

## ABSTRACT

EPHRAIM, PETER. Formulation and Nutritional Evaluation of Dehydrated Sweetpotato Products Fortified with Protein Ingredients. (Under the direction of Dr. Jonathan Allen).

Globally, the levels of malnutrition are very high, especially in Asia and Africa. The number of children with stunting has been increasing in Africa while it has been declining in all regions. Commercial malnutrition-preventing products such as Ready-to-Use Therapeutic Foods (RUTF), and corn soya blend (CSB) are distributed in the region to combat malnutrition, especially among the children, but are not adequate due to unreliable supply and stringent specifications on aflatoxin contamination. Sweetpotato flesh, sweetpotato leaves, and edible insects are rich in different macronutrients and micronutrients important for growth and development. Incorporating edible insect and sweetpotato leaf powders in dehydrated sweetpotato products for young children could help prevent malnutrition. The objectives of this study were to evaluate the nutritional composition of sweetpotato flesh, sweetpotato leaves, and edible insects and to formulate and evaluate the nutritional composition of dehydrated sweetpotato product fortified with edible insect and sweetpotato leaf powders. Four varieties of sweetpotato leaves (Bonita, Murasaki-29, Covington and Purple Majesty), two varieties of sweetpotato roots (Beauregard and Covington), and edible insect from fresh mealworms dried using air fryer, freeze-dryer, food dehydrator, and convection oven dryer. The proximate compositions was determined using the standard methods (AOAC 2012). Mineral contents were determined using Perkin Elmer Ion Coupled Plasma Emission and color was measured using ColorFlexEZ colorimeter. Results showed that the proximate composition differed significantly ( $p < 0.05$ ) among the four varieties of sweetpotato leaves. The drying methods did not significantly ( $p > 0.05$ ) affect the nutritional composition of the dehydrated samples except for ash and moisture contents. The second part of this study involved flour formulation and evaluation of nutritional composition. The flour was formulated by blending Covington sweetpotato flour, Covington sweetpotato leaf powder and mealworm powder in different proportions using WFP's nutritional composition requirements for corn soya blend (CSB) as a standard. Overall, the results obtained showed that the proximate composition, energy and mineral content of the formulated flour meets the World Food Program's requirements for CSB flour. The beta-carotene (pro-vitamin A) content was found to be in a considerable amount such that when converted to vitamin A can meet the vitamin A content requirement for CSB flour. The

formulated flour can be used as a cheaper alternative to commercial RUTF's in combating malnutrition especially, in developing countries where commercial products are not affordable and sweetpotato can be grown locally in place of certain non-food crops.

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Formulation and Nutritional Evaluation of Dehydrated Sweetpotato Products Fortified with  
Protein Ingredients

by  
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## **DEDICATION**

To my family and academic advisors who made my graduate study possible.

## **BIOGRAPHY**

My name is Peter Ephraim and I am originally from Malawi. I completed my undergraduate studies in Food Science and Technology at Lilongwe University of Agriculture and Natural Resources in Malawi in 2017.

My passion for understanding the science behind the food we eat combined with the rapidly changing trends in food science, motivated me to pursue a Master of Science in Food science degree. In 2020, I was accepted into the Food, Bioprocessing, and Nutrition Sciences (FBNS) department at North Carolina State University under the Agricultural Transformation Initiative (ATI) scholarship to pursue my Masters in Food science. Throughout my entire two years at NC State, I enjoyed attending classes and learning about different cultures in my spare time. I appreciate the high-quality instruction offered by NC State professors and I am inspired by the level of scientific research, innovations, and outreach from the FBNS department and the entire NC State University.

Not only my dedication and hard work, have contributed to my success during my journey as a graduate student, but also support from my advisor, Dr. Jonathan C. Allen, FBNS professors, and my fellow graduate students from the FBNS department was crucial to my success.

As I graduate, I feel excited to use my skills and knowledge NC State has equipped me with to contribute to the advancement of the field of food science in my country and the entire world

## **ACKNOWLEDGEMENTS**

Many thanks to the Agricultural Transformation Initiative (ATI) under the Foundation for the Smoke-free World for funding my two years of graduate studies.

A sincere thank you to my advisors Dr. Jonathan Allen, Dr. Tawanda Muzhingi, and Dr. Josip Simunovic for their support and guidance throughout my research journey.

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## **CHAPTER 1: LITERATURE REVIEW**

## **1.1. Sweetpotatoes**

Scientifically, sweetpotatoes are known as *Ipomoea batatas* and are a common staple food source for the population of North America. Sweet potato is a perennial plant but is most often cultivated as an annual agriculture product. The plant is grown around the year and has a thin stem reaching up to 4 m long, variable size of the leaves and roots growing into tubers, the edible part. The plant completely matures in four months producing flesh of the sweet potato and harvested later when the leaves are turned yellow (Ellong et al., 2014). The skin of tubers is smooth to rough, granular, and rigid presenting emission points of the roots (Mukhtar et al., 2010). This crop is natively associated with Central and South America with old Spanish roots distributing the seeds around the globe. The color varies from white, yellow, brown, dark purple, orange, red, cream, and light pink. Some of the varieties reflect a diffusion of secondary colors as well corresponding to the coloration of the skin. The leaves of the plant have variations from yellow to purple (Hatamipour et al., 2007). According to Ellong et al., (2014), some varieties of sweet potato react differently to cooking and processing methods depending upon the texture, firmness, rigidity, and concentration of starch, sugars, anthocyanin, and carotenes. Some of the varieties of sweet potatoes that are recognized internationally include Beauregard, Regal, Golden, Red Garnet, and Jewel. The nutritional properties, historical consumption patterns and easy cultivation measures make it a highly accessible and cultivated crop in North America.

### **1.1.1. History of Sweetpotato Crop**

The sweet potato crop belonging to genus *Ipomoea* and family Convolvulaceae consists of more than 500 species including 14 wild species (Campos et al., 2017). The history of the sweet potato crop also records its originality from the Northwestern South American region mainly between the Mexican Peninsula Yucatan and Orinoco River (Zhang et al., 2004). However, this crop has been cultivated in both southern and northern regions of America representing two prehistoric gene pools. It is also known as a lifesaver crop because of the historical record of cultivation for food security. For example, the Japanese used sweet potato crop in typhoons and China cultivated them in famines which prevented malnutrition and starvation in the region. Uganda cultivated sweet potato after viral demolition of the staple crops (Mu and Li, 2019).

Furthermore, the center of diversity in the gene pool of sweet potato crops is attributed to the existing Sub-Saharan Africa, Indonesia, and other areas of the Pacific (Loebenstein and Thottappilly, 2009). The early records identified that sweet potatoes were an indigenous edible crop of Central and South Americans, Hawaiians, and Caribbean people (Bovell-Benjamin, 2007). The dispersal of sweet potato crops around the world originated from northwest South America, emerging as a hybrid cross of the unknown plant of genus *Ipomoea* and spreading to Europe, China, Japan and Malaysia through Spain. The Southeast Asia, Africa and Indonesia incorporated it through Portuguese traders or travellers (O'Brien, 1972). The phylogenetic study of sweet potatoes analyzed the combined genome skimming and target DNA capture research sequencing the genetic information of wild crop relatives and strongly supported the close relationship of sweet potatoes with *Ipomoea trifida* (Muñoz-Rodríguez et al., 2018). The literature reported a high dry matter content and sensory properties of the sweet potato (SP) crop making it a nutritional agriculture product (Alam et al., 2016).

