EFFECT OF DRYING TEMPERATURE AND PACKAGING MATERIAL ON THE QUALITY PARAMETER OF ORANGE-FLESHED SWEET POTATOES

BY

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AUGUST 2022

DECLARATION

I hereby declare that this is an original work done by me and is a record of my research work. It has been not been presented in any previous application for any higher degree at this or any other university. All citations and sources of information are acknowledged using references.

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ADETAYO, MODUPE PEACE

…….

Date

CERTIFICATION

This is to certify that this project entitled **"Effect of Drying Temperature and Packaging Material on The Quality Parameter of Orange Fleshed Sweet Potatoes**" was prepared and submitted by **ADETAYO MODUPE PEACE** in partial fulfillment of the requirements for the degree of **BACHELOR OF TECHNOLOGY IN FOOD SCIENCE AND TECHNOLOGY.** The original research work was carried out by her under my supervision and is hereby accepted.

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Head of Department

DEDICATION

This project is dedicated to God most highly for his protection, love, wisdom, and knowledge, which he provided me with throughout the compilation of my research project. Also, to my loving parents and siblings for their undying love and care and support and encouragement throughout my academic years.

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ABSTRACT

Orange fleshed sweet potatoes (OFSP) contain significant quantities of β-carotene, a precursor for vitamin A. The crop is being promoted to tackle vitamin A deficiency, a serious public health problem affecting children and pregnant/lactating women in sub-Saharan Africa. This research aims to evaluate the effect of drying temperature and packaging material on the quality parameter of OFSP flour. This study evaluated the effect of drying temperature on the quality parameter of OFSP flour, this was done using two drying methods, sun drying, and oven drying (90°C, 45°C, and 65°C), and was further studied by evaluating the effect of five packaging material (Transparent low-density polyethylene (LDT), dark low-density polyethylene (LDD), dark high-density polyethylene (HDD), transparent high-density polyethylene (HDT) and Laminated brown paper(HDDL)) on the retention and degradation kinetics of carotene during storage. The moisture, ash, protein, fat, fibre, and carbohydrate were in the range of 7.91 to 10.92%, 1.67 to 3.67%, 3.36 to 4.39%, 0.75 to1.25%, 0.30 to 0.69%, 81.15 to 84.12% respectively. The sugar, carotene, TTA, and pH were in the range of 2.88 to 7.89 mg/100g**,** 2.92 to 9.18µg/100g, 0.67 to 1.05 %, and 4.89 to 5.96 respectively. The color difference and yellowness index were in the range of 59.47 to 71.92, and 49.80 to 67.81 respectively. The OFSP dried at 65 ^{o}C had the highest yellowness index of 67.81, implying carotene retention at 65 ^{o}C was higher, the yellowness index was directly proportional to the carotene content in the samples. The OFSP that was dried at 65℃ produced the flour with the highest carotene retention (9.18µg/100g) and was used for storage. At the beginning of storage, all packaging material had (100%) carotene, after a month of storage, HDDL packaging material retained the highest carotene (95.06 %) followed by HDD (82.36 %), LDD (72.49 %), HDT (58.96 %), and LDT (51.28%) respectively, this shows the impact of light in carotene

retention OFSP flour has shown potential to combat vitamin A deficiency (VAD). Hence, OFSP flour should be advocated as a tool for achieving not only food security but nutritional security.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of Study

Root and tuber crops play a significant role in agriculture and facilitate many developing nations to attain food security. 494.6 million tons of roots and tubers (including potatoes) were produced globally in 2017. (Neela, and Fanta 2019). Root and tuber crops such as yam, cassava, cocoyam, and potato provide food and income to many households in Nigeria. They are second only in importance to cereals as a global source of carbohydrates (Nanbol, K. K., and Namo, O. 2019). Roots and tubers are rich sources of carbohydrates, crude fibre, and energy as well as some minerals and essential vitamins (Suleiman *et al.,* 2018). Roots and tubers are part of the diet for the majority of the global population, with a world average per capita consumption of 19.4 kg/year (2013–2015) and projected to achieve 21.0 kg/year by 2025 (Siddig *et al*., 2020) and also contributing to animal feeds and industrial needs (starch source). Among the roots and tubers, sweet potatoes (Ipomoea batatas) are very important after potatoes based on production and consumption. Sweet potato has been reported to have good sensory acceptability due to the eye-pleasing colors and sweet taste (Neela, and Fanta 2019) Sweet potato (Ipomea batatas Lam) is the seventh most important staple crop in sub-Saharan Africa. It is a rich source of energy, fiber, minerals, and vitamins. Orange-fleshed sweet potato (OFSP) contains β-carotene, a precursor for vitamin A (VA) in the body. In sub-Saharan Africa, traditional methods of sweet potato preparation include boiling, steaming, roasting, and drying (Beveridge *et al*., 2007). Dried OFSP products like chips and flour are the common ingredients for food preparations at the household level (Singh *et al*., 2013) These studies will demonstrate carotenes loss during the processing and

storage of OFSP products. However, there is a need to investigate the carotene retention of various OFSP products as affected by processing and storage. In addition, information on βcarotene bioaccessibility of OFSP traditional products is limited. Carotenoids bioaccessibility is defined as the fraction of carotenoids transferred by food to mixed micelles (small aggregates of mixed lipids and bile acids suspended within the ingesta), therefore becoming accessible for subsequent uptake by intestinal mucosa (Cunningham *et al.,* 2019). this study is aimed at evaluating the effect of different drying temperatures on the physicochemical and sensory properties of orange-fleshed sweet potatoes (OFSP) flour, As well as the appropriate packaging material.

1.2 Statement of Problem

Nigeria is not only faced with the problem of food security but that of nutritional insecurity leading to different forms of micronutrient deficiencies in the diet. An insufficiency of vitamin A in the diet results in vitamin A deficiency (VAD). Vitamin A deficiency is responsible for night blindness, increased susceptibility to infections, and impaired growth and development. Hidden hunger or micronutrient deficiencies afflict more than 2 billion people in the world effects of which can be devastating, leading to mental impairment, poor health, low productivity, and even death. Its adverse effects on child health and survival are particularly acute, especially within the first 1000 days of child life, resulting in serious physical and cognitive consequences. Too low micronutrient intake or absorption impairs sustaining health and development in children and mental function in adults the provitamin A-rich OFSP can address the life-threatening vitamin A deficiency disorders (Islam *et al*., 2021). It has been used in sub-Saharan Africa, to combat vitamin A deficiency. About 43 million <5 years children, 90 million preschool children, and 19 million pregnant women are affected by vitamin A deficiency in sub-Saharan Africa (De Onis, M., et al 2013). Vitamin A deficiency is contributing to high rates of blindness, disease, and premature

death in children and pregnant women. It also induces immunodeficiency disorder. Micronutrient deficiency, although mostly affects pregnant women, children, and adolescents, it impairs health throughout the life cycle. The drying and packaging of Orange Fleshed Sweet Potato (OFSP) flour is very important in the processing and storage of Orange Fleshed Sweet Potato (OFSP) flour. Since carotenoid is temperature and light-sensitive.

1.3 Objective

The general objective of this work is to evaluate the effect of drying temperature and packaging material on the quality parameter of Orange Fleshed Sweet Potatoes.

The specific objectives were to:

a) produce orange-fleshed sweet potatoes flour
b) evaluate the effect of drying methods on the physicochemical properties of orange-fleshed sweet potatoes (OFSP) flour
c) evaluate the sensory attribute of dough from OFSP flour
d) determine the effect of packaging materials during storage on the retention of carotene.

1.4 Scope of The Study

This study examines how varying drying temperatures affect OFSP flour's ability to retain beta-carotene as well as its sensory appeal.

1.5 Significance of The Study

The relevance of this study is to establish the proper temperature for drying OFSP and the proper packaging material. This is because the retention of carotenoids in OFSP is highly influenced by the drying temperature and the packaging material used for storage.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Food and Nutrition Security

When everyone, at all times, has physical, social, and economic access to food that is consumed in quantities and of a quality that satisfies their dietary needs and preferences and is supported by a setting with adequate hygienic conditions, health services, and care, there is food and nutrition security (Driouech et al., 2014). Several numbers of conceptual frameworks have been created during the past three decades to characterize food security, nutrition, and their relationship. Even if the connection between food security and nutrition is obvious from a technical standpoint, the definition of food security and nutrition has changed as a result of difficulties in coming to an understanding regarding the definition's political acceptability and commitment. The following summarizes how terminology has changed over time:

2.1.1 Food security

The concept and definition of food security have changed since its first introduction in the early 1940s. In the 1970s, the definition of food security was developed from the perspective of food supply to ensure that all people everywhere have enough food to eat. The current terminology in use, as adopted from the 1996 World Food Summit, emphasizes the multidimensionality of food security: food security exists when all people at all times have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for active and healthy life (Sobol *et al.*, 2010). This definition has widely established the four pillars of food security: availability, accessibility, utilization, and stability. The World Food Summit defined food security as “a situation that exists when all people, at all times, have physical, social, and

economic access to sufficient, safe, and nutritious foods that meet their dietary needs and food preferences for a healthy life" (Barrett *et al*., 2010). This definition incorporates several needs: availability of food, access to food, and for the food to be culturally appropriate. Many factors in today's global environment exacerbate food security. It is true, that we live in an age where we are growing and producing more food than ever before. We have enough food to feed the world's population, but it is not distributed properly nor is all food culturally appropriate across the globe. Local food access differs dramatically and the greatest difference exists between developed and developing countries. The primary reason for this inequity is an income-related difference between these populations (Hazell and Wood, 2008).

From this definition, **four main dimensions** of food security can be identified:

2.1.1.1 Physical availability of food

The quantity of food produced, stock levels, and net trade all affect the "supply-side" of food security, which is addressed.

2.1.1.2 Economic and physical access to food

A sufficient quantity of food at the national or international level does not automatically provide food security for households. To achieve food security goals, policies now place a larger emphasis on incomes, expenditures, markets, and prices as a result of concerns about inadequate food access**.**

2.1.1.3 Food utilization

Utilization is commonly understood as the way the body makes the most of various nutrients in the food. Sufficient energy and nutrient intake by individuals are the results of good care and feeding practices, food preparation, diversity of the diet, and intra-household distribution of food.

Combined with good biological utilization of food consumed, this determines the nutritional status of individuals.

2.1.1.4 Stability of the other three dimensions over time

Even if you now consume an acceptable amount of food, you are still seen as having food insecurity if you occasionally have insufficient access to food, putting your nutritional status in danger. Your level of food security may be impacted by unfavorable weather conditions, unstable political environments, or economic issues (such as increased food prices and unemployment).

For food security objectives to be realized, all four dimensions must be fulfilled simultaneously.

2.1.2 Nutrition Security

The term nutrition security emerged with the recognition of the necessity to include nutritional aspects in food security. Unlike food which is mostly defined as any substance that people eat and drink to maintain life and growth, nutrition adds the aspects of health services, a healthy environment, and caring practices. More precisely, "a person both F is considered nutrition secure when she or he has a nutritionally adequate diet and the food consumed is biologically utilized such that adequate performance is maintained in growth, resisting or recovering from disease, pregnancy, lactation, and physical work". Articles published in a special series of the Lancet 3 pointed out that nutrition was regarded as one of the most important parts of development priorities but underemphasized by both donor and developing countries. This notion is now widely shared and triggered a broad framework for collective action among key stakeholders. Based on the initiative of these stakeholders through the Road Map for Scaling-Up Nutrition (Fox *et al.*, 2015), nutrition security is deemed to be achieved when secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services, and care, to ensure a healthy and

active life for all household members. Recently, FAO has defined nutrition security as a condition when all people at all times consume food of sufficient quantity and quality in terms of variety, diversity, nutrient content, and safety to meet their dietary needs and food preferences for an active and healthy life, coupled with a sanitary environment, adequate health, and care (CFS 2012). Nutrition security, by contrast, exists when, in addition to having access to a healthy and balanced diet, people also have access to adequate caregiving practices and to a safe and clean environment that allows them to stay healthy and utilize the foods they eat effectively. For young children, for example, this means that they have enough of the right foods, and this includes breast milk for up to two years of age, along with appropriate quantity and quality of complementary foods starting at six months of age because breast milk can no longer fulfill all of the infant's nutrient needs after that age. In addition, young children also need caregivers who have the time, education, knowledge, physical and mental health, and nutritional well-being to care for them adequately. Adequate caregiving means that caregivers can attend to all their children's multiple needs, including adequate feeding, hygiene, health-seeking practices, and supportive parenting. Finally, to be nutrition secure, young children must also be free of repeated (chronic) or acute infections, which interfere with the absorption and utilization of food and nutrients for body functions (Ruel *et al.,*2013). Thus, borrowing from both definitions, "food and nutrition security" can be defined as a situation that exists when all people at all times have physical, social, and economic access to food, which is consumed in sufficient quantity and quality to meet their dietary needs, requirements for growth and food preferences, and is supported by an environment of adequate sanitation, health services and caregiving (Brem-Wilson *et al*., 2015). This allows the appropriate utilization of food and nutrients by the body and therefore creates the conditions for a healthy and

active life. Nutrition security, therefore, implies an optimal nutritional status. figure 2.1 shows the linkage between food and nutritional security.

2.2 Approach to achieving food and nutrition security

2.2.1 Diversification

Food diversification encompasses all dietary improvement approaches focusing on food systems, from production to consumption. Food-based strategies other than food fortification are often narrowed down to community-based gardening and nutrition education. Food systems as a whole must be considered to address not only nutritionally-relevant food production and consumption, but also processing, marketing, and distribution potential and constraints. Increasing the variety of foods that are accessible and acceptable to nutritionally-vulnerable groups is the whole thrust of food diversification strategies. Agriculture-based and food diversification approaches to nutrition are comparable in many aspects, but the former places more of an emphasis on micronutrient nutrition while the latter may also seek to increase the security of staple foods. Improved processing, the right dietary mix (for example, increasing fat intake for vitamin A or increasing vitamin C intake for iron), and, in some cases, public health initiatives like immunization, infection control, access to clean water, and sanitation are additional dietary interventions to increase the bio-efficacy of micronutrients. Despite its importance for the susceptibility of micronutrient, Food diversification produces a variety of foods that can boost economic welfare. In this context, diversification has an impact on raising food production and economic value. Food's added economic value has the potential to boost wellbeing, household resiliency, and income. Stainable prevention of micronutrient deficiencies, food diversification is still little developed.

