Nutrition* (Vol. 7, Issue 6, pp. 1920–1945). Wiley-Blackwell. https://doi.org/10.1002/fsn3.1063.

Ngamwonglumlert, L., & Devahastin, S. (2017). Microstructure and its relationship with quality and storage stability of dried foods. *Food Microstructure and Its Relationship* *with Quality and Stability*, 139–159. https://doi.org/10.1016/B978-0-08-100764-8.00008-3.

Nicanuru, C. (2016). *Effect of Pretreatments and Drying on Nutrient content of Orange Fleshed Sweet Potato tubers and Cowpea leaves used in Maswa district, Tanzania*.

Nyirenda, B. Z., Nankhuni, F. J., & Brett, M. A. (2019). An Analysis of the Mango Value Chain in Malawi. *Policy Research Brief 80*, 1–6.

Ohanenye, I. C., Emenike, C. U., Mensi, A., Medina-Godoy, S., Jin, J., Ahmed, T., Sun, X., & Udenigwe, C. C. (2021). Food fortification technologies: Influence on iron, zinc and vitamin A bioavailability and potential implications on micronutrient deficiency in sub-Saharan Africa. In *Scientific African* (Vol. 11). Elsevier B.V. https://doi.org/10.1016/j.sciaf.2020.e00667.

Okoye, J. S. I., & Oni, K. (2017). Promotion of Indigenous Food Preservation and Processing Knowledge and the Challenge of Food Security in Africa. *Journal of Food Security*, *5*(3), 75–87. https://doi.org/10.12691/jfs-5-3-3.

Onwude, D. I., Hashim, N., & Chen, G. (2016). *Recent advances of novel thermal combined hot air drying of agricultural crops*. https://doi.org/10.1016/j.tifs.2016.09.012.

Onwude, D. I., Hashim, N., Janius, R., Abdan, K., Chen, G., & Oladejo, A. O. (2017). Non-thermal hybrid drying of fruits and vegetables: A review of current technologies. *Innovative Food Science & Emerging Technologies*, *43*, 223–238. https://doi.org/10.1016/J.IFSET.2017.08.010.

Owino, W. O., & Ambuko, J. L. (2021). Mango Fruit Processing: Options for Small-Scale Processors in Developing Countries. *Agriculture 2021, Vol. 11, Page 1105*, *11*(11), 1105. https://doi.org/10.3390/AGRICULTURE11111105.

Parikh, D. (2015). *Vacuum Drying: Basics and Application*. www.Chemengonline.Com.

Perera, C. O., & Perera, A. D. (2019). Technology of processing of horticultural crops. In *Handbook of Farm, Dairy and Food Machinery Engineering* (pp. 299–351). Elsevier. https://doi.org/10.1016/B978-0-12-814803-7.00013-0.

Phing, P. L., Abdullah, A., Sin, C. L., & Foong, S. C. Y. (2022). The effect of drying methods on the physicochemical and antioxidant properties of Bintangor Orange (Citrus nobilis) powders. *Acta Scientiarum Polonorum, Technologia Alimentaria*, *21*(1), 111–122. https://doi.org/10.17306/J.AFS.2022.0901.

Porat, R., Lichter, A., Terry, L. A., Harker, R., & Buzby, J. (2017). *Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention*. https://doi.org/10.1016/j.postharvbio.2017.11.019.

Precisa. (2023). *Ash Content Analysis in Food*. Presica: The Balance of Quality.

Radoiu, M. (2020). Microwave drying process scale-up. *Chemical Engineering and Processing - Process Intensification*, *155*. https://doi.org/10.1016/J.CEP.2020.108088.

Radojčin, M., Pavkov, I., Kovačević, D. B., Putnik, P., Wiktor, A., Stamenković, Z., Kešelj, K., & Gere, A. (2021). Effect of Selected Drying Methods and Emerging Drying Intensification Technologies on the Quality of Dried Fruit: A Review. *Processes 2021, Vol. 9, Page 132*, *9*(1), 132. https://doi.org/10.3390/PR9010132.

Rahman, M. S., & Perera, C. (2020a). Drying Methods Used in Food Preservation. In *Handbook of Food Preservation* (Vol. 3, p. 443).

Rahman, M. S., & Perera, C. O. (2020b). Quality changes during drying of foods. In M. S. Rahman (Ed.), *Handbook of Food Preservation* (3rd ed., pp. 443–453). CRC press.

Ritchie, H., & Roser, M. (2017, August). *Micronutrient Deficiency*. Our World in Data. https://ourworldindata.org/micronutrient-deficiency;#citation.