According to International Potato Center (CIP), there have been 6500 varieties of tubers reported by 2000 including 'wild' varieties. The selection of varieties to grow appears to be heavily influenced by how the produce, the roots, are used, whether as food directly or in processed forms, as feed components, or as sources of industrial starch. Preferences for food varieties appear to differ across and even within countries (Loebenstein and Thottappilly, 2009). However, the morphological characteristics of the varieties vary giving specific characteristics, cooking properties, and nutritional composition (Ellong et al., 2014). The nutritional content of the variable varieties is different depending upon the color, soil, and genotype (Slosar et al., 2019). The orange-fleshed sweet potato is highly studied because of the pleasant sensory attributes of color, high carotene content and human health benefits (Neela and Fanta, 2019; Slosar et al., 2019). In African sub-Saharan region, sweet potato is used as a food security crop because it contains a high amount of dry matter, especially white-fleshed types of sweet potatoes (Low et al., 2017).

Various varieties of sweet potato were used as a nutraceutical crop in 1995 to address the widespread deficiency of vitamin A. Later, the nutritional and therapeutic benefits of sweetpotato were recognized and used to develop food-based approaches to meet the needs of farmers and consumers in the 42 OFSP meeting (Low et al., 2017). In the US, the leading varieties of sweetpotato in terms of acreage are Beauregard and Covington occupying 60% and 30% of the

sweetpotato production area respectively (Loebenstein and Thottappilly, 2009). Covington variety, released in 2005 by North Carolina Agricultural Research Station is high yielding, with rose-colored skin and orange fleshed roots. Covington has green leaves that range in shape from heart-shaped to slightly lobed. Other varieties being grown are Jewel and Evangeline- with consistent root shape and darker orange root flesh (Loebenstein and Thottappilly, 2009). Bonita, Murasaki-29, and purple Majesty are newly developed sweetpotato varieties in the US. Bonita is the main cream-skinned, cream-fleshed cultivar which is sold largely in the Northeastern US where there is a long history of white-fleshed sweetpotatoes and mostly sold to Asian markets in the US. Murasaki-29 is the main purple-skinned, cream-fleshed cultivar, a moderately dry, sweet type and mostly sold to Asian markets in the US. Purple Majesty is a new purple-fleshed, purple-skinned release from the North Carolina horticultural crops research station's breeding program. Few purple-fleshed sweetpotato varieties are grown in the US currently (Kenneth Pecota, personal communication, September 30, 2022).

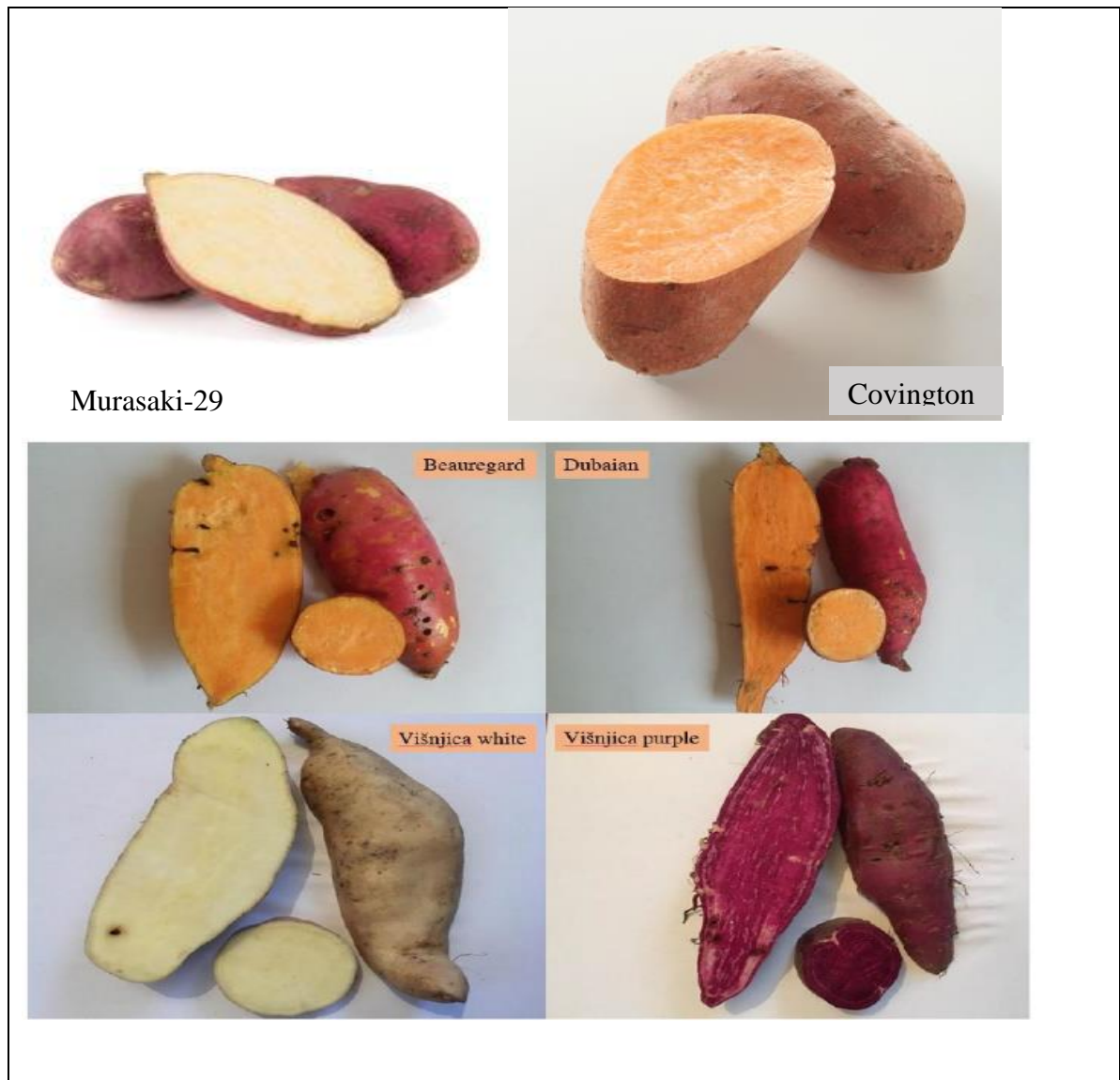


Figure 1.1. Selected Sweetpotato varieties

Source: (Loebenstein and Thottappilly, 2009)

### 1.1.2. Sweetpotato Cultivation

According to Kays (2018), the sweet potato plant has the ability to reproduce through multiple means including storage roots sprouting into new plants, and seed formation and dispersion. There are three major functional parts of the sweet potato plant i.e., tuber, storage roots (later modified into stem structures), and leaves. The major purpose of the cultivation of sweet potato crops is for production of desirably sized storage of roots and flesh. Low et al., (2017) reported that many

locally grown varieties of sweet potatoes in Africa lack vitamin A, so more cultivation of orange fleshed sweet potato can increase the regional nutritional availability of vitamin A to young children.

Sweet potato has been deemed as a sustainable crop because of economic crop production, multi-dimensional production benefits (health, economy, and gender equality) and global availability of the crop (Allemann et al., 2004). The current researchers have attributed the cultivation of sweet potatoes as a source of achieving sustainable development goals (SDGs) of ending poverty, zero hunger, and ensuring access to affordable, reliable sustainable, and modern energy. As reported by the study of Afzal et al., (2021) overlaps with the SDGs by providing means for sustainable income generation for the low farming market, reflects the potential of diversification into the market consumption, enhances food security by addressing malnutrition and hunger issues, increases resilience by reducing the food shortage, empowers local women and girls, enhances the biodiversity of the crop, and has potential use for biofuel production and reduced global disease impact.