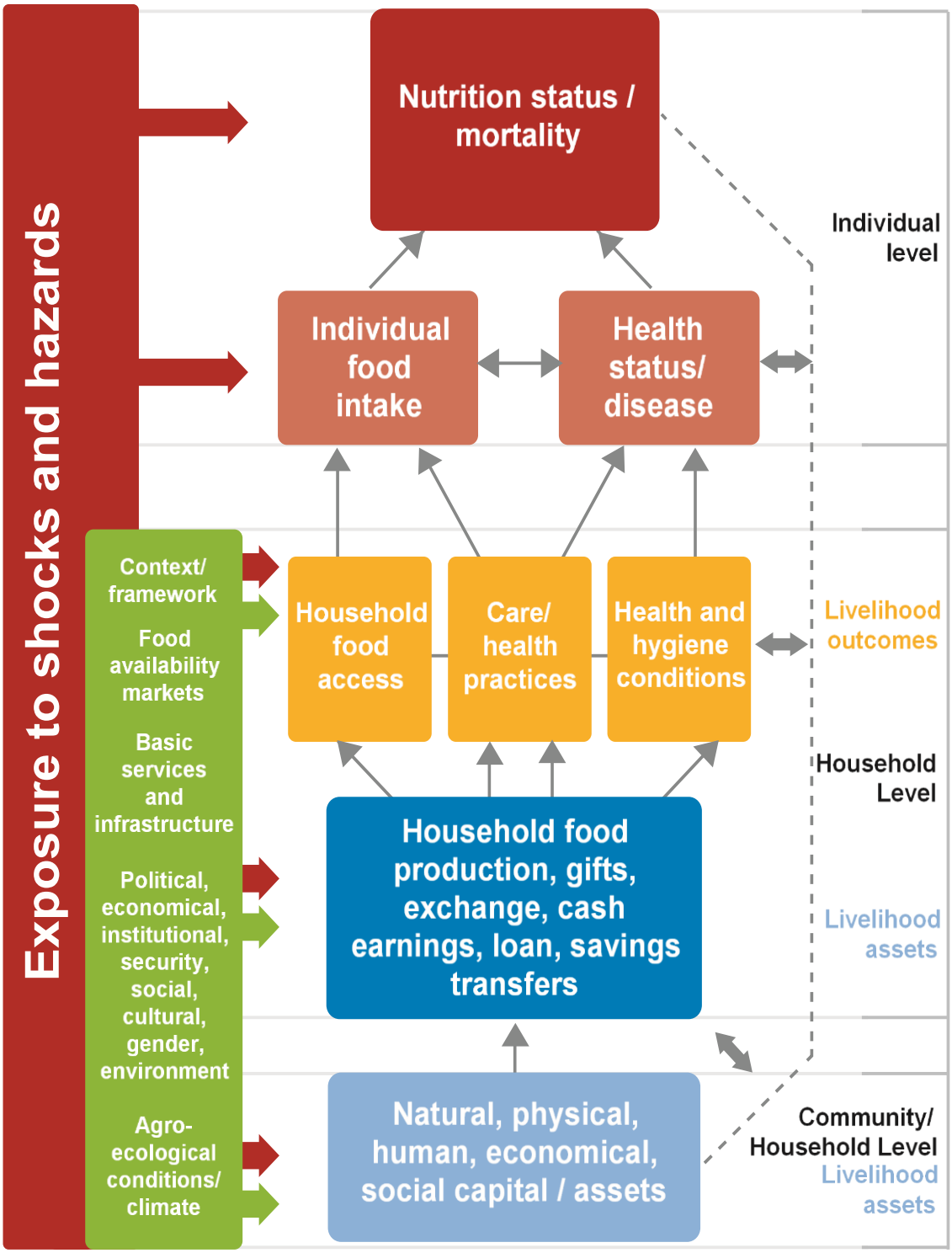


Figure 2.1: Linkages between food and nutrition security

Improved welfare can be seen in the decline in the number of rural poor by 4.7% from 16.31 to 15.54. It was positively correlated with the increase in farmers' income by (IDR) 30.37 million per capita (4.47%). Thus, food diversification is one of the instruments that can be used by the government to increase the household income of the population in reduce rural poverty and social inequality

2.2.2 Supplementation

A substance that broadens the diet by elevating total dietary intake is known as a dietary supplement. A dietary supplement's main purpose is to supply nutrients. It consists of vitamins, minerals, and other uncommon substances including animal extracts, biochemicals, amino acids, and herbals. Dietary supplements are goods that are consumed in addition to the regular diet to add more nutrients that are good for your health. Any vitamin, mineral, chemical, herbal product, plant, amino acid, or other ingestible preparation that is added to the diet to promote human health is referred to as a dietary supplement.

2.2.2.1 Types of Food Supplements:

There are many types of dietary supplements.

Vitamins: A vitamin is an organic substance that an organism needs in little amounts as a critical nutrient. When an organism is unable to produce an organic chemical molecule in sufficient quantities and must instead acquire it from the diet, it is referred to as a vitamin. For instance, vitamin C (ascorbic acid) is a vitamin for humans but not for the majority of other species. Although vitamin supplements are crucial for the treatment of some medical conditions, there is less support for their usage in healthy individuals.

Dietary supplements: These are required by living organisms, other than the four elements carbon, hydrogen, nitrogen, and oxygen present in common organic molecules. The term "dietary mineral" is archaic, as the substances it refers to are chemical elements rather than actual minerals.

Herbal medicine: For the majority of human history, medicinal treatments have been based on plants, and traditional medicine as such is still in use today. These are the types of complementary medicine that are loosely based on data gathered through the scientific method. The basis for many of the pharmaceutical pharmaceuticals used in modern medicine are plant-derived chemicals, and physiotherapy works to apply current standards of effectiveness testing to herbs and medicines that are derived from natural sources.

Amino acids and proteins: These significant chemical compounds contain side chains unique to each amino acid as well as amine (-NH2) and carboxylic acid (-COOH) functional groups. Although extra elements can be found in the side chains of some amino acids, the main elements of amino acids are carbon, hydrogen, oxygen, and nitrogen.

Bodybuilding supplements: Bodybuilding supplements are dietary supplements commonly used by those involved in bodybuilding and athletics. These may be used to replace meals, enhance weight gain, improve weight loss or improve athletic performance. Glutamine, essential fatty acids, meal replacement products, weight loss products, and testosterone boosters are used mostly overall.

2.2.3 Fortification

Food fortification (FF) is defined as the addition of one or more essential nutrients to a food, whether or not it is normally contained in the food, to prevent or correct a demonstrated deficiency of one or more nutrients in the population or specific population groups. Fortification, therefore,

differs from enrichment, which is the process of restoring the nutrients to a food removed during refinement or production. Since the 1930s, fortification has been used to target specific health conditions, such as iodine deficiency through the iodization of salt, anemia through the fortification of cereals with iron and vitamins, and neural tube defects through the fortification of wheat flour with folic acid. Fortification commonly uses staple foods as vehicles to deliver micronutrients that are generally lacking or not contained in sufficient concentration in the diet of a population. One of the most economical long-term approaches to ensuring adequate mineral intake is food fortification (Horton 2006). In industrialized nations, fortifying dairy products with various minerals (and vitamins), such as milk and bread, has proved successful. However, because it depends on a robust infrastructure for food distribution and processing, this technique is challenging to put into practice in poor nations. Food processing involves fortification, which raises the cost of the finished product. Due to these issues, fortified products are out of reach for the poorest individuals living in isolated rural locations. Since many parts of the world suffer from multiple deficiencies, strategies must also be developed to fortify foods simultaneously with several micronutrients without adverse interactions among them (Christou *et al.,* 2010). The addition of a single micronutrient would have more or less the same cost implications as the addition of several (Sachdev *et al.,* 2021). Zinc fortification has been implemented in the industrial world but rarely in developing countries. One exception is Zn-fortified wheat and maize flour in Mexico, which are used to make bread and tortillas, the two principal staples (IZINCG 2007). Organizations such as the Zinc Task Force (ZTF) and the International Zinc Nutrition Consultative Group (IZiNCG) are fighting Zn malnutrition by promoting diverse strategies to eliminate it. Given that Zn and Fe deficits frequently coexist, it has been proposed that double fortification would be efficient and very inexpensive, especially if Fe fortification was already in place.

2.3 Biofortification

"Biofortification" or "biological fortification" refers to those food crops which are enriched with micronutrients, and vitamins and show enhanced bioavailability to the human population that is developed and produced by using genetic engineering techniques, traditional plant breeding, seed priming, and agronomic practices. This term originated from the Greek word "bios" which means "life" and the Latin word "fortificare" which means "make strong".

More micronutrients can be delivered over a long period of time and at a relatively low cost by biofortification, the process of breeding nutrients into food crops. This strategy will not only help them retain their improved nutritional status but also reduce the number of severely malnourished individuals who need treatment through additional measures. Additionally, biofortification offers a practical way to reach rural people that are undernourished and may have little access to commercially available fortified foods and supplements. The goal of the biofortification strategy is to introduce the nutrient-dense micronutrient trait into cultivars that already have desirable agronomic and dietary features, such high yield. In contrast to complementary interventions like fortification and fortification, marketed surpluses of these crops may find their way into retail establishments, reaching consumers in rural areas first and then urban areas. in contrast to complementary interventions, such as fortification and supplementation, that begin in urban centers. Biofortified staple foods cannot deliver as high a level of minerals and vitamins per day as supplements or industrially fortified foods, but they can help by increasing the daily adequacy of micronutrient intakes among individuals throughout the life cycle (Bouis *et al*., 2017).

2.3.1 Process of biofortification

The process by which the nutritional value of food crops is enhanced by various methods which include agronomic practices, plant breeding, and other modern biotechnological techniques. It is a process of growing crops to increase the nutritional value of the seed. Fortification is different from food fortification which involves the improvement of the nutritional content which is present in the food crops during the stage of processing. In biofortification, the nutritional value which is present in the crops is improved during the growth stage of the plant as the nutritional micronutrients in the plant are fixed in the crop which is being grown.

2.3.2 Strategies for Biofortification of Food Crops

Producing nutritious and safe foods, sufficiently and sustainably, is the ultimate goal of biofortification. Biofortification of essential micronutrients into crop plants will be achieved through four main approaches, namely; Conventional, Transgenic, Seed Priming, and Agronomic (Figure 2.2)

2.3.2.1 Conventional breeding approach

Biofortification through conventional breeding within the most accepted method of biofortification offers a sustainable, cost-effective alternative to other strategies. Sufficient genotypic variation within the trait of interest is important for conventional breeding to be feasible. Breeding programs can utilize this variation to boost the number of minerals and vitamins in crops. In conventional plant breeding, parent lines with high nutrients are crossed with recipient lines with desirable agronomic traits over several generations to supply plants with desired nutrients and agronomic traits. However, breeding strategies need sometimes depend on the limited genetic variation present within the gene pool (Merlin *et al.,* 2016). In some cases, this may be overcome by crossing

to distant relatives and thus moving the trait slowly into the commercial cultivars. Alternatively, new traits are introduced directly into commercial varieties by mutagenesis.

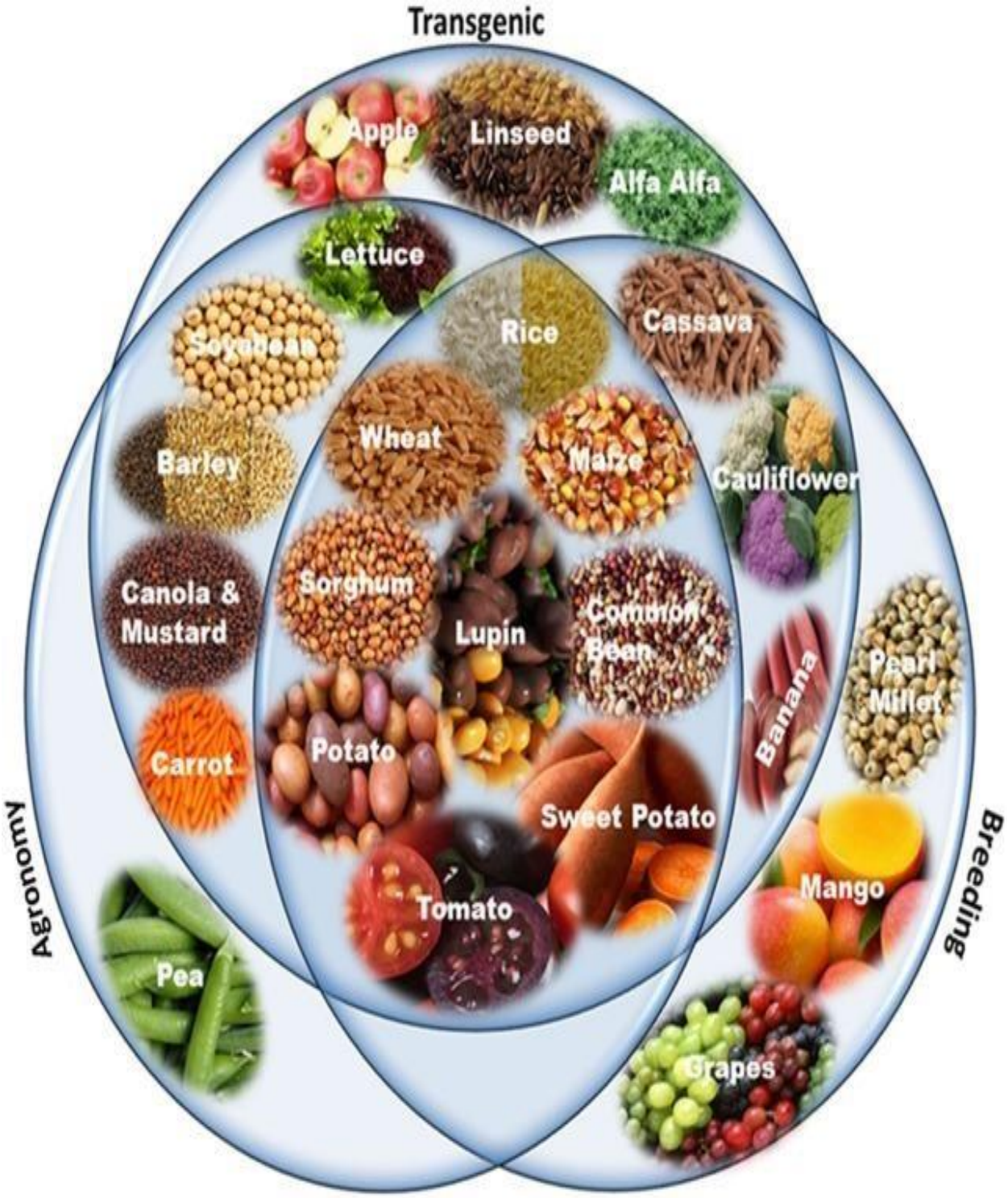


Figure 2.2: Examples of Biofortified Crops

Because this approach is probably going to be the foremost expedient method to boost plants, several international organizations have initiated programs to boost the nutritional content of crops through breeding programs.

2.3.3.2 Genetic engineering approach

The transgenic approach is often a legitimate alternative for the event of Biofortified crops when there's a limited or no genetic variation in nutrient content among plant varieties (Arora *et al* ., 2018). For the transfer and expression of beneficial genes from one plant species to another, independent of their evolutionary and taxonomic standing, it depends on access to the infinite genetic pool. Furthermore, transgenic methods remain the only practical option to supplement crops with a particular micronutrient when it does not naturally occur in those crops (Perez-Massot et al., 2013). The flexibility to spot and characterize gene function and so utilize these genes to engineer plant metabolism has been a key for the event of transgenic crops (Dyer *et al*., 2015). Furthermore, pathways from bacteria and other organisms may be introduced into crops to use alternative pathways for metabolic engineering (Bouwmeester *et al.*, 2014).

Transgenic methods can be used to simultaneously incorporate genes that improve the concentration of micronutrients, their bioavailability, and the reduction of antinutrient concentrations that restrict the bioavailability of nutrients in plants. Furthermore, genetic alterations are frequently used to redistribute micronutrients among tissues, increase the concentration of micronutrients in edible plant parts, improve the efficiency of biochemical pathways in edible tissues, or even reconstruct specific pathways (Beyer et al., 2008). Development of transgenically Biofortified crops initially involves a substantial amount of your time, efforts, and investment during the research and development stage, but in the future, it's a

cheap and sustainable approach, unlike nutrition-based organizational and agronomic Biofortification programs (Hefferon *et al.*, 2016).

Furthermore, biotechnology has no taxonomic constraints and even synthetic genes are often constructed and used. Transgenic crops with enhanced micronutrient contents hold a possibility to cut back micronutrient malnutrition among their consumers, especially poor people in developing countries (Hirschi., 2009). Numerous crops are genetically modified to boost their micronutrient contents. Among micronutrients, vitamins, minerals, essential amino acids, and essential fatty acids are targeted by the utilization of assorted genes from different sources to boost the food crop's nutritional level. It's been found that PSY, carotene desaturase, and lycopene β-cyclase for vitamins, ferritin and nicotinamide synthase for minerals and albumin for essential amino acids, and desaturase for essential fatty acids are widely reported as targets for Biofortification. Successful samples of the transgenic method are high lysine maize, high unsaturated carboxylic acid soybean, high carotene and iron-rich cassava, and high carotene Golden rice. Reports are available for Biofortified cereals, legumes, vegetables, oilseeds, fruits, and fodder crops.

2.3.3.3 Seed priming approach

Because seeds have an impact on the propagation of vital phases like germination and dormancy, they are regarded as an essential component of the crop life cycle. One of the promising approaches to generate value-added solutions to maximize the inherent capacity of seed to align the plant for maximum yield potential in terms of both quality and quantity is seed priming prior to sowing. Iron-oxide nanoparticle treatment had a favorable impact on the shoot and root growth of wheat (Triticum aestivum L.) seedlings. This innovative cost-effective and user-friendly method of Biofortification has proven to extend grain iron deposition upon harvesting (Sundaria

et al., 2019). Hence, the intervention of nanotechnology in terms of seed priming might be a cheap and user-friendly smart farming approach to extend the nutritive value of the grains in an eco-friendly manner.