Rodrigues, *, Da, N., Junior, B., & And Barbosa, J. L. (2016). Determination of physico-chemical composition, nutritional facts and technological quality of organic orange and purple-fleshed sweet potatoes and its flours. In *International Food Research Journal* (Vol. 23, Issue 5).

Roratto, T. B., Monteiro, R. L., Carciofi, B. A. M., & Laurindo, J. B. (2021). An innovative hybrid-solar-vacuum dryer to produce high-quality dried fruits and vegetables. *LWT*, *140*. https://doi.org/10.1016/j.lwt.2020.110777.

Roshanak, S., Rahimmalek, M., & Goli, S. A. H. (2016). Evaluation of seven different drying treatments in respect to total flavonoid, phenolic, vitamin C content, chlorophyll, antioxidant activity and color of green tea (Camellia sinensis or C. assamica) leaves. *Journal of Food Science and Technology*, *53*(1), 721–729. https://doi.org/10.1007/s13197-015-2030-x.

Rowe, S., & Carr, A. C. (2020). Global vitamin c status and prevalence of deficiency: A cause for concern? In *Nutrients* (Vol. 12, Issue 7, pp. 1–20). MDPI AG. https://doi.org/10.3390/nu12072008.

Samoticha, J., Wojdyło, A., & Lech, K. (2016). The influence of different drying methods on chemical composition and antioxidant activity in chokeberries. *LWT*, *66*, 484–489. https://doi.org/10.1016/J.LWT.2015.10.073.

Sandman. (2021, September 19). *Water Activity (aw) And Food Safety - The Food Untold*. https://thefooduntold.com/blog/food-science/water-activity-aw-and-food-safety/.

Santos, S. F. dos, Cardoso, R. de C. V., Borges, Í. M. P., Almeida, A. C. e., Andrade, E. S., Ferreira, I. O., & Ramos, L. do C. (2020). Post-harvest losses of fruits and vegetables in supply centers in Salvador, Brazil: Analysis of determinants, volumes and reduction strategies. *Waste Management*, *101*, 161–170. https://doi.org/10.1016/j.wasman.2019.10.007.

Sehrawat, R., Nema, P. K., & Kaur, B. P. (2018). Quality evaluation and drying characteristics of mango cubes dried using low-pressure superheated steam, vacuum and hot air drying methods. *LWT*, *92*, 548–555. https://doi.org/10.1016/j.lwt.2018.03.012.

Sharma, H. K. (2016). *Introduction to Tropical Roots and Tubers*. www.fao.org.

Shende, D., & Datta, A. K. (2019). Refractance window drying of fruits and vegetables: a review. *Journal of the Science of Food and Agriculture*, *99*(4), 1449–1456. https://doi.org/10.1002/JSFA.9356.

Shivanand, A., & Mukhopadhayay, S. (2017, July 12). *A review on lyophilization: A technique to improve stability of hygroscopic, thermolabile substances*. Pharmatutor. https://www.pharmatutor.org/articles/a-review-on-lyophilization-a-technique-to-improve-stability-of-hygroscopic-thermolabile-substances.

Siddiq, M., Sogi, D. S., & Roidoung, S. (2017). Mango Processing and processed Products. In M. Siddiq, J. K. Brecht, & J. S. Sidhu (Eds.), *Handbook of mango fruit: production, postharvest science, processing technology and nutrition* (pp. 196–213). John Wiley & Sons Ltd.

Silva-Espinoza, M. A., Ayed, C., Foster, T., Del Mar Camacho, M., & Martínez-Navarrete, N. (2020). The impact of freeze-drying conditions on the physico-chemical properties and bioactive compounds of a freeze-dried orange puree. *Foods*, *9*(1). https://doi.org/10.3390/foods9010032.

Sogi, D. S., Siddiq, M., & Dolan, K. D. (2015). Total phenolics, carotenoids and antioxidant properties of Tommy Atkin mango cubes as affected by drying techniques. *LWT - Food Science and Technology*, *62*(1), 564–568. https://doi.org/10.1016/J.LWT.2014.04.015.

Stamenkovi´c, Z. S., Pavkov, I., Radojčin, M., Tepi´c, A., Horecki, T., Kešelj, K., Bursa´c, D., Kovačevi´c, B. K., & Putnik, P. (2019). *Convective Drying of Fresh and Frozen Raspberries and Change of Their Physical and Nutritive Properties*. https://doi.org/10.3390/foods8070251.

Tec2Med. (2021). *Vacuum Oven- Principle, Design, Working, Operation, and Supplier*. https://www.tec2med.com/vacuum-oven-dryer-principle-working-supplier/.

Tincheva, P. A. (2019). The effect of heating on the vitamin C content of selected vegetables. *World Journal of Advanced Research and Reviews*, *03*, 2581–9615. https://doi.org/10.30574/wjarr.