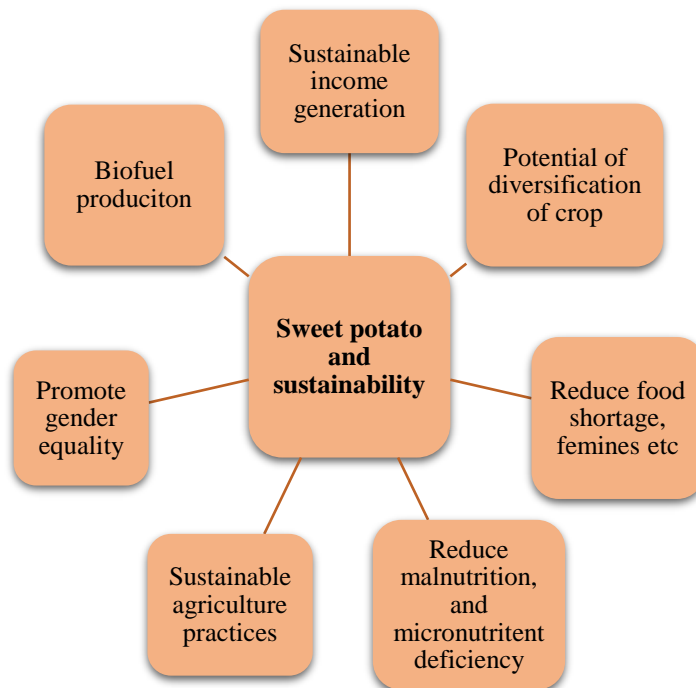


Figure 1.2. Sweet potato crop and its link with the sustainable developmental goals (SDGs).

SP production in 2017 was 112.8 million tons with the leading producers of China, Nigeria, Tanzania, Indonesia, and Uganda (FAOSTAT, 2019). However, in recent years the consumption and cultivation of SP have increased in Africa, Asia, and South America making SP the third vital food of the eastern African countries. Many countries grow SP as a domestic crop because of low input and high output, especially families led by women in Africa (Neela and Fanta, 2019). According to the statistical analysis of the Food and Agriculture Organization from 2007-2017 Asia was the global highest producer of the sweet potato crop followed by Africa producing 20.8% and the Americas at 3.3% (FAOSTAT, 2019). The production of SP crops has also increased since 2007 showing a gradual increase in Africa and Asia. The FAOSTAT data shows that global production of the sweet potato crop increased at a higher rate than the area cultivated which reflects SP as a sustainable crop.

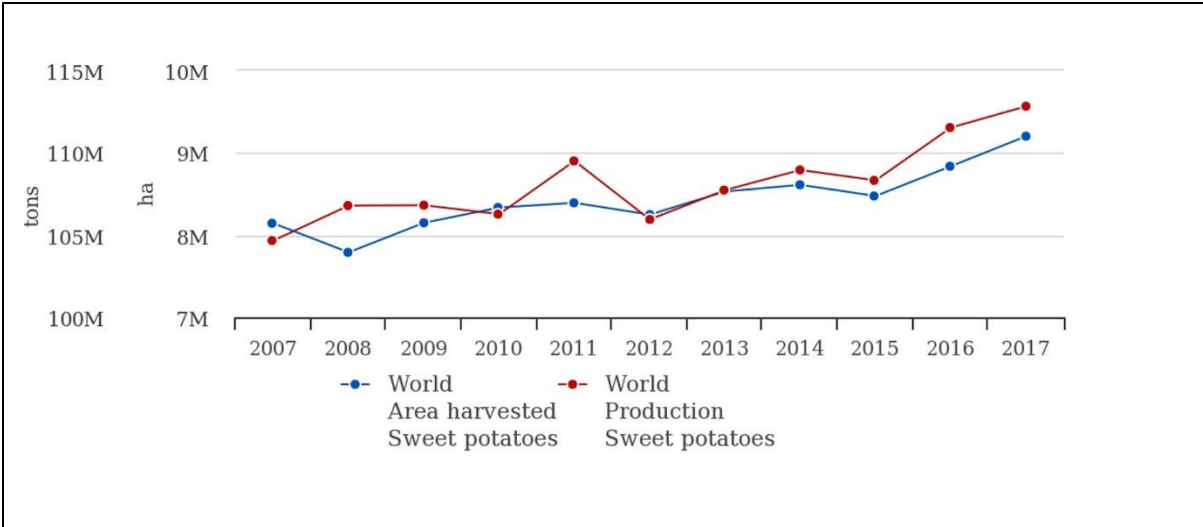


Figure 1.3. Geographical description of the global sweet potato production and area harvested trends (FAOSTAT, 2017).

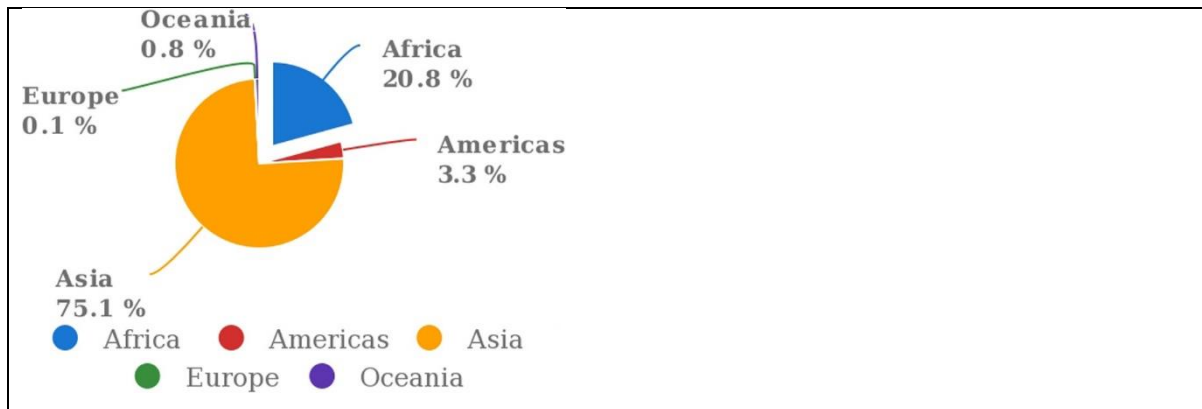


Figure 1.4. Sweetpotato production dataset from 2007-2017 (FAOSTAT, 2019).

According to the records of the Food and Agriculture Organization (FAO) the sweet potato crop is cultivated in more than 117 countries around the globe with 104 million tons of production in 2011 with Asia as the largest cultivator producing 80% of the annual global production of sweet potatoes (Campos et al., 2017). The state of North Carolina produced 1.8 billion pounds of sweet potatoes in 2021 which account for 85% of the total U.S. production (Statista, 2022). Sub-Saharan Africa also cultivated a large part of the global sweetpotato crop compared to China, Japan, and Korea. In many regions of the sub-continent of Africa sweet potato crop was introduced as a means of generating agricultural revenue, reducing food insecurity, and supporting the economy. The ‘Seed of Hope’ project promoted the supply and distribution of sweet potato crop seeds across the region, but mainly in Rwanda (Rose and Vasanthakalam, 2011).

Sweet potatoes cultivation has increased in the tropical and subtropical regions because of high rural and urban consumption patterns (Oduro, 2000). A large part of the African farming system is also supported by this crop production specifically in Rwanda. The farmer market of Rwanda has attributed the sweet potato crop as the most resourceful, low-input product.