2.3.3.4 Agronomic approaches

Biofortification through agronomic methods requires the physical application of nutrients to temporarily improve the nutritional and health status of crops and consumption of such crops improves the human nutritional status (Cakmak and Kutman, 2018). Compared to inorganic types of minerals, the organic ones are more available for a person, as they'll be absorbed more easily; and are less excreted and their toxicity symptoms are less intensive (Smith, T. W., et al 2014). It generally relies on the application of mineral fertilizers and/or an increase in their solubilization and/or mobilization from the soil in the edible parts of plants. Macro minerals like nitrogen, phosphorus, and potassium (NPK) make a vital contribution to the attainment of upper crop yields (Mauromicale, G., et al 2017).). Through the application of NPK-containing fertilizers, agricultural productivity increased in many countries around the globe within the late 1960s and resulting in revolution and saving them from starvation. Now a day, these fertilizers are important and necessary to enhance crop yield and save the human population from starvation as low-input agriculture cannot feed the present seven billion world population. Micro minerals like Fe, Zn, Cu, Mn, I, Se, Mo, Co, and Ni are found in varying degrees within the edible portion of certain plants and are usually absorbed from the soil. Improvement of the soil micronutrient status by their application as fertilizers can contribute to a decreasing in micronutrient deficiency in humans. When crops are grown in soils, where mineral elements become immediately unavailable within the soil and/or not readily translocated to edible tissues targeted application of soluble inorganic fertilizers to the roots or the leaves are practiced.

Agronomic Biofortification is straightforward and cheap but needs special attention in terms of source of nutrients, application method, and effects on the environment. These should be applied regularly in every crop season in a year and thus are less cost-effective in some cases. The use of mineral fertilizers is feasible within the developed world, as exemplified by the success of Se fertilization of crops in Finland (Arora, P., et al 2018).), zinc fertilization in Turkey (Cakmak, I., et al 2012), and I fertilization in irrigation water in China (Huang, G., et al 2020).

In addition to fertilizers, plant growth-promoting soil microorganisms will be accustomed to enhance the nutrient mobility from soil to edible parts of plants and improve their nutritional status. Different species of soil microorganisms like genera *Bacillus*, *Pseudomonas*, *Rhizobium*, *Azotobacter*, etc. may also be utilized to extend the phytoavailability of mineral elements (Freitas, H., et al 2016). The N_2-fixing bacteria play important role in increasing crop productivity in nitrogen-limited conditions (Svensson, B. H., et al 2013). Many crops are related to mycorrhizal fungi that may release organic acids, siderophores, and enzymes which are capable of degrading organic compounds and increasing mineral concentrations in edible produce (Broadley, M. R.., et al 2009).

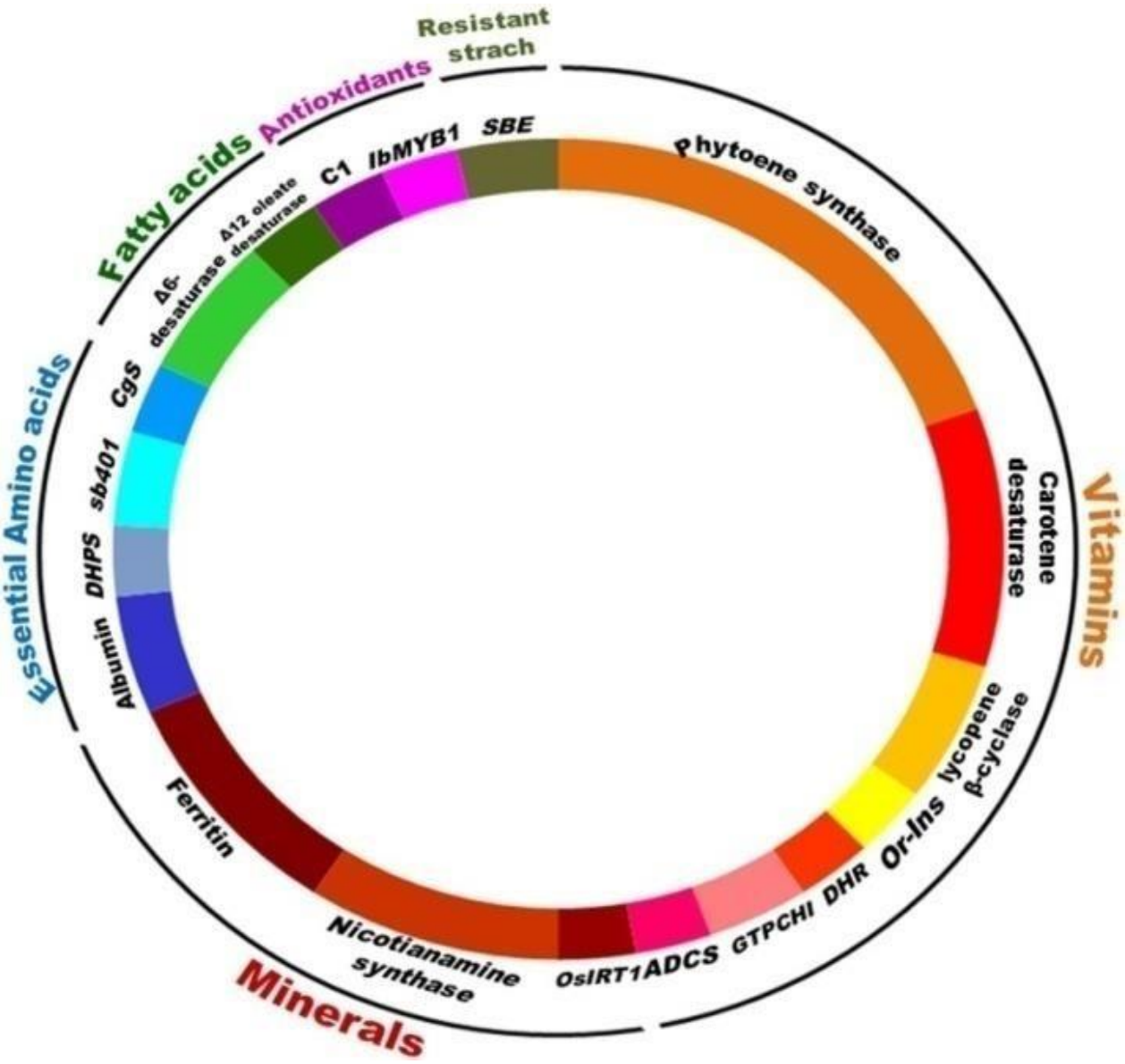


Figure 2.3: Name of a large number of genes that have been used for Biofortification

2.3.2 Why do we need biofortification?

Hidden Hunger - Hidden hunger is known to be lacking essential vitamins and minerals.

Hidden hunger occurs when the standard of food people eat doesn't meet their nutrient requirements, so the food is deficient in micronutrients like vitamins and minerals that they need for peoples' growth and development.

More than 2 billion people within the world today are also stricken by Micronutrient malnutrition. Vitamin A deficiency, Fe (iron) deficiency, and I (iodine) deficiency disorders are the foremost common types of micronutrient malnutrition.

A major challenge is that one-sixth of the population across the world is suffering from hunger, a situation that is completely unacceptable (Jaydeb, S., et al 2011). Additionally, more people, over half of the global population, are afflicted by a distinct form of food deficiency (Andrushko, V. A., et al 2009). The UN Food and Agriculture Organization has estimated that around 792.5 million people across the globe are malnourished, out of which 780 million people are living in developing countries. Apart from this, about 2 billion people across the globe are suffering from another style of hunger known as "hidden hunger," which is caused by an inadequate intake of essential micronutrients within the daily diet despite increased food crop production. Besides this nutrition is a growing matter of concern.

2.3.4 Advantages and Disadvantages of Biofortification

2.3.4.1 Advantages of Biofortification

After the primary investment to develop the Biofortified seed, it can be replicated and distributed with no reduction in the nutrient concentration. This makes it highly cost-effective and sustainable.

Biofortified crops are also more resilient to pests, and diseases and they are also resistant to higher temperatures and drought, which are essential qualities as many countries are becoming increasingly susceptible to global climate change. Biofortification results in higher yields in an environmentally friendly way. Biofortified crops reach the world's poorest and most vulnerable people living in remote rural areas having no money to access commercially cultivated fortified crops (M Gary., et al 2018).

2.3.4.2 Disadvantages of Biofortification

One of the drawbacks of food biofortification is the possibility of nutrient overconsumption by certain groups. Calculating the optimal amount of nutrients to be utilized is thus a major component of biofortification. It must be effective while being safe.

2.3.5 Biofortified foods

2.3.5.1 Rice

Golden Rice is the result of transgenic approaches to enhance pro-vitamin A concentration in the rice grain. Golden Rice β-carotene concentration has reached 37 μg/g dry weight (Paine 2005). Humans have been fed intrinsically deuterium-labeled rice with β-carotene concentrations of 5 and 20 μg/g. In 5 healthy adults, the conversion factor for Golden Rice β-carotene to retinol was 3.8 + 1.7 μg to 1 μg with a range of 1.9–6.4 to 1 (Tang 2009). When fed to Chinese children, pure β-carotene, Golden Rice β-carotene, and spinach β-carotene to retinol bioconversion factors were 2.0, 2.1, and 7.3 μg to 1 μg, respectively. These favorable bioconversion factors likely reflect the low level of β-carotene in the rice as well as favorable bioaccessibility (& Tanumihardjo, S., et al 2013). Rice is particularly highlighted for micronutrient improvement due to its global role as one of the main staple food crops, giving rice biofortification a huge potential for alleviation of malnutrition globally. In 2013, the first high Zn rice cultivar (with 20–22 mg kg−1 Zn in brown

rice) was spread through Harvest Plus and the Bangladesh Rice Research Institute. Increases of 17.4, 0.123, and 14.2 mg kg−1 for Zn, Se, and Fe, respectively, have been reported in rice. Provitamin A biofortified “Golden Rice” has proved itself as a cost-effective intervention in the areas where rice is the staple crop. Recently, screened 484 rice lines and found co-localized QTL regions for Fe and Zn along with high yield attributes. The composition of rice grains, including localization of Fe and Zn, their chelators, transporters, promoters, and inhibitors, needs to be considered to improve the bioavailability of micronutrients in rice and consequently the nutrition and health of consumers. Zinc management in soil has also significantly improved the grain Zn content in aromatic rice.

2.3.5.2 Wheat

Wheat grain makes a major contribution to the human diet as it provides many nutrients and minerals. Therefore, wheat production is required to double by 2050 for global food security. Wheat germplasm has been extensively screened for its mineral contents of Fe, Zn, Se, Mn, Mg, proteins, and vitamins. The screening also included phytic acid which is important due to its role in limiting the bioavailability of nutrients. Breeding as well as agronomic and genetic solutions have been dissected for the objective of wheat biofortification in recent decades. The dedication of the International Maize and Wheat Improvement Center (CIMMYT) gene bank and the Harvest Plus project set the basis for breeding competitive bread wheat cultivars with 40% higher Zn concentration in South Asia. Following this process, five biofortified wheat cultivars have been released, cv. Zincol 2016 in Pakistan, cv. Bari Gom 33 in Bangladesh and cv. Zinc Shakti (Chitra), WB02, and HPBW-01 in India. Ranges of Fe concentrations of 20–60 mg kg−1 and Zn concentrations of 15 to 35 mg kg−1 in a set of high-yielding genotypes were reported. This confirmed that sufficient genetic variation exists within the wheat gene pool that can be explored

for substantial increases in grain micronutrient concentrations. In addition, up to 3-fold enhancements of Fe and Zn concentrations in wheat grains through the soil and foliar application methods have been reported. Creating awareness for balanced fertilization among farmers in the developing world will further contribute to meeting micronutrient concentration targets to combat hidden hunger. Enhancing the concentration of Zn and Fe in the most edible part, the endosperm is not simple to achieve through agronomic practices, nevertheless, an increase in the concentration of Fe and Zn through soil application has been reported.

2.3.5.3 Maize

Maize is often considered a cash crop, but it is also a staple in many countries and provides food for humans and animals globally. Exogenous application of Zn in the form of seed priming, foliar spray, or incorporation in the soil enhances the germination of maize seed, Agronomy 2022, 12, 452 10 of 18 seedling vigor, and tolerance against different stresses. Maqbool and Bashir reported a high accumulation of Zn, i.e., 36 mg kg−1, in maize grains with an application of ZnO nano-particulates. Significant genome-wide association between micronutrient concentration in maize kernel and yield has been reported previously, suggesting that biofortification of maize is achievable using specialized phenotyping tools and conventional plant breeding techniques. Among 1000 CIMMYT maize lines, concentration ranges of Zn, Fe, and provitamin A have been reported, and maize lines with 15–35 mg kg−1 Zn, an average of 20 mg kg−1 Fe, and about 0–15 mg kg−1 total provitamin A concentration have been identified.

2.3.5.4 Pearl Millet

Pearl millet (Pennisetum glaucum L., R. Br.) is a major warm-season cereal grown in the arid and semi-arid tropical regions of Asia and Africa and is used as food and fodder. It is a staple food for

millions of people in Africa and Asia and contains higher levels of micronutrients such as Zn and Fe than wheat and rice. Variations in Fe concentration (35–116 mg kg−1), Zn (21–80 mg kg−1), and protein (6–18%) were reported in 281 advanced breeding lines bred at ICRISAT. Pearl millet has also been shown to exhibit great genetic variation (30–140 mg kg−1 Fe and 20–90 mg kg−1 Zn) which can be used to breed new cultivars that have high contents of Zn and Fe and are high yielding. Pujar et al. found highly significant and positive correlations between general performance and Fe/Zn density in pearl millet populations. The incorporation of parental lines with a high degree of average heterosis could prove to be beneficial in breeding programs with a focus to enhance Fe/Zn in pearl millet. The high iron and zinc pearl millet varieties AIMP92901 and ICMR312 have been developed. In India, open-pollinated pearl millet varieties (Dhanashakti) and hybrids (ICMH 1202, ICMH 1203, and ICMH 1301) with high concentrations of iron (70–75 mg kg−1) and zinc (35–40 mg kg−1) have been introduced.

2.3.5.5 Cassava

In many African countries, cassava (Manihot esculenta) is a staple, but it contains only low concentrations of Zn, Fe, I, and vitamin A. Therefore, there is a need to biofortify this crop for Fe, Zn, I, and vitamin A in poor resource countries to reduce micronutrient deficiencies. Outside of Africa, cassava is also used as a staple crop in Latin America and Caribbean countries. It is being considered an important crop to biofortify with beta carotene to enhance the vitamin A level of its consumers. Cassava is tolerant to various stresses and poor soils, therefore, an important crop for tropical and sub-tropical climatic conditions. Ortiz-Monasterio et al. investigated and introduced transgenic cassava that can accumulate a high concentration of beta carotene in roots based on nptII, crtB, and DXS genes. It has been described that transgenic cassava is high in concentration of carotenoid through overexpressing a PSY transgene. However, the natural variability of

carotene contents in cassava is also high and linked to the color of the roots. It is reported that higher carotene content is observed in orange varieties (12.6 μg g−1) while low carotene content is found in white varieties (1.3 μg g−1). In African countries, cassava has been utilized for mitigation of beta carotene deficiency by the partnership of Harvest plus with the International Institute of Tropical Agriculture (IITA), and they are utilizing beta-carotene biofortified cassava for mitigation of vitamin A deficiency in rural populations. Until 2014, this partnership has produced six vitamins A fortified varieties of cassava in Nigeria, i.e., TMS 01/1368-UMUCASS 36 and TMS 01/1412-UMUCASS 37 in 2011, TMS 01/1371-UMUCASS 38, NR 07/0220-UMUCASS 44, TMS 07/0593-UMUCASS 45, and TMS 07/539-UMUCASS 46. Meanwhile, biofortified cassava has been introduced in many more countries. Cassava also has a wide variety of genotype modifications for minerals (Fe and Zn) and proteins that resulted in the development of enhanced nutritional standards for cassava and this diversity is a potential asset for the development of Fe, Zn, and protein-enriched cassava varieties.