Tiyayon, C., & Paull, R. (2017). Mango Production. In M. Siddiq, J. K. Brecht, & S. S. Jiwan (Eds.), *Handbook of mango fruit: production, postharvest science, processing technology and nutrition* (pp. 17–21). John Wiley and Sons Ltd.

Truong, V. D., Avula, R. Y., Pecota, K. V., & Yencho, G. C. (2018). Sweetpotato Production, Processing, and Nutritional Quality. In M. Siddiq & M. Uebersax (Eds.), *Handbook of Vegetables and Vegetable processing* (second, Vol. 1). John Wiley & Sons Ltd.

United Nations. (2022). *The Sustainable Development Goals Report 2022*.

United States Department of Agriculture. (2019, April 1). *Mangos, raw*. FoodData Central. https://fdc.nal.usda.gov/fdc-app.html#/food-details/169910/nutrients.

United States Department of Agriculture. (2022, October 28). *Sweet potatoes, orange flesh, without skin, raw*. FoodData Central. https://fdc.nal.usda.gov/fdc-app.html#/food-details/2346404/nutrients.

United States Department of Agriculture. (2023, June 20). *Food Security in the U.S.* Economic Research Service; United States Department of Agriculture. https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-u-s/.

Valentina, Pratiwi, R., Hsiao, P., Tseng, H., Hsieh, J., & Chen, C. (2016). *Sensorial Characterization of Foods Before and After Freeze-drying*.

Verma, D. K., Thakur, M., Srivastav, P. P., Karizaki, V. M., & Suleria, H. A. R. (2020). Effects of Drying Technology on Physiochemical and Nutritional Quality of Fruits and Vegetables. In *Emerging Thermal and Nonthermal Technologies in Food Processing* (pp. 69–116). Apple Academic Press. https://doi.org/10.1201/9780429297335-3.

Vu, H. T., Scarlett, C. J., & Vuong, Q. V. (2017). Effects of drying conditions on physicochemical and antioxidant properties of banana (Musa cavendish) peels. *DRYING TECHNOLOGY*, *35*(9), 1141–1151. https://doi.org/10.1080/07373937.2016.1233884.

Wang, Gao, Y., Zhao, Y., Li, X., Fan, J., & Wang, L. (2021). Effect of different drying methods on the quality and microstructure of fresh jujube crisp slices. *Journal of Food Processing and Preservation*, *45*(2). https://doi.org/10.1111/jfpp.15162.

Wang, S., Nie, S., & Zhu, F. (2016). Chemical constituents and health effects of sweet potato. *Food Research International*, *89*, 90–116. https://doi.org/10.1016/J.FOODRES.2016.08.032.

Williams, A. M., Tanumihardjo, S. A., Rhodes, E. C., Mapango, C., Kazembe, B., Phiri, F., Kang'ombe, D. D., Sheftel, J., Orchardson, V., Tripp, K., & Suchdev, P. S. (2021). Vitamin A deficiency has declined in Malawi, but with evidence of elevated vitamin A in children. *American Journal of Clinical Nutrition*, *113*(4), 854–864. https://doi.org/10.1093/ajcn/nqab004.

Wojdyło, A., Lech, K., Nowicka, P., Marszałek, K., Li, S., Kapusta, I., & Lorenzo, J. M. (2020). Effects of Different Drying Methods on the Retention of Bioactive Compounds, On-Line Antioxidant Capacity and Color of the Novel Snack from Red-Fleshed Apples. *Molecules*, 2–17. https://doi.org/10.3390/molecules25235521.

World Health Organization. (2022, July 5). *Micronutrients*. World Health Organization (WHO). https://www.who.int/health-topics/micronutrients#tab=tab_1.

World Health Organization. (2023). *Vitamin A deficiency*. World Health Organization.

Yahaya, S., & Mardiyya, A. (2019). Review of Post-Harvest Losses of Fruits and Vegetables. *Biomedical Journal of Scientific & Technical Research*, *13*(4). https://doi.org/10.26717/bjstr.2019.13.002448.

Yanik, D. K., Istanbullu, Y., Guzelsoy, N. A., Yavuz, A., & Gogus, F. (2019). Strategies to Reduce Post-Harvest Losses for Fruits and Vegetables. *International Journal of Scientific and Technological Research*, *5*(3). https://doi.org/10.7176/jstr/5-3-04.

Yenumula, D. R. L., & Thilakavathy, s. (2018). Sweet potato– Wholesome nutrition in a SPUD. *International Journal of Applied Home Science*, *5*(1), 262–263.