### 1.1.3. Sweetpotato Utilization/Consumption

The increased awareness of the nutritional and functional properties of sweet potato flesh is attracting high consumption patterns across the globe. Sweet potato is consumed as a staple food in various indigenous forms, processed products, for medicinal purposes, and regional preferences. The developing countries consume the flesh of sweet potato as homestead food and feed purposes with high availability in the local markets. The vines and roots of this crop are used as feed in China, Vietnam, and Japan (Yamakawa and Yoshimoto, 2021). According to Rose and

Vasanthakaalam, (2011), sweet potato is a versatile crop in Rwanda with high consumption of about 130 kg/ person per year (Ferris et al., 2002). Uganda, one of the poorest countries in the world, implemented agricultural development as a means of uplifting the economy by producing a high number of sweet potatoes (Scott et al., 1997). The actual per capita consumption of sweet potato varies in the African regions from approximately 100 to 300kg (Srinivas, 2009). In Rwanda, the high consumption is attributed to the nutritional properties of the crop and consumption is in the form of boiled and fried edible products (Rose and Vasanthakaalam, 2011).

Furthermore, the consumption of sweet potato flesh has been promoted in literature because of the underlying therapeutic effect in various metabolic conditions. According to Dutta (2015) the high amount of fiber in the flesh reduced the glycemic index in animal and human-based trials. Still, further research is required for the identification of specific varieties and nutritional evaluation of sweet potato in diabetic patients.

Sweet potatoes are consumed in diverse forms in households and processing industries. The household uses are raw, pie fillings, sauce, boiled, snacks, chips, baking products, beverage etc. The processing industry uses sweetpotato for making multiple food products like sweet potato flour, beverages, chips, biscuits, cake bread, doughnuts, juice, jam, as well as cooked products like curries, chutney etc. (Allemann et al., 2004).

## **1.2. Nutritional Composition of Sweet potato**

Sweet potato has been analyzed for the nutritional components in leaves, stems, roots, and tubers (flesh) (Mwanri et al., 2011; Van Hal, 2000; Woolfe, 1992).

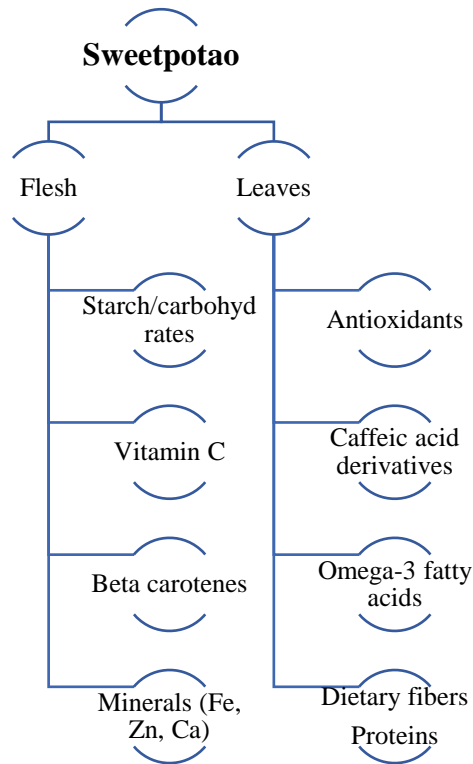


Figure 1.5. Nutritional components of the sweetpotato crop.

The quantitative and qualitative analysis of the various white, orange and purple varieties of sweet potato identified a difference in the nutritional components. According to Slosar et al., (2019), the orange variety contains the highest amount of carotenoid (78.47 -122.89 mg/kg) of fresh weight as compared to purple containing 4.22 mg/kg, and white sweet potato containing 10.71 mg/kg. In addition, the total soluble solids (TSS) reflected a high sugar content in purple sweet potatoes with 10.13 Brix followed by orange 8.52-9.72 Brix, and white sweetpotao with 5.57 Brix. Sun et al., (2014) suggested that leaves of sweet potatoes have a significant antioxidant and polyphenolic content that is mainly attributed to the presence of functional components, e.g. 4,5 di-O-caffeoylquinic acid and other components.

The comparative study of sweet potato and other tubers suggested that sweet potatoes contain high amounts of proteins, carbohydrates (starch), and minerals. Approximately all varieties of sweet potatoes contain free sugars that give a sweeter taste. Moreover, certain vitamins A, B, and C are also present in a significant amount. The orange flesh variety is rich in beta carotene which is a precursor for vitamin A and has a potential therapeutic effect to prevent night blindness (Rose, I.M. and Vasanthakaalam, 2011; Ndirigwe et al., 2016).

The orange-fleshed sweet potato is rich in Vitamin A as reported by Low et al., (2017). A 100-g serving of orange-fleshed sweet potato (OFSP) has the potential to meet the daily vitamin A requirement of young child. The orange variety contains the highest number of antioxidants and beta carotenes that are converted to vitamin A, required for a healthy immune system and eye health (Manzi et al., 2002). The intensity of the orange color of the flesh of SP also describes the amount of beta carotene, the darker the orange color, the more beta carotene (Cervantes-Flores, et al., 2011).

The storage root of the SP contains dry matter within the range of 15-35% with an average dry matter of 18 and 20% in the two most popular varieties of Beauregard and Covington respectively (Yencho et al., 2008). Study by Cervantes-Flores et al., (2011) on Beauregard and Tanzania sweetpotato varieties reported the total starch content in the storage roots from 5.4 to 21.9% of the fresh weight with a mean of 15%. Furthermore, the correlation analysis of the beta carotene and Beauregard orange fleshed SP was observed in the literature within 15% of the OFSP clones.

### **1.2.1. Health Benefits of Sweetpotato**

Several studies have reported the high fiber content in the different varieties of sweet potatoes through dietary fiber analysis. According to Mei et al., (2010), the 10 major varieties of sweet potatoes have 9.97-75.19% dietary fiber with average cellulose at 31.19 g/100g, lignin at 16.85 g/100g, pectin at 15.65 g/100g and hemicellulose as 11.38 g/100g. In addition, Mei et al., (2010) also analyzed the monosaccharide content of dietary fiber (DF), finding the highest concentrations as glucose and uronic acid while less amount of mannose. The characteristic physicochemical properties of the sweetpotatoes were also analyzed, finding 8.11-12.56 mL/g of swelling capacity, 1.43-2.48 g/g oil holding capacity, and 0.54-1.27 mmol/g glucose absorption capacity. The orange-fleshed sweet potato variety contains a healthy blend of nutrients, antioxidants, and phytochemicals, including iron, zinc, manganese, vitamins A, B, and C, and carotenoids, specifically beta carotene (Alam et al., 2016). There are significant health benefits of polyphenols, for example, protection against the heart disease, preventing oxidative stress in the body created by regular metabolic reactions, scavenging free radicals (peroxides) and neutralizing the cellular environment (Fraga et al., 2010). The vitamin C can reduce skin diseases, increase blood clotting function, and increase the absorption of iron in the body (Pullar et al., 2017).

Several authors have addressed the polyphenol activity of the sweet potato in relation to the reduction of chronic diseases including cancer, heart disease, liver injury, etc. For example, according to Tang et al., (2021), extracted purple sweet potato anthocyanin (PSPA) analyzed through High-Performance Liquid Chromatography Mass Spectrometry (HPLC-MS) reduces the excessive release of inflammatory factors, mainly nitric oxides and tumor necrosis factor (TNF- $\alpha$ ) that is induced in the body through redox reaction chains. The anthocyanins of the purple sweet potato decrease the secretion of trimethylamine oxide (TMAO), creatine kinase (CK), and enzymes like lactic dehydrogenase (LDH). The in vivo analysis of Tang et al., (2021) also reported significant histopathological findings in the reduction of the NO, LDH, CK, and oxidative stress as well as cardiotoxicity providing a heart-protective effect.