2.3.5.6 Beans

The common bean (Phaseolus vulgaris) is an essential grain legume, consumed by humans in all parts of the world. It is an annual herbaceous plant and its dry grains are edible. The beans are a rich source of amino acids, i.e., threonine, valine, leucine, isoleucine, and lysine, but their nutritive value is insufficient due to low concentrations of the essential amino acid methionine and cysteine. However, the methionine concentration in beans can be enhanced through the expression of methionine-rich storage albumin protein from seeds of the Brazil nut. Common beans also have a potential for Zn biofortification through foliar application of Zn fertilizer. It has been reported that in common beans N, P, K, Mn, Cu, and Zn concentrations can be enhanced by the administration of organic and chemical fertilizers. Furthermore, it has been shown that in common beans the Fe

concentration can be enhanced by 60–80% and Zn concentration by around 50%, using different strategies. High genetic diversity in common beans has been discovered for Fe and Zn concentration and genes have been reported in navy bean that are related to Zn accumulation. Generally, staple crops are poor sources of dietary folates but legumes and particularly beans were shown to be a good source of dietary folates. Thus, biofortification of common beans with minerals and amino acids can play a significant role to uplift the nutritional status of resource poor people of developing countries and promising work is in progress.

2.4 Orange fleshed sweet potatoes (OFSP)

Sweet potato roots vary in color, with the Orange-fleshed sweet potatoes (Ipomoea batatas L.) being particularly rich in β-carotene, the most important pro-vitamin A carotenoid. The OFSP is one of the bio-fortified crops being developed as part of the global effort to control vitamin A deficiency (HarvestPlus, 2009). It is one of the starchy staple crops which contain ascorbic acid and the amino acid lysine that is deficient in cereal-based diets like rice in addition to appreciable amounts of β-carotene. It also contains soluble fibre which helps in reducing cholesterol concentration and anti-oxidant nutrients which can inhibit the development of coronary heart disease. According to Alam,. (2021) the leaves of OFSP contain chlorogenic acids, a phenolic compound responsible for suppressing obesity in humans. They also contain considerably higher amounts of minerals such as phosphorus, nitrogen, potassium, magnesium, copper, iron, and zinc than what is contained in commonly cultivated vegetables (Islam., et al 2020). Recently, OFSP varieties are gaining great attention as a means of reducing common health-related problems associated with vitamin A deficiency in low-income communities. This variety is believed to be the least expensive source of dietary vitamin A available to poor families (Adeniyi ., et al 2019).). Many varieties of sweet potato contain high levels of all-trans-β-carotene, and therefore reaching

100 µg β-carotene equivalents/g is easily accomplished in countries that wish to use these varieties or breed them into their popular white- or cream-fleshed varieties. The vitamin A value of β-carotene from sweet potato was determined in Bangladeshi men to be approximately 13 µg β-carotene to 1 µg retinol using stable isotope methodology with deuterated vitamin A before and after a 60-d intervention study based on improvement in total body stores of vitamin A (Haskell 2004). A study in South Africa evaluated the impact of sweet potato feeding to children for five months during the school year on their liver reserves of vitamin A. Children who ate OFSP had a positive change in liver reserves compared with those children eating white sweet potatoes, measured using the modified relative dose-responses test (van Jaarsveld 2005), which is a semi-quantitative method to evaluate liver reserves (Tanumihardjo 2011). More recent work in Bangladeshi women who were fed OFSP 6 days/week over 10 weeks, however, did not result in a net gain of total body reserves of vitamin A over negative controls but did contribute to higher circulating serum β-carotene concentrations (Jamil 2012). Effectiveness studies are used to assess the impact on nutritional status after the crop of interest has been broadly released for an extended period of time. A two-year integrated effectiveness study was undertaken in Mozambique that included the introduction of sweet potato vines into households and monitoring for two agricultural cycles. Children in intervention households ate more OFSP and had higher dried-blood spot retinol concentrations than controls (Low J. W., et al 2007). However, after this study, many of the children still had low serum retinol concentrations, i.e., <0.7 µmol/L (WHO, 2011). In an effectiveness study in Uganda, vitamin A status was improved in children but only after making corrections and changing the currently recommended cutoff value for serum retinol from 0.7 to 1.05 µmol retinol/L (Hotz C 2012). This underscores the need to use more accurate biomarkers

of vitamin A status in populations of interest, such as quantitative methods of liver reserves (Tanumihardjo 2011) when evaluating agriculture-based interventions

2.5 Vitamin A

Vitamin A is an essential micronutrient required for normal body growth and human health. Vitamin A deficiency, a condition emanating from inadequate intake of vitamin A in foods is a major public health problem worldwide. The problem is most prevalent in under-five children and pregnant/lactating mothers (Dureab., et al 2021). Cases of vitamin A deficiency are very high in sub-Saharan Africa where about 33 million preschool children have been affected accounting for one-third of global cases (Rohner., et al 2020). Consequences of severe vitamin A deficiency include stunted growth, weak immunity, xeropthalmia, and death (Ngondi,, et al 2012). Traditionally vitamin A supplementation is the main strategy to combat vitamin A deficiency whereby under-five children are given vitamin A capsules every six months. Food fortification is another approach involving addition of vitamin A in food products such as sugar, cereal, and oil to increase vitamin A intake among vulnerable groups. Recently, biofortification has been identified as a better sustainable strategy to provide various vitamins and minerals to the population through-out the year at low cost (Birol., et al 2019). The method works by enriching promising crop varieties with various vitamins and micronutrients to enhance their nutrient profile.

2.5.1 Vitamin A deficiency

Vitamin A (retinol) is an essential nutrient required in small amounts for normal functioning of the visual system, growth and development, and maintenance of epithelial cellular integrity, immune function, and reproduction by humans (Bhende *et al.*, 2021). In the diet, vitamin A is but found in two forms, namely preformed and provitamin A. In animal foods, preformed vitamin A

occurs as retinyl esters of fatty acids in association with membrane-bound cellular lipid and fat-containing storage cells. Provitamin A carotenoids in plant foods are also associated with cellular lipids but are embedded in complex cellular structures such as the cellulose-containing matrix of chloroplasts or the pigment-containing portion of chromoplasts (Harrison *et al.*, 2007). Green leafy vegetables (spinach and amaranth), yellow vegetables (pumpkins, squash, and carrots), and yellow and orange non-citrus fruits (mangoes, papayas, and apricots) are good sources of provitamin A (Davidson *et al*., 2013). Preformed vitamin A is more bioavailable than provitamin A. This becomes a problem among low-income people, especially in developing countries who depend on plant foods as source of vitamin A, making them more susceptible to vitamin A deficiency. Vitamin A deficiency is a condition that results from insufficient intake of vitamin A in the diet causing low concentration of the nutrient in body tissue leading to adverse health consequences even if there is no evidence of clinical xerophthalmia (Holick *et al*., 2008). The main specific sign and symptom of vitamin A deficiency is xerophthalmia and the risk of irreversible blindness. Other nonspecific symptoms include; increased morbidity and mortality, poor reproductive health, increased risk of anemia, and contributions to stunted growth and development. Global vitamin A deficiency prevalence is categorized according to seriousness on the basis of clinical and subclinical indicators of deficiency.

Daily vitamin A requirements for different groups were evaluated and intake levels were developed by FAO/WHO in order to tackle vitamin A deficiency. The mean requirement for an individual is defined as the minimum daily intake of vitamin A, expressed as mg retinol equivalents (mg RE), to prevent xerophthalmia in the absence of clinical or subclinical infection. The safe level of intake for an individual is defined as the average continuing intake of vitamins A required to permit adequate growth and other vitamins A dependent functions and to maintain an acceptable

total body reserve of the vitamin (WHO/FAO,2004). The values were set with consideration for bioavailability of preformed vitamin A and Pro-vitamin A diets with adequate fat.

2.5.2 OFSP and vitamin A

Result of OFSP consumption A research-based evidence strengthens the importance of OFSP as a source of provitamin A and suggests the need to intensify research and Orange-fleshed sweet potato (OFSP) is one crop that has been biofortified with β carotene, a precursor for Vitamin A (Low *et al.,* 2007). In Kenya, varieties with varying and significant amounts of provitamin A have been developed and released in the recent past (Ndolo *et al.,* 2007). As a staple food in the larger sub-Saharan region, OFSP has an advantage over most fruits and vegetables in supplying the much-needed provitamin A, thus helping to fight vitamin A deficiency. Compelling evidence is available of the potential contribution of OFSP to improve nutrition among the vulnerable groups. A South African based study proved that OFSP is effective in improving vitamin A status among school going children (Jaarsrveld *et al.,* 2005). In a separate study conducted in the rural setting of Mozambique, significant improvements in vitamin A intake and serum retinol concentration were obtained as an advocacy to include the crop in diets of the vulnerable groups.

In Africa there are efforts through Vitamin A Partnership for Africa (VITAA) Initiative and also through a Gates Foundation Project led by the Harvest-Plus Challenge Program (Reaching End Users) and Centre for International Potato (CIP) to promote the use of OFSP varieties. CIP, a part of a Consultative Group on International Agricultural Research in collaboration with various research institutes, plays a pivotal role in breeding and multiplying OFSP varieties. It also promotes the processing of OFSP by working directly with the community as well processors to

ensure increased consumption of OFSP-based products and consequently eradicate vitamin A deficiency.

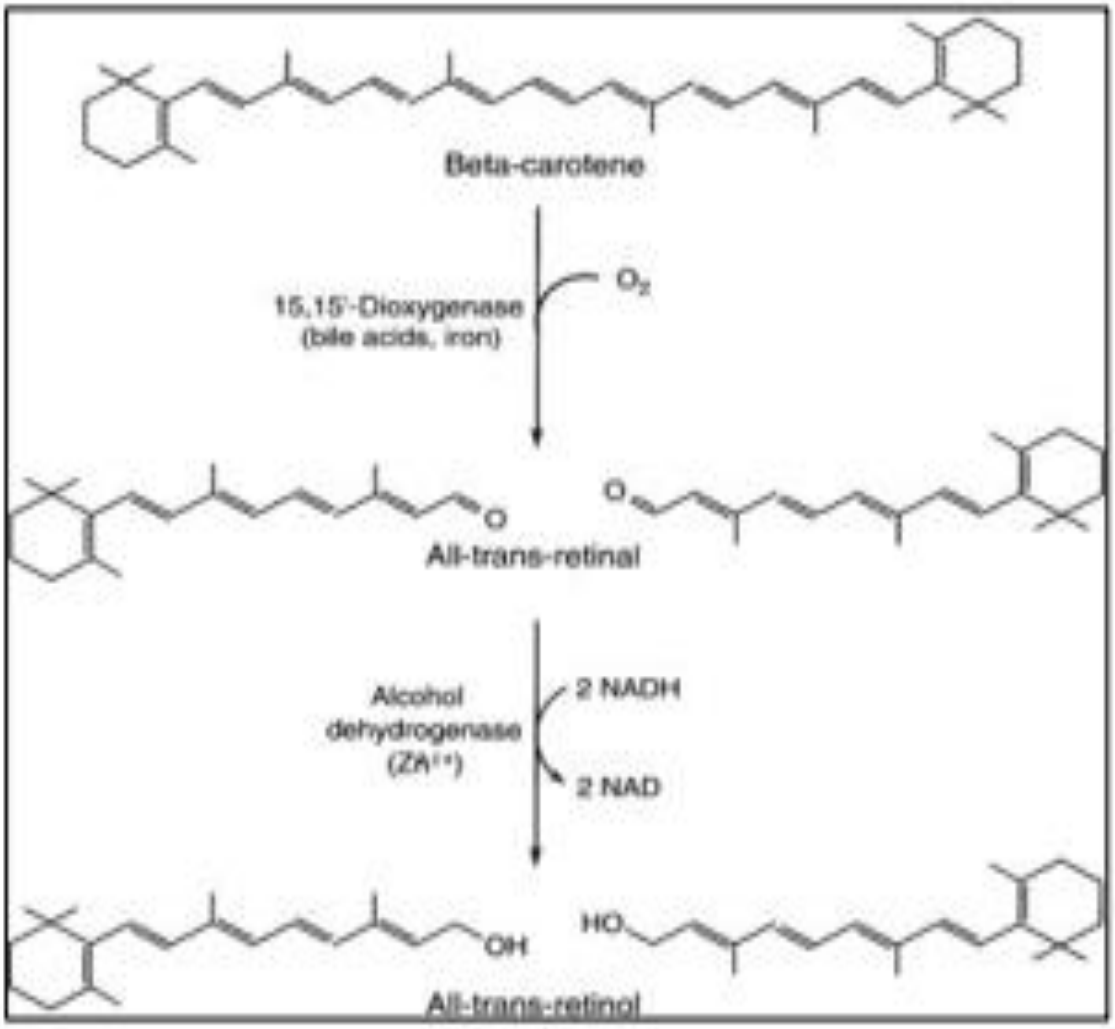
2.5.3 Pro-vitamin A Carotenoids

A common concept applied in the calculation of the target level for provitamin A carotenoid concentration is the bioconversion factor to retinol. This number is determined by evaluation of human studies and was set by the Institute of Medicine as 12 μg β-carotene and 24 μg for other provitamin A carotenoid to 1 μg retinol (IOM 2001). However, applying the established conversion factors to calculate a target level for provitamin A carotenoid content in staple crops without factoring in variations in the health status of individuals, the carotenoid content, or the food matrix in which it is packaged may not reflect what actually happens in vivo when provitamin A carotenoids are fed to different groups (Tanumihardjo *et al.,* 2013). Nonetheless, many studies use the Institute of Medicine's bioconversion number for predictions or calculate it based on experimental outcomes. In Harvest Plus, the experimental bioconversion factors were determined from human studies for sweet potato, cassava, and maize. Carotenes are natural pigments, responsible for orange-yellow-red color and flavor in fruits, vegetables, and flowers. In addition to β-carotene, OFSP contains high amount of α-carotene, β-cryptoxanthin, anthocyanin, lutein and zeaxanthin, which contribute its flesh color into orange, purple, jewel, garnet, and red. Carotene exists as trans- and cis-isomers rise. The β-carotene- provitamin A is converted into retinol in small intestine, also in liver and kidney one molecule βcarotene is converted into two molecule vitamin A. It is a safe source of vitamin A; does not make hypervitaminosis in excess intake. Thermal processing increases the bio-accessibility of β-carotene of OFSP. Boiling increases cis-β-carotene and decreases trans-β-carotene. It is because of the isomerization of Trans to cis isomer.

2.6.1 Mechanisms of Carotenoid Degradation/Retention

The mechanisms of carotenoid degradation/retention may involve: the reaction of carotenoids with atmospheric oxygen (auto-oxidation), light (photodegradation), and heat (thermal degradation), as well as degradation by the interactions of carotenoids with singlet oxygen, acid, metals, and free radicals. These mechanisms have been, for the most part, theorized based on a combination of studies in model systems, mostly in organic solutions; however, in food systems, the degradation mechanisms are more complex (Boon *et al.*, 2010).

In the intact fruit, vegetable, root/tuber, or grain, the carotenoid molecules are less susceptible to degradation because they are protected within tissues through molecular interactions and association into supramolecular proteolipid complexes or crystal formation and the antioxidant regime within living cells. Differences in sequestration and intracellular localization of carotenoids in the tissue may be crucial factors in the susceptibility of these pigments to *trans-cis* isomerization and oxidation (Borsarelli & Mercadante 2009).


Beta-carotene
15,15'-Dioxygenase
(bile acids, iron)
O_2
O
O
All-trans-retinal
Alcohol
dehydrogenase
(ZA^{++})
2 NADH
2 NAD
OH
HO
All-trans-retinol

Additionally, when the crop tissues are disrupted by cutting, chopping, shredding, cooking, or natural aging these physical barriers are affected thus rendering the carotenoids open to exposure to oxygen and oxidizing enzymes (Britton and Khachik, 2009). Given all these possible factors and their interactions, there are still many questions about the exact chain of reactions at the physiological level.

2.6.1.1 Isomerization

The most prevalent type of carotenoids found in foods, all-trans-carotenoids, can isomerize to the cis-isomer when exposed to bright sunlight. The molecule may twist during the isomerization process, resulting in an unpaired spin state that can easily react with oxygen to create carbon-peroxyl triplet diradicals that cannot be converted to retinol. It is possible for an isomer to arise first, followed by the generation of a diradical, or for both processes to happen simultaneously and reversibly (Merino et al., 2014).