Zafar, T., & Sidhu, J. (2017). Composition and Nutritional Properties of Mangoes. In M. Siddiq, J. Brecht, & J. Sidhu (Eds.), *Handbook of Mango Fruit* (pp. 217–230). John Wiley & Sons Ltd.

Zaizuliana Rois Anwar, N., & Abd Ghani, A. (2019). *Effect of Different Processing Methods on the Physicochemical Properties and Sensory Evaluations of Sweet Potatoes Chips*. https://journal.unisza.edu.my/agrobiotechnology/index.php/agrobiotechnology/index.

Zhang, C., Liu, D., & Gao, H. (2018). Kinetics, physicochemical properties, and antioxidant activities of Angelica keiskei processed under four drying conditions. *LWT*, *98*, 349–357. https://doi.org/10.1016/J.LWT.2018.08.054.

Zotarelli, M. F., da Silva, V. M., Durigon, A., Hubinger, M. D., & Laurindo, J. B. (2017). Production of mango powder by spray drying and cast-tape drying. *Powder Technology*, *305*, 447–454. https://doi.org/10.1016/j.powtec.2016.10.027.

APPENDIX

Table 2: Color values of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	OFSP FD	OFSP HAD	OFSP VOD	std error
L2	84.21^{a}	72.48^{c}	78.79^{b}	79.53^{ab}	77.48^{bc}	76.3^{bc}	1.71
a2	3.73^{d}	8.61^{ab}	5.59^{cd}	11.11^{a}	8.95^{ab}	8.18^{bc}	0.91
b2	34.55^{a}	40.14^{a}	35.37^{a}	30.16^{b}	26.91^{b}	24.62^{b}	2.45

Table 3: Water activity of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	OFSP FD	OFSP HAD	OFSP VOD	std error
Aw final	0.29^{a}	0.35^{a}	0.24^{b}	0.29^{a}	0.3^{a}	0.23^{b}	0.02

Table 4: Dry matter content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	OFSP FD	OFSP HAD	OFSP VOD	std error
Dry matter	92.79^{b}	91.43^{c}	93.38^{b}	92.98^{b}	93.07^{b}	94.66^{a}	0.19

Table 5: Ash content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	OFSP FD	OFSP HAD	OFSP VOD	std error
Ash	2.63^{a}	2.39^{a}	2.15^{a}	5.42^{b}	5.78^{b}	5.4^{b}	0.32

Table 6: Carotenoids content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	OFSP FD	OFSP HAD	OFSP VOD	Std error
Cis-β-carotene	1.38^{b}	2.16^{ab}	0.58^{b}	3.56^{a}	1.35^{b}	2.12^{ab}	0.48
Trans-β-carotene	4.1^{c}	6.67^{c}	1.58^{c}	33.84^{a}	14.9^{b}	20.12^{b}	1.71
Total-β -carotene	5.49^{c}	8.84^{c}	2.17^{c}	37.39^{a}	16.23^{b}	22.22^{b}	1.97
All-E-β-cryptoxanthin	0.27^{c}	0.23^{c}	0.09^{c}	1.85^{a}	0.53^{b}	0.44^{bc}	0.07

Table 7: Carotenoids content of mango only subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	std error
Lutein	0.26^{a}	0.37^{a}	0.07^{a}	0.99
Zeaxanthin	0.21^{b}	0.46a	0.25^{ab}	0.06

Table 8: Carotenoids content of OFSP only subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	OFSP FD	OFSP HAD	OFSP VOD	std error
Cis- lycopene	2.33[a]	0.58[b]	0.49[b]	0.29
Trans-lycopene	1.64[a]	1.13[b]	1.37[ab]	0.13
Total lycopene	3.97[a]	1.71[b]	1.86[b]	0.31

Table 9: Total carotenoids content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	OFSP FD	OFSP HAD	OFSP VOD	Std error
Total carotenoids	6.18[cd]	10.01[c]	2.59[d]	44.13[a]	18.95[b]	24.62[b]	2.18

Table 10: Titrimetric ascorbic acid content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	OFSP FD	OFSP HAD	OFSP VOD	std error
Ascorbic acid	289.83[ab]	185.34[ab]	327.41[a]	66.07[b]	58.25[b]	118.72[b]	60.52

Table 11: HPLC ascorbic acid content of mango and orange fleshed sweet potatoes subjected to freeze drying, hot air drying, and vacuum oven drying methods.

Parameter	Mango FD	Mango HAD	Mango VOD	OFSP FD	OFSP HAD	OFSP VOD	std error
Ascorbic acid	307.72[a]	244.41[ab]	285.52[a]	48.61[b]	60.14[b]	217.98[ab]	71.72