In another study by Lin et al., (2013), the probiotic fermentation potential of purple sweet potatoes was analyzed on the toll-like receptor 4 (TLR-4) for inflammation and fibrosis of the heart. Inflammation and fibrosis are identified as the preliminary components of cardiac dysfunction (Van Linthout, S., & Tschöpe, 2017). Lin identified that Gamma-aminobutyric acid (GABA) has a hypotensive effect that can be enhanced by milk fermented with lactic acid. The study reported a reduction in the toll-like receptor-4 and fibrosis-associated proteins TGF- $\beta$  as well as FGF2 in heart conditions after purple sweet potato prebiotic consumption. It indicates that oral consumption of prebiotic fermented sweet potato consumption, specifically purple sweet potato reduces the risk of cardiac fibrosis and hypertension by reducing the inflammatory biomarkers.

According to Hwang et al., (2011) the anthocyanins in purple sweet potatoes exhibit antidiabetic properties by activating adenosine monophosphate-activated protein kinase (AMPK). The in vivo study identified that consumption of 200 mg/kg per day of purple sweet potato anthocyanin fraction reduces weight gain, and hepatic triglycerides accumulation and significantly improves the biomarkers of serum lipid and glucose concentration.

Other than the flesh of the sweet potato crop, the leaves, stalk, and stem of the plant also possess certain nutritive values and functional components. Specifically, the leaves are rich in amino acid content, proteins, polyphenols, soluble dietary fiber, minerals like iron, vitamins, including vitamin

C and vitamin B, and carotene content. The stem of the sweet potato plant is rich in insoluble dietary fibers (Ishida et al., 2000).

Vitamin A deficiency (VAD) is a common global concern effecting individuals of all age groups exhibiting consequences of night blindness, eye diseases, and immune system dysfunctions that impact malaria, diarrhea, respiratory infection onset and certain vaccine-preventable infections (Rice et al., 2004). VAD also contributes to the 25% of the child mortality in relation with diarrhea and malaria (Rice et al., 2004). It can cause retarded growth and development, causing slow progress at school, and can progress from night blindness to total blindness, increased susceptibility to diseases and in severe cases, death. The elderly, children, pregnant and lactating women are the most affected.

### **1.2.2. Factors Affecting the Nutritional Composition and Quality of Sweetpotato Flour**

Sweet potato also possesses certain inhibitory factors that reduce the absorption of micro and macronutrients. According to Pace et al., (1988) the storage conditions and processing methods affect the proximate nutritional composition of sweet potatoes. The SP mineral content of the old, freeze-dried leaves is less than the fresh leaves with calcium 836 mg/100g, iron 10.88 mg/100g, and zinc 2.48 mg/100g. The harvesting time and cultivar also affect the proximate composition as reported by Pace et al., (1988) that old leaves contain high crude fat in Canned Carver SP as compared to Jewel SP leaves in the range of 7.1 -7.5%.

Drying temperature and drying methods also affect the concentration and availability of certain nutrients in the sweet potato crop. As reported by Sun et al., (2014) that the heating methods of boiling, steaming, microwave drying, baking, and frying the leaves of sweet potatoes significantly affect the polyphenol and antioxidant content. The findings of Sun et al., (2014) suggested that total polyphenol content was increased after steaming and boiling while decreasing by boiling (30.51%), microwave drying (25.70%), and frying (15.73%). On the other hand, the antioxidant activity of the leaves decreased by 63.82% after boiling and microwaving by 32.35%. At the same time, baking steaming, and frying increased the antioxidant activity by 81, 30 and 85%. Furthermore, Cervantes-Flores et al., (2002) reported that over 80% of beta carotene is retained in SP through boiling. Only a few plants can match this level of beta carotene. In addition, the boiling

and baking of the SP also reduced the proximate composition content as compared to the fresh plant, specifically affecting the beta-carotene and phenolic content (Dincer et al., 2010).

### **1.3. Processing Technologies of Sweetpotato and Sweetpotato Products**

SP is consumed and marketed in different forms of products like flour, baking products, and processed cooked foods. The dehydrated SP is used as chips, snacks, and baking products like cookies, cakes, and bread providing an alternative to the farmers selling only raw SP (Ahmed et al., 2010). Sweet potatoes are rich in water content, approximately 64%, which makes them highly perishable foods. Therefore, processing technology is required to convert SP into stable ingredients that can be used by food industries during off-season periods. Drying can improve the stability of foods by reducing their water and microbiological activity and minimizing their physical and chemical changes during storage. Various drying methods can be used such as hot air drying, drum drying, spray and freeze-drying. Traditional hot air drying is usually preferred due to its simplicity and low cost (Ahmed et al. 2010). The drying and heat processing of the products is variable for example hot air drying, microwave drying, microwave convection oven-assisted drying, and vacuum drying allowing the massive chain of product formulation with alternative proximate compositions (Sun et al., 2012). The reduction in time for heat treatment and retaining the quality of fruits and vegetables has been investigated by several authors. The comparative analysis of the three heating methods i.e., microwave spouted bed drying (MSBD), microwave vacuum drying (MVD), and hot air drying (AD). The MSBD exhibited the highest drying rate along with MVD with a 2.5 W/g microwave power level. The diced SP dried through MSBD and MCD depicted good puffing and rehydration ratio. The MSBD dried SP showed retention of beta carotene to about 80% as compared to the air-dried and microwave vacuum drying (Yan et al., 2013). In another study by Jing et al., (2010) the 5 mm thick slices of the SP steamed at 100 °C for 10 minutes were dried in the hot air, microwave, and vacuum freeze drier exhibiting the highest antioxidant capacity and phenolic content in microwave-dried SP.

The global demand for nutrient-rich and convenient foods is increasing worldwide, leading to the blend of the SP industry to formulate processed products. The study by Monteiro et al., (2020) analyzed the carbohydrate with low glycemic index potential of the SP. The physicochemical properties of the microwave vacuum-dried crispy oil-free chips of SP obtained in <30 mins of

vacuum drying presenting low moisture 0.028 g/100g DB and water activity 0.262 but high porosity of 67.5% and low density 0.456g/cm<sup>3</sup>.

### **1.3.1. Sweetpotato Flour and Its Quality**

The SP flour exhibits variable proximate composition depending upon the processing method and conditions. As reported by Ahmed et al., (2010) the  $\Delta E$  values and browning index of the sweet potato flour are significantly different for peeled and unpeeled SP ( $p < 0.05$ ) and when dipped in sodium-hydrogen sulfite ( $\text{NaHSO}_3$ ). The flour treated with sulfite has high  $L^*$ ,  $a^*$ , and  $b^*$  values, swelling capacity, total phenolic content, and vitamin C. On the other hand, the sulfite-treated and unpeeled SP flour had higher beta carotene and ascorbic acid contents that were decreased after drying. Ahmed et al., (2010) found the best quality SP flour was made from the sulfite treatment.

Heat treatment in flour production is used in the baking industry as a potential measure to enhance the quality parameters of flour attributed to color and enthalpy changes. The study by Dincer (2015) investigated the effect of heat treatment at variable temperatures of 90, 100, 110, and 120 °C for 20 minutes for evaluating the dough properties of SP bread flour. The study reported a change in the lightness  $L^*$  and  $a^*$  with a significant decrease in the particle size, volume, and diameter ( $P < 0.05$ ). The loaf volume was increased at increased heat treatment with the largest at 90 °C i.e., 2.53 cm<sup>3</sup> /g.

Furthermore, the mechanism through which the heat treatment improves the flour properties is the protein denaturation and partial gelatinization properties of the starch as well as its viscosity (Neill et al., 2012). The heat treatment of the SP flour at 100 °C temperature for 12 minutes increased the stability of the dough, which is considered the most important property of baking products (Bucsella et al., 2016).