2.6.1.2 Photodegradation

The photochemical process may produce isomers and/or degraded products from oxidation or volatile compounds, such as β-ionone. The degraded products are lighter colored because of the resulting shorter chromophore, while in the isomerization process the *cis*-isomer retains most of the properties of the parent carotenoids. Furthermore, photooxidation produces species thought to be carotenoid radicals (Decker *et al*., 2010). The photosensitized transformation of carotenoids has been studied using several sensitizer molecules, such as chlorophylls, iodine, rose Bengal (RB), and methylene blue (MB), and, in general terms, isomerization is the major pathway of reaction (Isbell *et al*., 1987).

2.6.1.3 Auto oxidation

Formations of oxidation products with molecular weight lower than β-carotene have been extensively reported. Eccentric cleavage products such as retinal and β-apocarotenals, as well as epoxy carotenoids, were produced by auto-oxidation of β-carotene (Nagao *et al.,* 2004). Bechoff and colleagues investigating the β-carotene degradation in dried sweet potato chips at various temperatures, water activity, and oxygen levels, observed that in all cases that, β-carotene submitted to oxidation was degraded into epoxides, apocarotenals, and apocarotenones, which were further oxidized into lighter and volatile compounds, e.g., β-cyclocitral, β-ionone, 5,6-epoxy-β-ionone, and dihydroactinidiolide (DHA) (Bechoff *et al*., 2010). The authors suggested that the greater β-carotene degradation rate at lower water was due in particular to autooxidation.

2.6.1.4 Singlet Oxidationss

Carotenoids can also interact with singlet oxygen present in the food matrix (which is more reactive than the triplet oxygen, present in the air) to yield triplet oxygen and an excited triplet carotenoid. The highly reactive molecules can interact with other free radicals, such as peroxyl or hydroxyl radicals, to generate further oxidative products (Britton *et al.,* 2011). Similarly, to autooxidation, β-apocarotenals can also be originated from the oxidation of β-carotene with a radical generating reagent and singlet oxygen (Bohuon *et al.,* 2011).

2.6.1.5 Thermal Degradation

The isomerization and degradation of pure β-carotene were evaluated in an oven heated at temperatures between 50°C and 150°C for up to 30 minutes, as well as by reflux heating at 70°C for 140 minutes, using first-order kinetic decay (Eckl *et al.,* 2015). The major isomers formed during heating were 13-*cis*-β-carotene, both under oven and reflux heating, while the 13,15-di-*cis*-

β-carotene was only found at temperatures higher than 120°C. Similar results were obtained by Henry et al., 1998, heating β-carotene at several temperatures formed 13-*cis*-β-carotene in higher amounts, followed by 9-*cis*-β-carotene. In summary, isomerization is the main reaction that occurs during heating at atmospheric pressure and temperatures lower than 100°C; the 13-*cis*-isomer is formed at higher rates than the 9-*cis*-isomer; the formation of oxidation products from β-carotene, such as epoxides and apo-carotenals, as well as di-*cis* isomers, occur under higher temperature, longer time, and higher pressure (Mercadante, 2008).

2.6.2 Factors affecting carotenoid retention

The stability of carotenoids in dried OFSP products is adversely affected by temperature, light, oxygen, and water activity as elaborated in the sections below:

2.6.2.1 Temperature

The isomerization of carotenoids is what causes carotenoid degradation during storage to be influenced by storage temperature, with low heat intensity causing less harm than high heat intensity. Orange peel, sweet potato, and carrot freeze-dried powders held at 4, 20, 40, and 45°C revealed a significant change in carotenoid content as a result of temperature (Tang & Chen, 2000; Cinar 2004). When red guava (Psidium guayaba L.) was freeze-dried and stored at room temperature, carotene losses increased during the first six months before gradually decreasing and becoming essentially insignificant by the end of the storage period (Patel et al., 2015). However, (Westby *et al*., 2010) reported no influence of storage temperature (at 0, 7, 14 or 21°C) on the β-carotene content in sweet potato products. A slight degree of isomerization of β carotene was noted in the pumpkin puree samples stored at 23°C but with low concentrations of cis-isomers. (Provesi *et al*., 2011) further reported that storage for 180 days did not significantly affect the concentrations

of the carotenoids under study. Based on the reviewed literature, high storage temperature and extended storage at ambient temperature negatively affected the carotene content of foods. Such losses could be minimized by storing in a freezer or refrigerator as well as limiting the storage period in order to preserve the nutrient.

2.6.2.2 Water activity

There is little information on the impact of water activity on the loss of beta-carotene during the preservation of dried sweet potatoes. Based on the scant information available, Westby et al. (2010) demonstrated that water activity had an impact on the carotenoids' ability to degrade in OFSP-dried products.

2.6.2.3 Light

Carotenoid degradation due to light is mostly due to photo-oxidation. The light increased cis isomerization of α-carotene, β-carotene, and lutein standards compared to samples stored in the dark (Tang & Chen, 2000). Moderate effects of light on β-carotene isomerization compared to temperature have been reported. (Carle *et al*., 2003), observed that the isomerization of β carotene in hexane reached the same level in 40 min at 70°C in the dark and in 12 hours at –5°C under 2000 lux. Contradictory information is available on the effect of light on carotene loss. Rodriguez and Rodriguez-Amaya (2007) did not observe a significant impact of light exposure on β-carotene degradation in the time scale chosen (21 days). Carotene-rich foods' photo-oxidation effects can be reduced both during preparation by keeping light away from the product and during storage by using dark/opaque packaging.

2.6.2.4 Oxygen

The current school of thought on the mechanism of carotene oxidation with molecular oxygen is that the whole process involves the first isomerization of the all-trans to the cis-isomer, followed by the formation of a di-radical, or they may both occur simultaneously and reversibly. Head-space oxygen in the storage bags influences β-carotene content. Samples stored for six weeks under 2% oxygen suffered an average loss of 4.4% of β-carotene more than samples stored under 0% oxygen (Van Hal *et al*., 2000). Even greater carotene losses were expected with an extended storage period. High oxygen concentrations were related to high levels of carotenoid degradation during storage in dried sweet potato flakes (Boy et al., 2015), in pasteurized mango puree (Vásquez-Caicedo *et al.,* 2007) ,and in semi-preserved tomato sauces (Baiano *et al*.,2005). The impermeable packaging to oxygen (laminate) with oxygen absorber was effective at preventing carotenoid degradation through oxidation (Cichello *et al*., 2015).

2.7 Effects of Processing on Carotenoid Retention in OFSP Product

Many carotenogenic foods are seasonal and processing at peak harvest is necessary to minimize losses, make the products available all year round, and permit transportation to places other than the site of production. Processing and storage of foods should, however, be optimized to prevent or reduce degradation while accentuating bioavailability (Rodriguez-Amaya *et al*., 2003).

During food processing and storage, carotenoids can change or disappear due to physical removal (such as peeling), geometric isomerization, enzymatic or non-enzymatic oxidation, and other factors (Rodriguez-Amaya et al., 1999). To guarantee that carotenoids are retained as much as possible, steps should be done. Even though industrial processing is frequently the focus of attention, sometimes even more carotenoids might be lost through home preparation.

Carotenoid biosynthesis may continue, raising the carotenoid content, in fruits, fruit vegetables, and root crops even after harvest, provided the plant materials are kept intact, preserving the enzymes responsible for carotenogenesis. In leaves and other vegetables, post-harvest degradation of carotenoids may prevail, especially at high storage temperatures and under conditions that favor wilting (Rodriguez-Amaya *et al*., 1997).

Cutting, shredding, chopping, and pulping fruits and vegetables increases oxygen exposure and brings together carotenoids and enzymes that catalyze carotenoid oxidation. Carotenoids are naturally protected in plant tissues. Even under the same manufacturing and storage circumstances, the stability of carotenoids in various foods varies. So, the ideal circumstances for carotenoid retention during preparation or processing change depending on the food. Different carotenoids themselves are susceptible to deterioration (Rodriguez-Amaya et al., 2003).

The major cause of carotenoid destruction during food processing and storage is enzymatic or nonenzymatic oxidation. Isomerization of trans-carotenoids to the cis-isomers, particularly during heat treatment, alters their biological activity and discolors the food, but not to the same extent as oxidation. In many foods, enzymatic degradation of carotenoids may be a more serious problem than thermal decomposition (Rodriguez-Amaya *et al.*, 1999).

Moreover, reported increases in carotenoid content during cooking or thermal processing are more likely to be artifacts of the analytical/ calculation process linked to loss of carotenoids in fresh samples due to enzymatic activity during sample preparation for analysis, greater extractability of carotenoids from processed samples, unaccounted loss of water, and leaching of soluble solids during processing (Britton et al., 2009)

Whatever the processing method, carotenoid retention decreases with longer processing time, higher processing temperature, and cutting or puréeing of the food. Retention is significantly improved by reducing the processing time, lowering the temperature, and shortening the time lag between peeling, cutting, or puréeing and processing. Rapid processing at high temperatures is a good alternative.

The inactivation of oxidative enzymes that occurs during this sort of heat treatment minimizes further and higher losses during holding before thermal processing, slow processing, and storage. Blanching may cause some losses of carotenoids. Carotenoids are significantly lost during peeling and juicing, frequently more so than during heat treatment. Even while traditional sun-drying is the cheapest and easiest way to preserve food in underdeveloped areas, it significantly depletes the food's carotenoid content. Even a modest and affordable solar dryer can significantly cut losses during drying. Food that is shielded from direct sunlight benefits as well. Sulfiting and antioxidant compounds, whether natural or added, may slow the breakdown of carotenoids (Dutta et al.,2005).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sources of Raw Materials and Equipment

Orange fleshed sweet potatoes (OFSP) King J (UMUSPO1) variety was gotten from National Root Crops Research Institute (NRCRI) research farm, Iresi, Osun State, Nigeria. All analyses were carried out in laboratories of the Department of Food Science and Technology. Mountain Top University, Ogun state Nigeria.

3.1.1 Equipment:

Oven, milling machine, weighing balance, dicer, spoon, conical flasks, beakers, pipette, burette, retort stand, measuring cylinders, Kjeldahl apparatus, Kjeldahl tablet, crucibles, micropipette, UV-Visible spectrophotometer, centrifuge, spatula, nose mask, hand gloves, sample bottle rack, sample bottle, distilled water, Petri dishes, racks, water bath, pippete, measuring cylinder, conical flask, foil paper, spatula, Petri dishes, water bath (set at 100°C).

3.1.2 Chemical and reagents

Petroleum ether, acetone, conc H2SO4, methyl red indicators, boric acid, 0.1 NHCL, n-hexane, NaOH, HCL, HNO3.

3.2 Sample Preparation for Drying

The orange-fleshed sweet potatoes (OFSP) were processed into OFSP flour using a modified method by Pessu *et al*., (2020). The OFSP was washed to remove adhering soil particles, sand, and dirt. The OFSP peel was removed using a sharp stainless knife (the OFSP were kept in water during the peeling operation to prevent browning). Using dicing equipment, the flesh was diced using a

semi-dicing machine to obtain a uniform surface area for drying, after which it was oven-dried at 45°C, 65°C, and 90°C and sun-dried, a constant weight was obtained for each temperature indicating that the slices were properly dried. The dried slices were milled in an attrition milling machine to obtain smooth flour. The milled flour was sieved and stored at ambient temperature until it was used for analysis. Roots were Sorting and peeling, Washing and size reduction, blanching and cooling. Two drying methods sun drying, oven drying (90°C, 65°C, 45 °C), were used.

3.2.1 Drying of OFSP

3.2.1.1 Sun drying

The prepared sliced orange-fleshed sweet potatoes were spread under the sun and milled in an attrition mill to obtain the flour followed by sieving.

3.2.1.2 Oven drying

The prepared sliced orange-fleshed sweet potatoes were put in an oven and was dried at 45°C, 65°C, and 90°C. The dried orange-fleshed sweet potatoes slice and milled in an attrition mill to obtain the flour followed by sieving

3.2.2 Packaging and storage

The result of the OFSP flour with the highest carotene retention and sensory acceptability were stored for one (1) month using five types of packaging materials namely HDPE (dark), HDPE (transparent), LDPE (dark), LDPE (transparent) and brown paper were evaluated for their effect on carotene retention in relation to color. The storage of flour was included to simulate home storage condition. sealing was applied to HDPE (dark), HDPE (transparent), LDPE (dark), LDPE

(transparent), and laminated brown paper, and had air removed manually (so as to avoid degradation of carotene) and then sealed. The storage study Carotene retention, kinetic degradation parameters Babarinsa *et al*., 2020 was conducted for one month and the retention of carotene was done weekly during the entire storage period.

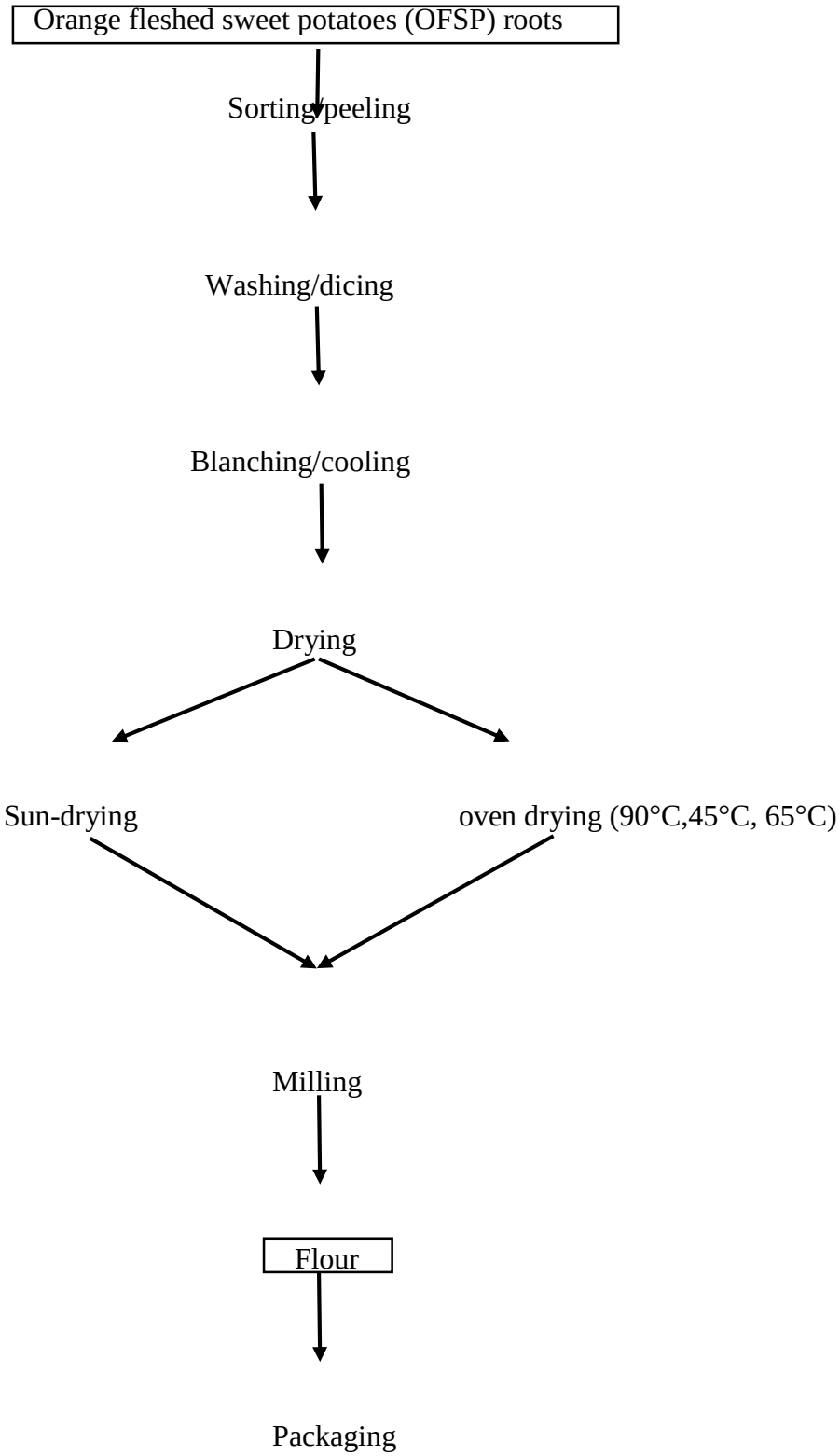


Figure 3.1: Flow chart of the production of OFSP Flour

3.3 Proximate Composition Determination

Proximate analysis was determined according to the official method of analysis described by the association of official analysis chemists (AOAC 2012).