### **1.4. Sweetpotato Leaves**

Sweet potato crop (*Ipomoea batatas* L.) is highly resistant to environmental conditions and cultivated immensely in Central America, China, and Africa with an annual production of 75,567,929 tons in 2011. However, the cultivation and production of the SP crop are viable across the continents for animal and human consumption purposes (Suárez et al., 2020). The leaves of SP

are harvested on ripening many times in a year which produces a much higher yield than the other green leafy vegetables. In addition, the leaves of SP have certain resistant properties including high heat resistance properties, are tolerant to diseases and pests, and endure high moisture conditions (Islam et al., 2006). The antioxidants present in the leaves display an important role in preventing disease and metabolic stress. The polyphenols and antioxidant potential of the SP leaves are also higher than the other leafy vegetables. Therefore, it acts as an antidiabetic, antihyperlipidemic, and anti-obesity plant.

#### **1.4.1. Nutritional Composition of Sweetpotato Leaves**

Several studies have reported the proximate nutritional composition of sweet potato leaves. According to Sun et al., (2014), the leaves of SP contain crude fiber, protein, carbohydrate, fat, and ash in variable amounts of 9.15-14.26, 16.69-31.08, 42.03-61.36, 2.02-5.28, and 7.39-14.66 g/100g of dry weight (DW) respectively. SP leaves are also rich in minerals mainly potassium, calcium, iron, magnesium, and sodium 3608.854 mg/100g, 320.125 mg/100g, 73.881/100g, 118.75 mg/100g, and 32.079 mg/100g respectively (Awol et al., 2014). Study by Allen et al. (2014) found that sweetpotato leaves provide more bio-accessible calcium than spinach. SP leaves also contain vitamin B1, B2, B3, C, and E 0.62, 6.36, 0.54, 21.9, and 3.24 mg/100g of dry weight respectively. Sweet potato leaves contain phenolic compounds and flavonols like caffeic acid, quercetin, and chlorogenic acid that contribute to the protection against cellular oxidative stress thus reducing protein nitration damage as well. The sweet potato leaves water extract to reduce the production of nitric oxide protein tyrosine residue production in an increased concentration of 0-1.0 mg/ml. On the other hand, sweet potato leaves also exhibit radical scavenging potential, chelating activity, and protecting liposomes against cellular oxidation stress (Haung et al., 2010). Leaves of sweet potato also contain flavonoid and anthocyanin content 0.6-3.3 mgQe/g DM and 12.7-36.5 mg c-3- gE/100g DM) in variable solvent extracts i.e., methanol, ethanol, and acetone (Fu et al., 2016). Sweet potato leaves contain approximately 15 different biologically active types of anthocyanins that significantly reduce the risk of human diseases and formulate natural food colorants (Islam, 2006). The content of crude protein in leaves of SP is similar to the concentration in milk i.e., 2.99g/100g FW which can be used for the management and treatment of malnutrition as a source of protein. Furthermore, the mineral content specifically Na/K is higher in sweet potato leaves as compared to the spinach leaves (Awol, 2014).

In addition to the polyphenol and antioxidant potential of the SPL, the high protein content has also been reported in the literature. The SPL extract was found to be high in linoleic acid and alpha-linoleic acid by Almazan and Adeyeye (1998). Furthermore, the Georgia Jet source of the SPL was found to be highest in the respective amino acid content with 14.2 and 33.5 % respectively extracted via hexane.

### **1.5. Edible Insects**

The practice of eating insects is known as entomophagy. Insects belong to the arthropod group and possess a chitinous exoskeleton, a body composed of three parts - the head, thorax, and abdomen - three pairs of jointed legs, compound eyes, and two antennae (Van Huis et al., 2013). Insects, which are cold-blooded, are the only winged invertebrates that undergo metamorphosis to adapt to seasonal variations, reproduce quickly, have large populations, and often do not require parental care (Van Huis et al., 2013). Insects have been part of the human diet for centuries, serving as emergency food, staples, and even delicacies (Durst et al., 2010). Although the consumption of insects as a food source has been a common practice across different cultures, the practice varies with location, ethnic group, and availability of insects in the region (Durst et al., 2010). For instance, in Mali, it is a tradition practice for children to hunt and consume grasshoppers as a snack food (Van Huis et al., 2013). The reasons for consuming edible insects vary among cultures. For example, in northeastern Thailand, local people consumed forest insects not because they are environmentally friendly, nutritious, or cheaper than meat and poultry, but solely because they taste good (Durst et al., 2010). In China, for at least 2300 years, earthworms (“Earth dragon”, Chinese name for earthworms) had been a traditional medicine used as an antipyretic, and anesthetic, for detoxification, treatment of hypertension, and aiding childbirth. Additionally, earthworms were used to treat common ailments like arthritis, itching, burns, and inflammation (Sun & Cheng, 2005). However, in most western countries, consumption of insects (entomophagy) is perceived as disgust and many people shun consumption of insects and associate the practice as primitive behavior (Ramos-Elorduy et al., 1997). Apart from innate human emotions, Van Huis et al. (2013) described the origins of disgust as rooted in culture i.e. “taste is culture” which reflects the idea that what one considers acceptable to eat is often shaped by cultural upbringing and surroundings. Ramos-Elorduy (2005) stated that, a population’s socioeconomic conditions are reflected in their diet, with dietary habits and taste perceptions being influenced by their history,

geographic origins, lifestyle, tradition, and education. This may also explain why some developed countries view insects as primitive food, while other cultures view them as a valuable and essential part of their diet. Another example of how culture impacts food preferences is evident in the 1992 Malawi Cookbook (Van Huis et al., 2013). The cookbook featured various insect-based recipes, which were under the heading “traditional delicacies” which suggests that in Malawian culture, insects are not viewed with the same disgust as in many Western culture.

Insects are eaten at all stages of development, including eggs, larvae, pupae, and adults (Ramos-Elorduy, 2005). Many studies have been conducted to identify the number of edible insect species across the world. It is estimated that there are about 2000 edible insect species that are known to be consumed by humans as food (Ramos-Elorduy, 2005). Edible insects are identified according to taxonomic orders, common English names, and the number of species eaten. Coleoptera, Hymenoptera, Orthoptera, and Lepidoptera are the four insects orders ranked in order of their predominance and account for 80% of the species eaten (Ramos-Elorduy, 2005). Several studies have evaluated the nutritional profile of different edible insect species (Chagwena et al., 2019; Ramos-Elorduy et al., 1997; Selaledi & Mabelebele, 2021). The excellent nutritional profile of edible insects reported has resulted in entomophagy, or the consumption of insects and insect-based food gaining recognition as a promising approach to enhance dietary variety and alleviate various forms of malnutrition (Matiza Ruzengwe et al., 2022). Furthermore, growing populations with increases affluence may result in a 75 percent increase in demand for meat by 2050 (Van Huis et al., 2013). Similarly, in many countries animal protein sources have become more scarce and expensive in recent years, necessitating the development of new protein sources (Sun, 2005). According to several research studies, insects have an advantage to supplement human diets because they are versatile and can be eaten in different forms such as whole (roasted, fried) or in ground or paste form and as an extract of protein, fat or chitin that can be subsequently used as ingredients in food products (Hernández-Álvarez et al., 2021; Van Huis et al., 2013). According to Van Huis et al. (2013), processing insects into powder or paste form and extraction of protein for human food products is a useful way to increase acceptability among Western consumers who may be reluctant to accept insects as food and a viable protein source.

Table 1.1. Number of edible insect species recorded in the world.