3.3.1 Determination of moisture content

2g of each sample was weighed, and the moisture content was determined using a moisture analyzer. At 103 c for 5 min, this was repeated until a constant weight was obtained for each sample the moisture content is done to determine the dried solid in the flour and the stability at room temperature (shelf life).

3.3.2 Determination of ash content

Ash content was determined using the AOAC (2012) method. 2g of the finely ground OFSP sample was weighed into a pre-weight empty crucible. This was transferred into the muffle furnace set at 600 and left for about 4 hours. The crucible and its content were cooled to room temperature in a desiccator. The crucible with the sample was weighed and the % ash content in the OFSP sample was calculated by the following formula:

$$Ash\ (\%) = (Wt.of\ ash\ /\ Wt.of\ the\ sample\ taken) \times 100.$$

3.3.3 Determination of protein

The protein content was determined according to AOAC, (2012). Ig of the sample was weighed into a digestion flask and 1 Kjeldahl catalyst tablet was added, 12ml of conc.H2SO4 was added and digested for 2 hours in a (baker) fume hood with (tecator 100l digester) until a clear solution was obtained. Leave until completely cool and rapidly add 100mls of distilled water. Rinse the digestion flask 2 times and add the rinse to a bulk. Markham distillation apparatus is used for

distillation. Steam up the distillation apparatus and add about 10mls of the digest into the apparatus via a funnel and allow it to boil. Add 10mls of sodium hydroxide to the measuring cylinder so that ammonia is not lost. Distill into 50mls of 2% boric acid containing screened methyl red indicator. Titration, the alkaline ammonium borate formed is titrated directly with 0.1N HCL. The titer value which is the volume of acid used is recorded. The volume of acid used is fitted into the formula which becomes

$$\% = \frac{(14 \times \mathrm{VA} \times 0.1) \times \mathrm{W} \times 100}{1000 \times 100}$$

VA= volume of acid used

W= weight of the sample

$$\%\text{Crude protein} = \%N \times 6.25$$

3.3.4 Determination of fat content

This was determined by using the method described by AOAC, (2012). 4g of dried OFSP sample was weighted into a fat-free thimble plugged lightly with cotton wool and extracted with n-hexane in Soxhlet apparatus set up for 5 hours. The residue extract was evaporated in an air oven at 100c for 30 minutes, cooled, and weighed. The fat content was calculated as

$$\% \text{ fat} = \frac{(\text{weight of flask + fat}) - \text{weight of empty flask} \quad \text{x } 100}{\text{The original weight of the sample}}$$

3.3.5 Determination of crude Fibre

The crude fiber was determined according to the method described by AOAC (2012). 2g of the sample was accurately weighed into a flask and 200ml of 1.25% H2SO4 was added. the mixture was heated under reflux for 30 minutes. The hot mixture was filtered through a fiber muslin cloth. The obtained filtrate was thrown off and the residue was returned to the fiber flask with 200ml of 1.25% NaOH was added and heated for another 30 minutes. The residue was removed and finally transferred into the crucible. The crucible and the residue were oven dried at 105 overnight to drive off the moisture. The oven-dried crucible containing the residue was cooled in a desiccator and later weighed to obtain the W1. The crucible with W1 was transferred to the muffle furnace for ashing at 550c for 4 hours. The crucible containing white or grey ash (free of carbonaceous material) was cooled in the desiccator and weighed to obtain W2.

The difference in W1 and W2 gives the weight of fiber

$$\%fibre = \frac{\text{W1} - \text{W2}}{\text{The original weight of the sample}} \text{ x } 100$$

3.3.6 Determination of carbohydrate

The total carbohydrate content of foods has been calculated by difference, rather than being analyzed directly. The constituents of food i.e., protein, fat, moisture and ash were determined individually except for carbohydrates and summed, then the sum was subtracted from the total weight of the food. This is referred to as total carbohydrate by difference.

Total carbohydrate

$$= 100 - (Weight\ in\ grams\ [protein + fat + moisture + ash + fiber]\ in\ 100\ g\ of\ sample).$$

3.4 Chemical analysis

3.4.1 pH Determination.

The pH of the OFSP sample was determined using AOAC (2012) method. Each of the OFSP samples (10 g) was put into a 100 ml beaker and 100 ml of distilled water was added to it. This was allowed to stay for a few minutes after which it was filtered with a Whatman filter paper. The filtrate was then taken and tested using a standardized pH meter. Triplicate values were obtained, the mean of which was then calculated.

3.4.2 Determination of total titratable acidity.

The percentage total titratable acidity of the OFSP samples was determined using the method described by using AOAC (2012) method. Five grams of each of the samples were dissolved in a beaker and made up to 100 ml with distilled water, then allowed to stand for about 30 mins. The resulting suspension was filtered with a filter paper, and 25 ml of the filtrate was taken and titrated against 0.1 M NaOH, using phenolphthalein as an indicator. The endpoint was obtained when the color became pink.

The mean (TTA) was then calculated from triplicate values.

$$\text{TTA } (\%) = 0.005X\ x\ 100 = 0.01X,$$

where X is the mean titre value.

3.4.3 Carotenoid Retention

One gram (1 g) of OFSP was weighed into a beaker, and 50ml of acetone was added to it. This was allowed to stay for a few minutes after which it was filtered with a Whatman filter paper. The filtrate was then transferred into the separating funnel. 5ml of petroleum ether was added to it. Shake the mixture vigorously. Added 100ml of distilled water slowly along the wall of the funnel. This was allowed to stay for a few minutes. Discard the aqueous phase, and collect the petroleum ether phase in a volumetric flask after passing through a funnel with anhydrous Na2So4 to remove the remaining water. make up the volumetric flask with petroleum ether. The absorbance of the extract taken was set at 450nm. the spectrophotometer was calibrated to zero using a 1cm cuvette with petroleum ether as blank, and a sample of the extract was added to the cuvette. The reading of the sample was taken immediately the figure displayed on the spectrophotometer window was steady.

The total carotenoid concentration was calculated using Beer Lamber's law, which states that the absorbance (A) is proportional to the concentration (C) of the pigment. The formula used for calculation is expressed

$$\text{Total carotenoid content} = \frac{\text{A} \times \text{V(ml)} \times 10\text{^}4}{2592 \times \text{P(g)}}$$

3.5 Functional properties

3.5.1 Swelling index

The determination of swelling index (SI)using AOAC (2012). Ten grams (10g) of the OFSP sample was transferred into a clean, dried, calibrated measuring cylinder. The OFSP was gently leveled by tapping the cylinder and the initial volume was recorded. Fifty milliliters (50 ml) of

distilled water were poured into the cylinder and allowed to stand for 4 h. The value for SI was taken as the multiples of the original volume.

$$\text{Swelling capacity} = \frac{weight\ of\ the\ paste}{\text{weight of the dry flour}}$$

3.5.2 Dispersibility

Ten grams of the flour sample would be weighed into a 100ml measuring cylinder, and water would be added to each volume of 100ml. the set-up is stirred vigorously and allowed to stand for three hours. The volume of settled particles would be recorded and subtracted from 100. The difference is reported as percentage dispersibility.

$$\%\ dispersibility = 100 - the\ volume\ occupied\ by\ the\ flour$$

3.5.3 Water Absorption Capacity.

The determination of water absorption capacity. One gram (1 g) of OFSP was weighed into an already weighed clean dried centrifuge tube. Twenty milliliters (20 ml) of distilled water were poured into the centrifuge tube and stirred thoroughly; centrifuge at a speed of 3500 rpm for 45 min. The supernatant was discarded and the tube and its content reweighed. The gain in mass was taken as the water absorption capacity.

3.5.4 Bulk density

The method was used for bulk density (BD) determination. Ten grams (2g) of the OFSP were transferred into a 10 ml measuring cylinder. The cylinder was tapped repeatedly for 2 min. The

BD of the OFSP sample was calculated as the mass of OFSP over the volume at the end of tapping. The mean value was recorded from triplicate determinations

$$\text{Loose bulk density}\left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{Weight of sample}}{\text{The volume of the sample before tapping}}$$

$$\text{packed bulk density}\left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{Weight of sample}}{\text{The volume of the sample after tapping}}$$

3.5.6 Pasting properties

Pasting properties of the flour samples Pasting parameters (pasting temperature, peak time, peak, trough, breakdown, final, and setback viscosities) of the flour samples were determined using a Rapid Visco Analyzer (Newport Scientific Pty Ltd) as described by Newport Scientific (1998). A 2.50 g of flour sample was weighed into a previously dried empty canister, and 25 ml of distilled water was dispensed into the canister containing the sample. The suspension was thoroughly mixed and the canister was fitted into the rapid visco analyzer. Each suspension was kept at 50% for 1 min and then heated up to 95°C at 12.2 °C/min and held for 2.5 min at 95°C. It was cooled to 50°C at 11.8°C/min and kept for 2 min at 50°C.

3.5.7 Colour measurement

The colour was measured using a colorimeter (CHROMA METER CR-410, Konica Minolta, INC, Japan) and recorded in the L*, a*, b* colour system. The colorimeter was calibrated using a standard white plate. Samples were placed in the sample holder for measurement. Colour values were recorded as L*(lightness), a* (redness), b* (yellowness) colour system as described by Akissoe *et al.*, (2003).

3.6 Determination of Mineral Composition

Five hundred milligram (500) of the sample was weighed in a digesting flask and 10 ml of each of HCL and HNO3 was added. the mixture was digested for 10 min on a Bunsen burner and allowed to cool. The mixture was then filtered using filter paper and the filtrate was made up to 100ml with distilled water and injected into the atomic absorption spectroscopy (Perkin Elmer, model 402) for quantification of the mineral elements except for potassium and sodium which were determined using flame photometer as described by Famuwagun and Gbadamosi (2021).

3.7 Thermal Properties

3.7.1 Determination of thermal conductivity

Determination of thermal conductivity using a predictive model has been used to estimate the effective thermal conductivity of foods. Thermal conductivity can be determined by Sweat 1986 (cited by Singh and Heldman, 2003), reported empirical equation for thermal conductivity as:

$$K = 0.25Mc + 0.155Mp + 0.16Mf + 0.135Ma + 0.58Mm \quad (W/m\,oC)$$

where M is the mass fraction of food components and c, p, f, a, and m are carbohydrate, protein, fat, ash, and moisture, respectively.

3.7.2 Determination of specific heat

Determination of specific heat using a predictive model has been used to estimate the effective specific heat of foods. specific heat can be determined by Sweat 1986 (cited by Singh and Heldman, 2003), who reported an empirical equation for specific heat as:

Specific heat can be expressed as:

$$Cp = 1.424Mc + 1.549Mp + 1.675Mf + 0.837Ma + 4.187Mm\,((KJ/kg\,oC))$$

where M is the mass fraction of food components and c, p, f, a, and m are carbohydrate, protein, fat, ash, and moisture, respectively.

3.7.3 Determination of energy value

The energy value of the samples was determined by multiplying the protein content by 4, carbohydrate content by 4, and fat content by 9.

$$Energy\ Value = (Crude\ protein \times 4) + (Total\ carbohydrate \times 4) + (Crude\ fat \times 9)$$

3.8 Sensory Evaluation of Dough Meal Prepared from OFSP Flour

Panelists who are familiar with dough meal were used for the organoleptic evaluation of the dough meal made from the OFSP flour dried at different temperature using a 9-point hedonic scale. 9 indicating like very much and 1 indicating dislike very much. The dough meal was assessed for aroma, appearance, texture, mouthful, aftertaste, taste, and overall acceptability.

3.9 Determination of kinetic carotenoid degradation parameters

In order to determine the carotenoid degradation of food materials as a function of time, several kinetic models can be used. Generally, the rate of change of a quality factor C can be represented by the below equation for zero-order.

$$C = \mathrm{Co} - \mathrm{kt}$$

Where (k) is the kinetic rate constant, C0 is the concentration at time zero and (C) is the concentration of a quality factor at time t. For the majority of foods, the time dependence relationships appear to be described by zero-order or first-order kinetic models.

MS-Excel 2013 (Microsoft, Inc., USA) was used to analyze the carotenoid degradation data. The constant decay rate was given by the slope of the line after adjusting the integrated, linearized models.

Half Life: Half -life which is the times needed for 50% degradation of carotenoids was calculated by the equations below:

$$\text{Half} - \text{life} = -\frac{\ln 2}{k}$$

D-values: The decimal reduction time, which is the time required to reduce the carotenoid content by 90%. It is calculated by using the Equation below

$$D_{value} = -\frac{\ln 10}{k}$$

3.10 Statistical Analysis

The experimental design employed in this study was a Completely Randomized Block Design. Data were reported as averages of triplicate determinations and analyzed using Analysis of Variance (ANOVA). Duncan's multiple range test at a 5% level of significance was applied to determine significant differences among samples. The statistical package used was IBM SPSS Statistics version 20 (IBM Corp, Armonk NY).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Proximate Composition of The OFSP Flour

4.1.1 Moisture Content

The result obtained from the proximate analyses of the OFSP flour dried at different temperatures as illustrated in Table 4.1 shows that there was no significant difference ($p< 0.05$) between the OFSP sun-dried and the OFSP dried at 45 ^{o}C and 65 ^{o}C. The moisture content of the OFSP flour dried at different temperatures ranges from 7.91 to 10.92% (Table 4.1). The range of moisture content of this study is similar to that reported by Nwankwo *et al.* (2013), who reported that OFSP flour ranges from 9.00 to 10.48%. The OFSP flour dried at 90 ^{o}C had the lowest moisture content. Studies have shown that low moisture of food products increases the nutrient composition and shelf life of the food product (Amankwah et al., 2009; Olaoye *et al*., 2006). Bolarinwa and Raji (2017) reported that the lower the moisture content the longer the shelf life of food products. Also, the low moisture content of food products inhibits the biochemical activities of invading microorganisms and thereby prevents food spoilage during storage (Kikafunda, 2006).

4.1.2 Ash content

The values of the ash content of the OFSP flour dried at different temperatures ranges from 1.67 to 3.67% (Table 4.1). Significant difference ($p<0.05$) existed between the ash values of the OFSP flour dried at different temperatures. The OFSP dried at 65 ^{o}C had the highest ash content (3.67%), OFSP which was sun-dried and the OFSP dried at 45 ^{o}C were not significantly different ($p< 0.05$) from each other.

Table 4.1 Proximate Composition of The OFSP Flour Dried at Different Temperatures

	Moisture (%)	**Ash (%)**	**Protein (%)**	**Fibre (%)**	**Fat (%)**	**CHO (%)**	**DMC (%)**
45 ºC	10.92±0.56^{a}	1.67±0.58^{b}	4.32±0.24^{c}	0.34±0.01^{c}	1.00±0.00^{a}	81.75±1.89^{a}	88.81±0.14^{b}
65 ºC	10.52±0.21^{a}	3.67±0.58^{a}	3.36±0.18^{a}	0.30±0.01^{d}	1.00±0.00^{a}	81.15±1.87^{a}	89.22±0.38^{b}
90 ºC	7.91±0.17^{b}	2.67±1.53^{ab}	3.61±0.20b^{b}	0.69±0.01^{a}	0.75±0.25^{a}	84.12±1.94^{a}	92.09±0.17^{a}
SUN	10.90±0.03^{a}	1.67±0.58^{b}	4.39±0.24^{a}	0.48±0.03^{b}	1.25±0.75^{a}	81.29±1.88^{a}	89.02±0.12^{b}

Values are the means of the attributes and standard deviation. Mean values having different superscripts within the same column are significantly different ($p < 0.05$).

The ash is a non-organic compound containing mineral content of food and nutritionally aids in the metabolism of other compounds (Ayo *et al.,* 2014). The ash content represents the total mineral content in food and serves as an available tool for nutrition evaluation Gallagher (2009). Since ash content indicates the presence of minerals, the OFSP flour containing high ash content could be a source of minerals for the biochemical activities of the body.

4.1.3 Protein Content

The protein contents of the OFSP flours dried at different temperatures were significantly different ($p< 0.05$). The protein content ranged from 3.36 to 4.39% (Table 4.1). The protein of orange-fleshed sweet potatoes is good for the human body as they serve as building blocks (Mohapatra., *et al* 2018). The OFSP dried at 65 ^{o}C had the lowest protein content of 3.36% and the OFSP sun-dried had the highest protein content of 4.39%.

4.1.4 Fat content

There was significantly difference ($p< 0.05$) in the fat contents between the OFSP dried at different temperatures. The fat con tent ranges from 0.75 to 1.25% (Table 4.1). The OFSP sun-dried had the highest fat content of 1.25%.

4.1.5 Crude fibre content

The crude fibre content of the OFSP dried at different temperatures is significantly different from each other, which ranged from 0.30 to 0.69% (Table 4.1). The OFSP dried at 65 ^{o}C had the lowest fibre of 0.30%, and the OFSP dried at 90 ^{o}C had the highest fibre of 0.69%. The dietary fibre content in a food product has been reported to promote beneficial physiological effects on health by improving satiety, and bowel function, and helping to overcome constipation (Slavin, *et*

al.,2013). However, crude fibre has recently received much importance, as it is believed to reduce the incidences of colon cancer, diabetes, heart disease, and certain digestive diseases (Alam *et al*., 2016).

4.1.6 Carbohydrate content

They're existed significant difference ($p< 0.05$) in the carbohydrate contents between the OFSP dried at different temperatures. The carbohydrate content ranged from 81.15 to 84.12% (Table 4.1). The OFSP dried at 90^{o}C had the highest carbohydrate content of 84.12%.

4.1.7 Dry matter content

The dry matter content of the OFSP dried at different temperatures is significantly different ($p< 0.05$) from each other ranging from 88.81 to 92.09% (Table 4.1). except the OFSP which was sun-dried and the OFSP dried at 45 ^{o}C and 65 ^{o}C were not significantly different ($p< 0.05$) from each other.

4.2 Chemical Properties of OFSP Flours Dried at Different Temperatures

4.2.1 Carotene content

The carotene content of the OFSP flour dried at different temperatures was significantly different ($p< 0.05$) from each other, ranging from 2.92 to 9.18 µg/100g, the OFSP flour sun dried had the lowest carotene of 2.92µg/100g, and the OFSP flour dried at 65°C had the highest carotene of 9.18 µg/100g has shown in Table 4.2. Temperature has a significant effect on the carotene content. The OFSP dried at 45°C had a low carotene because not just the temperature but also the time duration has an effect on the carotene retention.

Table 4.2 Chemical Properties of the OFSP Flours

Samples	Carotene(µg/100g)	SUGAR (mg/100g)	pH	TTA
45 ºC	4.32±0.05[c]	7.89±0.10[a]	5.96±0.02[a]	0.77±0.15[b]
65 ºC	9.18±0.01[a]	4.28±0.10[b]	5.45±0.02[c]	1.00±0.10[a]
90 ºC	6.43±0.05[b]	2.88±0.50[c]	4.89±0.03[d]	1.05±0.05[a]
SUN	2.92±0.07[d]	7.48±0.10[a]	5.88±0.01[b]	0.67±0.06[b]

Values are the means of the attributes and standard deviation. Mean values having different superscripts within the same column are significantly different ($p < 0.05$).

4.2.2 Sugar content

The sugar content of the OFSP flour dried at different temperatures ranged from 2.88 to 7.89 mg/100g, the sugar content of the OFSP flour dried at different temperatures were significantly different ($p< 0.05$) from each other, except for the OFSP which was sun-dried and dried at 45°C which were not significantly different ($p< 0.05$) from each other, the OFSP dried at 45°C had the highest sugar content of 7.89 mg/100g present as shown in Table 4.2.

4.2.3 pH

The pH of the OFSP flour dried at different temperatures was significantly different ($p< 0.05$) from each other, ranging from 4.89 to 5.96, the OFSP dried at 90°C had the lowest pH of 4.89, and the OFSP dried at 45°C had the highest pH of 5.96 has shown in Table 4.2. The high pH might have an implication on the keeping quality of the OFSP flour dried at different temperatures.

4.2.4 Total titratable acidity (TTA)

The values obtained for the total titratable acidity (TTA) are shown in Table 4.2 There were significant differences ($p < 0.05$) in the OFSP flour dried at different temperatures, ranging from 0.67 to 1.05%, except for the OFSP flour dried at 65°C and 90°C which were not significantly different ($p< 0.05$) from each other, the OFSP which was sun-dried and dried at 45°C were not significantly different ($p< 0.05$) from each other, the OFSP sun-dried had the lowest TTA of 0.67% and the OFSP dried at 90 had the highest TTA of 1.05% has shown in Table 4.2. The titratable acidity measures the organic acid content of the OFSP flour dried at different temperature. Table 4.2 shows that the OFSP flour dried at different temperature has a low acid content.

4.3 Functional Properties of The OFSP Flour Dried at Different Temperatures

The functional properties of food substances which depend on the quality attributes of their macromolecules such as protein, starch, carbohydrate, sugars, fibre, and fat, influence their utilization and industrial applications (Fetuga *et al.,* 2014). Table 4.3 shows the result for functional properties of the OFSP flour dried at different temperatures.

4.3.1 Packed and Loose bulk densities

There was a significant difference in the bulk densities of the OFSP flour dried at different temperatures. Densities ranged from 0.54 to 0.69 g/ml, and loose bulk densities ranged from 0.44-0.55 g/ml (Table 4.3). Sun dried flour had the highest packed bulk density of 0.69 g/ml and loose bulk density of 55 g/ml and 65°C had the lowest packed bulk density of 0.54 g/ml and the lowest loose Bulk density of 0.44 g/ml. The variation in the bulk density of the samples could be attributed to the differences in the individual particle mass, property, size, geometry, and density (Davé., *et al.* 2012). Bulk density is an important parameter to be considered in raw materials handling and in choosing and design of packaging materials (Oyeyinka *et al.,* 2014).

Table 4.3 Functional properties of the OFSP Flours

Samples	Packed Bulk density(g/ml)	Loose Bulk Density(g/ml)	Swelling index	Dispersibility (%)	WAI
45 ºC	0.58±0.01[b]	0.45±0.01[c]	2.53±0.00[a]	54.44±0.00[c]	3.55±0.15[b]
65 ºC	0.54±0.02[c]	0.44±0.01[c]	1.48±0.11[b]	63.03±1.29[b]	4.20±0.78[ab]
90 ºC	0.61±0.02[b]	0.49±0.01[b]	1.53±0.00[b]	66.36±0.00[a]	4.78±0.28[a]
SUN	0.69±0.02[a]	0.55±0.04[a]	2.39±0.12[a]	55.34±0.78[c]	5.05±0.81[a]

Values are the means of the attributes and standard deviation. Mean values having different superscripts within the same column are significantly different ($p < 0.05$).

4.3.2 Swelling index

The swelling index is an indication of the absorption index of the granules during heating (Coffman., et al 2007). There was significant difference ($p< 0.05$) in the swelling index of the OFSP flour dried at different temperatures which ranged from 1.48 to 2.53 (Table 4.3). Values obtained for OFSP samples dried at 65°C and 90°C were not significantly different ($p> 0.05$) from each other. Samples dried at 45°C and sun-dried samples were not significantly different ($p> 0.05$) from each other. The sample dried at 45°C had the highest swelling index.

4.3.3 Dispersibility

There was a significant difference at ($p< 0.05$) in the dispersibility of the OFSP flour dried at different temperatures which ranged from 54.44 to 66.36% (Table 4.3). Dispersibility is a measure of how individual molecules of a food sample, usually flour, are able to disperse and homogenize with the medium of dispersion, increased across the storage period (Babarinsa *et al.*, 2021).

4.3.4 Water absorption index (WAI)

The water absorption index capacity determines the amount of water the flour will absorb during mixing. Water absorption capacity could be influenced by the hydrophilic food constituents (Oyeyinka *et al.*, 2014). There was no significant difference at ($p< 0.05$) in the water absorption of the OFSP flour dried at different temperatures which ranged from 3.55 to 5.05. The OFSP sample dried at 45°C had the lowest WAI of 3.55 while the OFSP which was sun dried had the highest WAI of 5.05. There was no significant difference ($p> 0.05$) between the OFSP sample dried at 45°C and 65°C. OFSP samples dried at 90°C and sun-dried were not significantly different ($p>0.05$) from each other as shown in Table 4.3.

4.4 Pasting Properties of the OFSP Flours

Pasting property is important in determining the quality and aesthetic attributes of the food industry The digestibility, texture, appearance, and utilization of starch-based food materials are influenced to a large extent by their pasting properties (Ajibo *et al.*, 2018). It is an index for predicting the ability of a food to form a gel when exposed to heat application. The pasting properties of the flour samples are shown in Table 4.4. The results showed that the pasting temperature and the peak time of the flours ranged from 78.28 to 89.15 °C and 7.00 minutes for the OFSP flour dried at different temperatures respectively. Pasting temperature is the temperature at which there is a noticeable increase in viscosity due to the swelling of starch granules and it indicates the minimum cooking temperature (Ekunseitan *et al.*, 2017). The lower pasting temperatures obtained for the flour are, therefore an indication of lower energy cost, high components stability, lower gelatinization tendency, and high swelling properties of the starch granules. Peak time is the time required for cooking to be achieved. There is a significant difference in the pasting properties of the OFSP flour dried at different temperatures respectively. The sun drying has the lowest pasting temperature which indicates that the energy consumed is lower than 45°C, 65°C, and 90°C respectively, and has a lower gelatinization tendency. It takes 7 minutes for all the OFSP flour dried at a different temperature to be cooked. Peak, trough, and final viscosities of the flours ranged from 45.83-127.25 RVU, 41.79-117.17 RVU, and 87.25-227.75 RVU, for the OFSP flour dried at different temperatures respectively. Peak viscosity measures the ability of starch-based foods to swell freely soon after heating before their physical breakdown (Sanni *et al.*, 2008). It is also associated with starch, its components, and the degree of starch damage. Ekunseitan *et al.* (2017) reported that trough viscosity is the minimum viscosity value in the constant temperature phase of RVA and it indicated the ability of paste to withstand breakdown during cooling.

Table 4.4 Pasting Properties of The OFSP Flour Dried at Different Temperatures

Samples	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (Min)	Pasting Temp (°C)
45 °C	45.83±0.50^{d}	41.79±0.46^{d}	4.04±0.04^{d}	87.25±0.08^{c}	45.46±0.54^{d}	7.00±0.00	89.15±0.10^{a}
65 °C	127.25±1.25^{a}	117.17±0.58^{a}	10.08±1.83^{c}	212.54±6.29^{b}	95.38±6.88^{c}	7.00±0.00	86.88±0.03^{c}
90 °C	100.96±0.38^{c}	82.25±0.33^{c}	18.71±0.04^{a}	227.75±0.17^{a}	145.50±0.17^{a}	7.00±0.00	87.63±0.08^{b}
SUN	119.46±0.79^{b}	103.83±0.83^{b}	15.63±0.04^{b}	212.75±0.50^{b}	108.92±1.33^{b}	7.00±0.00	78.28±0.38^{d}

Values are the means of the attributes and standard deviation. Mean values having different superscripts within the same column are significantly different ($p < 0.05$).

Final viscosity measures the ability of starch to form paste after cooling (Shimelis et al., 2006). These indicated that the higher peak, trough and final viscosities of the OFSP flour dried at 65 °C could be due to its higher starch content than the other OFSP flour dried at 45 °C, 90°C, and sun drying, and a high degree of starch damage which enabled the starch granules to swell rapidly during heating. However, higher trough and final viscosities implied that 65 °C OFSP flour paste could not withstand breakdown during cooling and that the paste was less stable after cooling respectively. The breakdown viscosity of the OFSP flour dried at different temperatures ranged from 4.04 to 18.71 RVU, respectively as shown in table 4.4. Adebowale *et al.* (2005) stated that the higher the breakdown viscosity, the lower the ability of the sample to withstand heating and shear stress during cooking. Hence, OFSP flour dried at different temperature were susceptible to heating and shear stress during cooking. The values obtained for setback viscosity of the OFSP flour dried at different temperatures ranged from 45.46 to 108.92 RVU, they were significantly different from one another.

4.5 Color of the OFSP Flours

4.5.1 CIELAB coordinates (L*, a*, b*)

The results obtained for the CIELAB coordinates (L*, a*, b*) of the OFSP flour dried at different temperatures are presented in Table 4.5. The parameter L* indicated the sample lightness while a* and b* values obtained indicated redness and yellowness respectively (Granato and Masson, 2010). L* value of the OFSP flour dried at different temperatures are significantly different ($p<0.05$) from each other ranging from 55.09 to 67.26, the OFSP dried at 90°C has the lowest L* value of 55.09, and the OFSP which was sun dried had the highest L* value of 67.26.

Table 4.5 Color of the OFSP flour dried at different temperatures

Sample	L*	A*	B*	Color Difference	Yellowness Index
45 ºC	66.75±0.04[b]	8.45±0.05[c]	25.40±0.03[b]	71.92±0.04[a]	54.37±0.02[b]
65 ºC	60.11±0.03[c]	13.69±0.08[a]	28.53±0.02[a]	67.93±0.02[c]	67.81±0.03[a]
90 ºC	55.09±0.03[d]	9.66±0.01[b]	20.20±0.03[d]	59.47±0.02[d]	52.39±0.09[c]
SUN	67.26±0.03[a]	7.53±0.02[d]	23.45±0.03[c]	71.63±0.02[b]	49.80±0.07[d]

Values are the means of the attributes and standard deviation. Mean values having different superscripts within the same column are significantly different ($p < 0.05$).

The high redness (a*) and yellowness (b*) values obtained in OFSP flour dried at different temperatures attributed to the presence of carotenoid pigments, especially β-carotene. a* value of the OFSP flour dried at different temperatures are significantly different ($p<0.05$) from each other ranging from 7.53 to 13.69, the OFSP dried at 65°C has the highest a* value of 13.69, as shown in Table 4.5. b* value of the OFSP flour dried at different temperatures are significantly different ($p<0.05$) from each other ranging from 20.20 to 28.53, the OFSP dried at 65°C has the highest b* value of 28.53, as shown in Table 4.5. it has been shown that higher L* and lower a* values are desirable in dried food products such as flour (Doymaz *et al.*, 2006).

4.5.2 Color difference (ΔE)

The color difference of the OFSP flour dried at different temperatures were significantly different ($p<0.05$) from each other ranging from 59.47 to 71.92, As shown in Table 4.5 its seen that as the drying temperature increases there is a decrease in the color difference showing that the color of the OFSP became darker. This highlights the impact of high temperature processing conditions on the colour and quality of the flour samples

4.5.3 Yellowness index

The yellowness index of the OFSP flour dried at different temperatures are significantly different ($p<0.05$) from each other ranging from 49.80 to 67.81, the OFSP dried at 65 ^{o}C had the highest yellowness index of 67.81 as shown in Table 4.5 implying carotene retention in 65 ^{o}C was higher the yellowness index was directly proportional to the carotene content in the samples.

4.6 Mineral Composition of the OFSP Flours

Minerals are the inorganic components, having a very specific and important role in metabolism (Soetan, Olaiya, & Oyewole, 2010). Consumption of optimum concentration of minerals is recommended (Soetan *et al.,* 2010).

4.6.1 Calcium content

The mineral compositions of the OFSP flour dried at different temperatures are shown in Table 4.6. The Calcium content of the OFSP flour dried at different temperatures was significantly different from each other, ranging from 0.333 to 0.504%, The OFSP dried at 45°C has the lowest calcium, and the OFSP sun-dried has the highest calcium present as shown in Table 4.6. Calcium plays a major role in muscle function, formation, and strengthening of bones, and teeth, conducting nerve impulses, blood clotting, and maintaining a normal heartbeat (Zemel, 2009). Humans between the ages of 18 to 50 require 1,000 mg of calcium per day as recommended daily allowance (RDA). Individuals younger than 18 years need a superior concentration (1,300 mg) of Ca for developing bones and teeth (Wosje & Specker, 2000).

4.6.2 Magnesium content

Magnesium is one of the six important key macro minerals and essential minerals in >300 metabolic functions and possesses a role in strong bones, appropriate muscle tasks, optimal blood pressure, and appropriate cardiac tempo (Saris, Mervaala, Karppanen, Khawaja, & Lewenstam, 2000). The magnesium content of the OFSP flour dried at different temperatures were significantly different from each other, ranging from 0.029 to 0.158%.