Order	Common name	No. of species
Thysanura	Silverfish	1
Anoplura	Lice	3
Ephemeroptera	Mayflies	19
Odonata	Dragonflies	29
Orthoptera	Grasshoppers, cockroaches, and Crickets	267
Isoptera	Termites	61
Hemiptera	Bugs	102
Homoptera	Cicada and Leafhopper, Mealybugs	78
Neuroptera	Dobsonflies	5
Lepidoptera	Butterflies and Moths	253
Trichoptera	Caddishflies	10
Diptera	Flies and Mosquitoes	34
Coleoptera	Beetles	468
Hymenoptera	Ants, Bees, Wasps	351
Total		1681

Source: Ramos-Elorduy (2005).

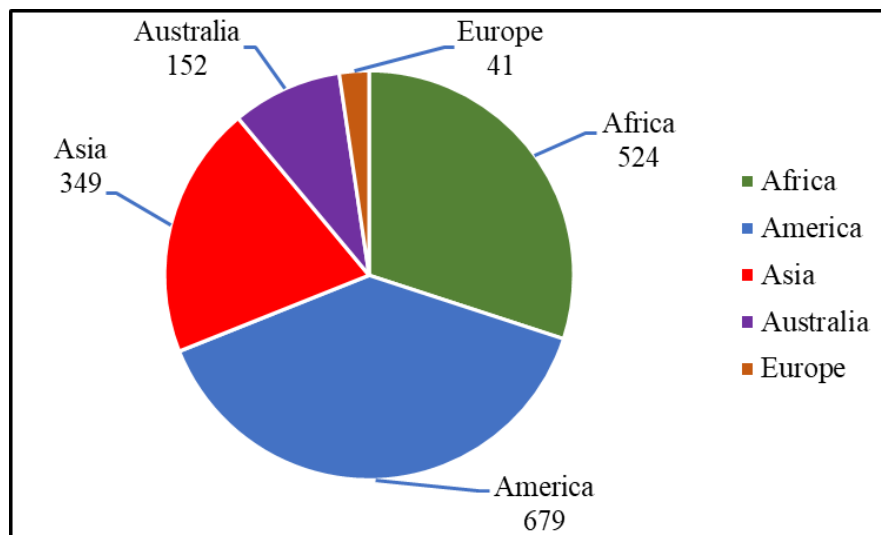


Figure 1.6. Geographic distribution of recorded edible insect species.

Source: Ramos-Elorduy (2005)

### **1.5.1. Nutritional Benefits of Edible Insects**

The reasons for consuming edible insects vary among cultures. In some societies, insects are consumed out of necessity due to food shortages. Many studies have been conducted to evaluate the nutritional profile of edible insects. Edible insects are reported to have high protein, fats, vitamin, and mineral content comparing favorably with other protein-food sources such as beef, poultry and fish (Ramos-Elorduy, 2005; Ramos-Elorduy et al., 1997; Rumpold & Schlüter, 2013).

#### **1.5.1.1. Protein Content**

Protein content is the largest nutritional profile of edible insect. Sun, (2005) analyzed the nutritional composition of earthworm and reported protein content in the range of 54.6 to 71.0% dry weight. Furthermore, the protein and amino acid content and quality were found to be comparable to those of fish meal and eggs and higher than cow milk powder and soybean meal. The high protein content in edible insects can help complement the human diet. For instance, cereals such as maize, which is a key staple diet for many people around the world, have protein that is deficient in lysine and sometimes lack the amino acids tryptophan and threonine. However, certain insects have these amino acids in significant amounts. For example several species of caterpillars, palm weevil larvae, and aquatic insects have high lysine scores of over 100 mg of amino acid per 100 g of protein (Rumpold & Schlüter, 2013; Van Huis et al., 2013). In the democratic Republic of Congo, lysine deficient staple proteins are supplemented with lysine-rich caterpillars. Likewise, the population of New Guinea consumes tubers that are deficient in lysine and leucine but offset this nutritional deficiency by including palm weevil larvae in their diet (Van Huis et al., 2013).

Ramos-Elorduy et al. (1997) analyzed nutritional composition of 78 species of edible insects which included the orders of Anoplura, Diptera, Orthoptera, Hemiptera, Homoptera, Lepidoptera, Coleoptera, and Hymenoptera in Mexico. The authors reported the protein content in the range of 15-81% and the protein digestibility, which reflects the quality of protein ranged between 76 and 98%. Wasp of the genus *Polybia* was found to contain the highest protein content. Several species of Grasshoppers were found to contain the lowest protein content (4.2%) while the larva of butterfly *phasus triangularis* contained 77.2%. Winged termites that are consumed in Kenya were analyzed for nutrient composition by Kinyuru et al. (2013). The results of their study reported

protein content in the range of 33.51-39.74 g/100g. According to Ramos-Elorduy et al. (1997), amino acid profile of edible insects can meet the amino acid requirements of children and adults indicated by FAO and the WHO (1985). Furthermore, edible insects are also rich in calories ranging from 293 to 762 g/100g.

Table 1.2. Average amino acid content (g/kg of dry matter) of *Tenebrio Molitor* and beef.

Amino acid	Yellow mealworm ( <i>T. Molitor</i> ) g/kg	Beef g/kg DM
<b>Essential</b>		
Isoleucine	24.7	16
Leucine	52.2	42
Lysine	26.8	45
Methionine	6.3	16
Phenylalanine	17.3	24
Threonine	20.2	25
Tryptophan	3.9	-
Valine	28.9	20
<b>Semi-essential</b>		
Arginine	25.5	33
Histidine	15.5	20
Methionine + cysteine	10.5	22
Tyrosine	36	22

Sources: (Finke, 2002; Van Huis et al., 2013)

### 1.5.1.2. Fats Content

Fat is the second largest component of the nutritional profile of edible insects after protein (Van Huis et al., 2013). In the human body, fats are the compounds that provide the most energy to the body, providing twice as much as that of carbohydrates or proteins (Ramos-Elorduy, 2005). Furthermore, human body cannot efficiently assimilate proteins if amount of energy is insufficient in the diet, hence incorporation of edible insect in the diet can help in generation of more energy from their fat for better utilization of protein. Energy values supplied by most edible insect are

higher than those supplied by plant or animal-based foods (Ramos-Elorduy, 2005). Pork is the only food that contains more calories than most edible insects.

Table 1.3. Fatty acid content of mealworms *Tenebrio Molitor* and beef on a dry matter basis.

Fatty acid	Saturation	<i>T. Molitor</i>	Beef
<b>Essential</b>			
Linoleic	Omega-6-polyunsaturated	91.3	10.2
Linolenic	Omega-3-polyunsaturated	3.7	3.9
Arachidonic	Omega-6-polyunsaturated	-	0.63
<b>Non-Essential</b>			
Capric	Saturated	-	1.05
Lauric	Saturated	<0.5	1.05
Myristic	Saturated	7.6	13
Pentadecanoic	Saturated	<0.05	-
Palmitic	Saturated	60.1	99
Palmitoleic	Omega-7-monounsaturated	9.2	17
Heptadecanoic	Saturated	<0.5	-
Heptadecenoic	Omega-7-polyunsaturated	0.8	-
Stearic	Saturated	10.2	48
Oleic	Omega-9-monounsaturated	141.5	159
Arachidic	Saturated	0.8	-
Eiconenoic	Omega-9-monounsaturated	-	0.63
Other		0.5	-

(Finke, 2002; Van Huis et al., 2013)

The molecular structure of fat comprises of triglycerides, each of which contains three fatty acids and a glycerol molecule (Van Huis et al., 2013). Fatty acids are grouped into (1) saturated fatty acids, (2) unsaturated fatty acids and (3) essential fatty acids-those that cannot be synthesized by the human body but can only be obtained from the diet. Saturated fatty acids which are solids at

room temperature tend to have higher boiling points than unsaturated fatty acids and their main sources include animal products and palm oils while unsaturated fatty acids are characterized by the number of double bonds, i.e., mono-unsaturated (one double bond) or poly-unsaturated (multiple double bonds) and are commonly found in vegetable oils. However, unsaturated fatty acids yield slightly less energy during metabolism but are considered better for human health than saturated fat (Van Huis et al., 2013). Edible insects' fat is high quality with significant contribution of unsaturated fatty acids, including omega-3s (Kinyuru et al., 2013). For example, Kinyuru et al. (2013) found high levels of unsaturated fatty acids (50.54-67.83%) in winged termites consumed in Kenya.