Table 4.6 Mineral Composition of The OFSP Flour Dried at Different Temperatures

Sample	Ca%	Mg%	K%	P%	Na mg/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg
45 ºC	0.333±0.003^{d}	0.081±0.001^{c}	0.563±0.002^{a}	0.074±0.002^{b}	0.400±0.001^{a}	0.026±0.000^{c}	0.288±0.052^{b}	0.010±0.001^{a}	0.053±0.003^{ab}
65 ºC	0.400±0.000^{c}	0.029±0.002^{d}	0.343±0.001^{b}	0.072±0.000^{c}	0.399±0.002^{a}	0.037±0.000^{b}	0.368±0.001^{a}	0.006±0.001^{c}	0.050±0.000^{b}
90 ºC	0.471±0.002^{b}	0.158±0.003^{a}	0.302±0.002^{c}	0.086±0.000^{a}	0.302±0.002^{c}	0.036±0.001^{b}	0.295±0.002^{b}	0.008±0.000^{b}	0.057±0.004^{a}
SUN	0.504±0.003^{a}	0.132±0.002^{b}	0.291±0.001^{d}	0.062±0.000^{d}	0.321±0.001^{b}	0.046±0.001^{a}	0.349±0.001^{a}	0.008±0.001^{b}	0.053±0.003kk^{ab}

Values are the means of the attributes and standard deviation. Mean values having different superscripts within the same column are significantly different ($p < 0.05$).

The OFSP dried at 65°C had the lowest magnesium of 0.029%, OFSP dried at 90°C had the highest magnesium of 0.158% present as shown in Table 4.6. Sales and Pedrosa (2006) reported that DNA synthesis and stability depend on magnesium. The RDA of Mg to men and women is 420 and 320 mg, respectively,

4.6.3 Potassium content

The Potassium content of the OFSP flour dried at different temperatures were significantly different from each other, ranging from 0.291 to 0.563%, The OFSP which was sun dried had the lowest potassium of 0.291%, while OFSP dried at 45°C had the highest potassium of 0.563% present as shown in Table 4.6. Potassium is a vital mineral and electrolyte for the body. The adequate intake (AI) for potassium is 4,700mg in healthy individuals. Sweet potatoes therefore can be an alternative food to support its intake (Endrias *et al*., 2016), Potassium in the range of 138–334 mg/100 g was reported in OFSP (Nicanuru *et al*., 2015).

4.6.4 Phosphorus content

The Phosphorus content of the OFSP flour dried at different temperatures were significantly different from each other, ranging from 0.062 to 0.086%, The OFSP which was sun dried had the lowest Phosphorus of 0.062%, OFSP dried at 90°C had the highest Phosphorus of 0.086% present as shown in Table 4.6. Phosphorus is a necessary mineral in human body after calcium and possesses a pivotal role in abundant metabolic process, including energy metabolism and bone mineralization, and DNA and RNA framework (Allardt et al., 2007). The RDA of 700 mg phosphorus is for healthy adults, and phosphorous of 15–51 mg/100 g was reported in OFSP (Endrias et al., 2016).

4.6.5 Sodium content

The sodium content of the OFSP flour dried at different temperatures were significantly different from each other, ranging from 0.302 to 0.400 mg/kg, except for the OFSP dried at 45°C and 65°C were not significantly different ($p< 0.05$) from each other, the OFSP dried at 90°C had the lowest sodium of 0.302 mg/kg, OFSP dried at 45°C had the highest sodium of 0.400 mg/kg present as shown in Table 4.6. OFSP was reported to contain sodium within the range of 23 to 59 mg/100 mg (Endrias *et al*., 2016).

4.6.6 Manganese content

The manganese contents of the OFSP flour dried at different temperatures were significantly different from each other, ranging from 0.026 to 0.046 mg/kg, except for the OFSP dried at 65°C and 90°C which were not significantly different ($p< 0.05$) from each other, the OFSP dried at 45°C had the lowest manganese of 0.026 mg/kg, OFSP which was sun dried had the highest manganese of 0.046 mg/kg present as shown in Table 4.6.

4.6.7 Iron content

OFSP dried at 45°C and 90°C which were not significantly different ($p< 0.05$) from each other, OFSP which was sun-dried and dried at 65°C which were not significantly different ($p< 0.05$) from each other, the OFSP dried at 45°C had the lowest iron of 0.288 mg/kg, OFSP dried at 65°C had the highest iron of 0.368 mg/kg present as shown in Table 4.6. The RDA of iron is 1.8 mg in adults, and merely 10%–30% of the Fe in the diet is bioavailable (Endrias *et al*., 2016). OFSP was reported to be 0.63 to 15.26 mg/100 g of iron, (USDA, 2018). So, OFSP is a good source for providing the RDA of iron.

4.6.8 Copper content

The copper contents of the OFSP flour dried at different temperatures were significantly different from each other, ranging from 0.006 to 0.010 mg/kg, except for the OFSP which was sun-dried and dried at 90°C which were not significantly different ($p< 0.05$) from each other, the OFSP dried at 65°C had the lowest copper of 0.006 mg/kg, OFSP which dried at 45°C had the highest manganese of 0.010 mg/kg present as shown in Table 4.6.

4.6.9 Zinc content

The zinc contents of the OFSP flour dried at different temperatures were significantly different from each other, ranging from 0.050 to 0.057 mg/kg, as shown in Table 4.6. Zn plays an important role in the body where deficiency symptoms are shown in many ways (Powell, 2000). Antinutritional factors are prime known inhibitors of zinc, which is abundantly present in cereals and grains (Janet, 2003). OFSP was reported to be 0.24–0.93 mg/100 g of zinc (Endrias *et al.*, 2016).

4.7 Thermal Properties of The OFSP Flours

4.7.1 Thermal conductivity

Thermal conductivity is the ability of a food material to conduct heat Thermal conductivity of foods depends on temperature, composition, and porosity of material. The thermal conductivity of the OFSP flour dried at different temperatures were not significantly different ($p< 0.05$) from each other, ranging from 21.31 to 22.70W/m^{o}C. has shown in Table 4.7.

Table 4.7 Thermal Properties of The OFSP Flour Dried at Different Temperatures

Samples	Thermal Conductivity (W/m ºC)	Specific Heat (KJ/kg ºC)	Energy (kj/g)
45 ºC	22.35±1.01[a]	178.54±0.39[a]	352.35±2.07[b]
65 ºC	22.70±0.35[a]	177.41±1.08[a]	353.47±0.69[b]
90 ºC	21.31±0.91[a]	169.88±0.70[b]	361.41±1.96[a]
SUN	22.32±0.77[a]	178.65±0.87[a]	352.68±3.50[b]

Values are the means of the attributes and standard deviation. Mean values having different superscripts within the same column are significantly different ($p < 0.05$).

4.7.2 Specific heat

The specific heat of the OFSP flour dried at different temperatures were significantly different ($p< 0.05$), except the OFSP dried at 45°C, 65°C and the OFSP which was sun dried, were not significantly different ($p> 0.05$) from each other, the OFSP dried at 90 ^{o}C had lowest specific heat of 169.88 KJ/kg ^{o}C, has shown in Table 4.7.

4.7.3 Energy

The energy of the OFSP flour dried at different temperatures were significantly different ($p< 0.05$), except for the OFSP dried at 45°C, 65°C, and the OFSP which was sun-dried, were not significantly different ($p< 0.05$) from each other, the OFSP dried at 90 ^{o}C had the highest energy of 361.41 kj/g, as shown in Table 4.7.

4.8 Sensory Evaluation of Dough Meal Prepared from OFSP Flour samples

Table 4.8 shows the result of the sensory analysis of dough meals prepared from the OFSP dried at different temperatures and a control sample. There was no significant difference ($p<0.05$) between the appearance of OFSP dried at different temperatures and the control sample, ranging from 5.20 to 6.55. the OFSP dried at 90 **º**C had the lowest appearance.

The texture of the OFSP dried at different temperatures and the control are significantly different ($p<0.05$) from each other ranging from 5.25 to 7.15. the OFSP dried at 90 **º**C had the lowest texture.

The mouldability of the OFSP dried at different temperatures and the control are significantly different ($p<0.05$) from each other ranging from 4.70 to 7.65. the OFSP dried at 65 **º**C had the lowest mouldability.

Table 4.8 Sensory Evaluation of Dough Meal Prepared from OFSP Flour Dried at Different Temperatures.

Sample	Appearance	Texture	Mouldability	Taste	Aroma	Aftertaste	Overall Acceptability
45 °C	6.00 ± 1.75^{ab}	5.65 ± 1.60^{b}	5.75 ± 1.92^{b}	5.00 ± 2.41^{b}	4.55 ± 1.67^{a}	4.70 ± 1.87^{b}	5.30 ± 2.36^{b}
65 °C	5.90 ± 1.55^{ab}	5.55 ± 1.96^{b}	4.70 ± 1.95^{b}	5.00 ± 2.20^{ab}	4.80 ± 1.82^{a}	4.50 ± 1.85^{b}	5.00 ± 1.62^{b}
90 °C	5.20 ± 1.85^{b}	5.25 ± 1.86^{b}	5.20 ± 2.31^{b}	4.20 ± 1.91^{ab}	4.30 ± 1.84^{a}	4.05 ± 1.96^{b}	4.95 ± 1.90^{b}
Sun Drying	5.40 ± 2.04^{ab}	5.80 ± 1.77^{b}	5.70 ± 1.89^{b}	4.20 ± 2.38^{b}	4.50 ± 1.85^{a}	4.15 ± 2.23^{b}	5.10 ± 1.83^{b}
Commercial Sample	6.55 ± 1.47^{a}	7.15 ± 1.14^{a}	7.65 ± 1.14^{a}	6.15 ± 1.73^{a}	5.15 ± 1.95^{a}	6.05 ± 1.19^{a}	6.65 ± 1.35^{a}

Values are the means of the attributes and standard deviation. Mean values having different superscripts within the same column are significantly different ($p < 0.05$).

The taste of the OFSP dried at different temperatures and a control sample, there was no significant difference ($p<0.05$) between the taste of OFSP dried at different temperatures and the control sample, ranging from 4.20 to 6.15.

The aroma of the OFSP dried at different temperatures and a control sample, there was no significant difference ($p<0.05$) between the aroma of OFSP dried at different temperatures and the control sample, ranging from 4.30 to 5.15.

The aftertaste of the OFSP dried at different temperatures and the control are significantly different ($p<0.05$) from each other ranging from 4.05 to 6.05. the OFSP dried at 90 ºC had the lowest aftertaste.

The overall acceptability of the OFSP dried at different temperatures and the control are significantly different ($p<0.05$) from each other ranging from 4.95 to 6.65.

4.9 Degradation Kinetics of Carotenoid

4.9.1 Carotene retention during Storage

The retention of carotene during storage was affected by light, the storage of the OFSP flour dried at 65°C using different packaging material is a pointer to the effect of light as a factor, affecting the retention of carotene during storage. After one month of storage, the HDDL of the OFSP flour dried at 65°C had the highest value (95.06%) of carotene compared to the samples stored in LDT which has the lowest retention of carotene (51.28%) as a result of high permissively of light., this shows the effect of light on the retention of carotene as described by Lewis *et al.*, 2016. As shown in fig 4.1

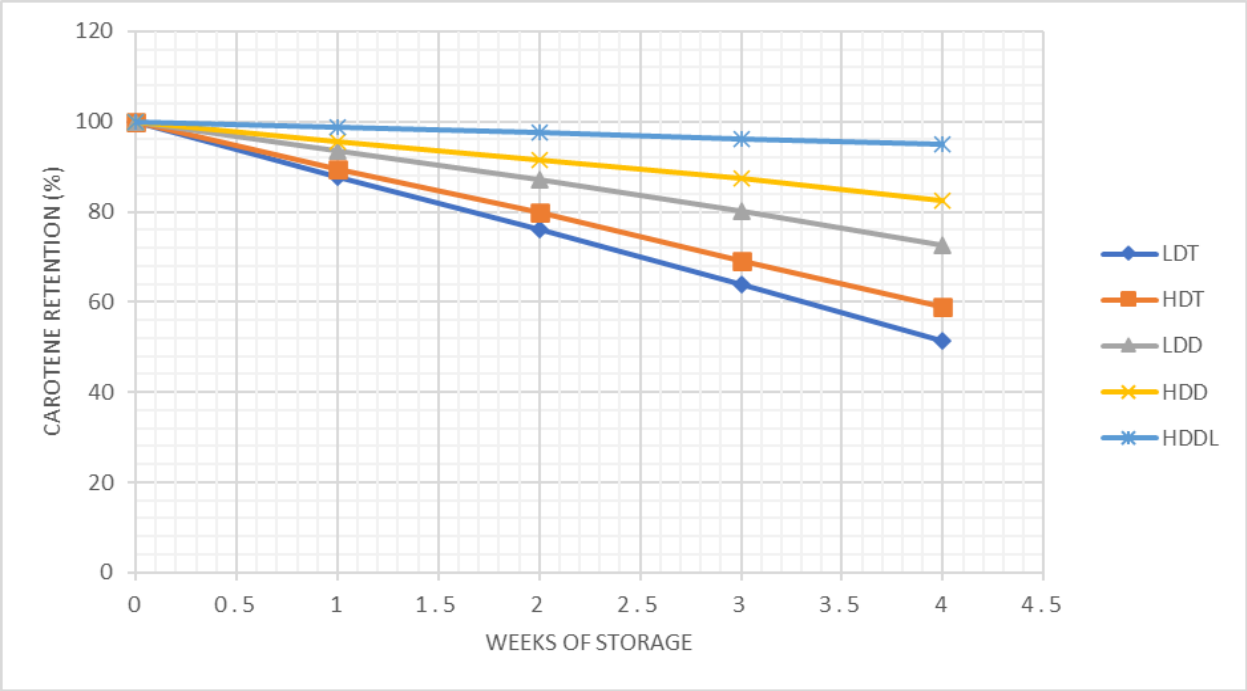


Figure 4.1: Carotene retention during storage

4.9.2 Degradation kinetics of carotene in stored OFSP dried at 65 ^{o}C

Table 4.9 shows the retention of carotene weekly, after the storage of one-month High Density Dark Laminated (HDDL) HDDL had the highest retention of carotene followed by High Density Dark (HDD), Low Density Transparent (LDD), HDT (High Density Transparent), and LDT (Low Density Transparent) HDD, LDD, HDT, and LDT respectively, this shows the impact of light on carotene retention. Table 4.9 shows the values for degradation constant k (weeks^{-1}), the half-life of carotene (weeks) and the D-values of the zero-order kinetic model. During the storage, The K (Weeks$^{-1)}$ was lowest in the HDDL packaging material followed by HDD, LDD, HDT, and LDT respectively, this means that the HDDL packaging material retained higher carotene more than the other packaging materials. The K value had direct influence on the half-life and D- value. The lower the K value the higher the half-life and D- value.

Table 4.9. Degradation kinetics of carotene in stored OFSP dried at 65 ^{o}C

	K (Weeks^{-1})	Half-Life (Weeks)	D-Value (Weeks)
LDT	0.1214	5.7	19.0
HDT	0.1024	6.8	22.5
LDD	0.0684	10.1	33.7
HDD	0.0436	15.9	52.8
HDDL	0.0125	55.4	183.9

LDT: Low Density Transparent

HDT: High Density Transparent

LDD: Low Density Dark

HDD: High Density Dark

HDDL: High Density Dark Laminated

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study showed that the temperature used in drying of the OFSP has a significant effect on the physical, chemical, sensory qualities and retention of carotene of the OFSP. OFSP flour dried at different temperatures was produced, and the dough was further produced from the OFSP dried at different temperatures. The OFSP flour produced at 65℃ had the highest carotene retention and good sensory acceptability. During the storage, HDDL packaging material retained the highest carotene followed by HDD, LDD, HDT, and LDT respectively, this shows the impact of light on carotene retention. During the storage, The K (Weeks-1) was lowest in the HDDL packaging material of the OFSP product, produced at 65℃, This means that the HDDL packaging material retained higher carotene than the other packaging materials. The K value had direct influence on the half-life and D- value. The lower the K value the higher the half-life and D- value.

5.2 Recommendation

The OFSP flour should be used in the production of food products such as bread, and cookies it will give better sensory acceptability on like dough because in this part of the country people are not used to dough that has a sweet taste. OFSP should be made available to the masses in order to reduce vitamin A deficiency (VAD). OFSP is indeed a true vehicle to achieve not only food security but also nutritional security.

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