### **1.5.1.3. Mineral Content**

Minerals are inorganic elements that are essential because they cannot be synthesized by the human body (Ramos-Elorduy, 2005). Minerals perform numerous vital metabolic functions in the body including building, activating, regulating, and controlling many chemicals. For example, iron is essential in hemoglobin, and zinc in insulin (Ramos-Elorduy, 2005). According to Ramos-Elorduy (2005), minerals are categorized as macronutrients (such as calcium, phosphorus, potassium, magnesium, chloride, and sulfur), micronutrients (such as iron, copper, iodine, manganese, cobalt, zinc, and molybdenum), and ultra-micronutrients (fluorine, cadmium, lithium, chromium, selenium, and boron). Edible insects typically contain low levels of sodium and sometimes, low levels of calcium. However, they are high in zinc, iron, and an excellent source of magnesium (Ramos-Elorduy, 2005). Depending on the age, sex, activity, and physiological state, edible insects can provide the daily mineral requirements of humans. Mineral content in edible insects also varies among the species, with some species containing significant amount of various minerals. For example, termites are good source of calcium and sulfur, while grasshoppers are abundant in iron and zinc (Ramos-Elorduy, 2005).

### **1.5.1.4. Vitamins**

Vitamins are essential micronutrients that are necessary in the human diet because the body is incapable of synthesizing them adequately. Vitamins help in regulating many metabolic functions such as the efficient operation of the enzymatic system. Vitamins can be water soluble (such as vitamin C, and those in the B group) and fat-soluble (such as vitamins A, D, E, and K) (Ramos-

Elorduy, 2005). A study by Ramos-Elorduy et al. (1997) who analyzed the nutritional composition of seventy-eight edible insects in Mexico found that insects were rich in B group vitamins such as niacin, riboflavin, and thiamine.

*Table 1.4. Energy contribution by edible insect vs Conventional foods.*

<b>Insect Order</b>	<b>Kcal/100g</b>	<b>Range reported</b>
Odonata	431-520	89
Ephemeroptera	354-355	1
Orthoptera	336-438	102
Isoptera	347-508	161
Hemiptera	329-629	300
Homoptera	394-469	75
Neuroptera	332-366	34
Lepidoptera	293-777	484
Coleoptera	283-653	370
Diptera	217-561	181
Hymenoptera	380-561	181
<b>Conventional Products</b>		
Cereals	330-370	40
Vegetables	308-352	44
Legumes	388-421	33
Meats	165-705	540

*Source:* Ramos-Elorduy (2005).

### **1.5.2. Processing of Edible Insects**

Drying of insects is important step that extends their shelf life by removing the moisture and it is in some cases a pretreatment requirement for some extraction technologies for ingredient production (Hernández-Álvarez et al., 2021). However, some processing techniques change the nutritional composition of edible insects (Kinyuru et al., 2010). El Hassan et al. (2008), evaluated

the nutritional and physiochemical properties of boiled and fried tree locusts and found that the proximate composition fluctuated for both methods with a maximum protein content of 67.75% and 66.24% for fried and boiled locust flour respectively. The levels of antinutritional factors varied with higher tannin content (9.00 mg/100g) in fried locust than boiled locust which contained 5.8 mg/100g.

Several factors such as processing method, insect matrix, and composition of the food matrix have been reported to influence the nutrient bioavailability and bioaccessibility of edible insect nutrients by many researchers (Matiza Ruzengwe et al., 2022). El Hassan et al. (2008) reported higher values of zinc and iron contents from the boiled tree locust than the fried ones. The authors also reported significant reduction on in vitro protein digestibility (41.13%) from fried tree locust.

In conclusion, the above review suggests that sweetpotato root, sweetpotato leaf, and edible insects provide distinct nutritional profiles that can be combined into more complete RUTF than the individual ingredients do separately. The following chapters measure these profiles, formulate several ingredient mixtures, and then further characterize the resulting RUTF products.

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**CHAPTER 2: SWEETPOTATO FLOUR, SWEETPOTATO LEAVES, AND EDIBLE  
INSECTS POWDER PROCESSING AND NUTRITIONAL COMPOSITION ANALYSIS**

## 2.1. Abstract

In recent years, there has been increased interest in the utilization of Orange Fleshed Sweetpotato in the food industry as a functional ingredient in various food products due to its excellent nutritional properties. However, low protein content of sweetpotato tubers has prompted food industry to consider fortification with protein-rich ingredients. Among the potential sources of protein-rich ingredients are sweetpotato leaves, which can also be eaten, and edible insects, which are gaining in popularity outside the USA as potential sustainable alternative sources of protein relative to meat. Considering the variations in nutritional composition among the Orange-Fleshed Sweetpotatoes flesh, sweetpotato leaves, and edible insects, there is a complementarity that can be explored. Processing methods and temperature of processing tend to alter the nutritional composition of foods. The purpose of this study was to (1) evaluate the nutritional composition of different varieties of sweetpotato flesh, sweetpotato leaves, and edible insects (2) investigate the effects of different processing methods and temperature on the nutritional composition of the dehydrated sweetpotato flesh, sweetpotato leaves, and edible insects. Covington and Bearegard sweetpotato tubers, Covington, Bonita, Murasaki-29 and Purple Majesty sweetpotato leaves, and yellow mealworms were dried using convection oven, food dehydrator, freeze dryer, and air fryer at two different temperatures (60 °C and 52 °C) with an additional freeze dryer treatment (-40 °C). Mealworms were dehydrated using convection oven only at 60 °C while sweetpotato roots were dried using all the methods at 60 °C and with freeze dryer (-40 °C).

The results showed no significant ( $p < 0.05$ ) changes in proximate composition of the dehydrated sweetpotato roots, sweetpotato leaves and mealworms among the drying methods and temperature except moisture and ash content. The range of proximate composition for all varieties of sweetpotato leaves under different drying methods and temperature were 2.82 g/100g to 7.81 g/100g for moisture, 2.53 g/100g to 4.46 g/100g for crude fat, 17.76 g/100g to 25.85 g/100g for crude protein, 7.69 g/100g to 10.10.79 g/100g for ash, 7.26 g/100g to 8.70 g/100g for crude fiber, and 53.45 g/100g to 63.16 g/100g for carbohydrate. Proximate composition differed significantly ( $p < 0.05$ ) among the four varieties of sweetpotato leaves. Sweetpotato roots had lowest fat and protein contents compared with sweetpotato leaves and edible insects. Significant differences ( $p > 0.05$ ) in moisture, crude fat, and crude protein were observed among the edible insects. For all samples, proximate composition ranged from 3.24-6.30 g/100g for moisture, 27.85-31.69 g/100g

for fat, 50.50-58.58 g/100g for protein, 2.68-4.07 for ash, and 5.92-7.58 g/100g for crude fiber. The results of this study showed that high protein content in sweetpotato leaves, and edible insects can help improve the protein content of sweetpotato flour during formulation development. However, the varietal differences and insect type/source which were the dominant factors influencing the nutritional composition of the sweetpotato leaves and edible insects should be considered during formulation, depending on the end use.

## 2.2. Introduction

The food industries in many countries have shown increased interest in the utilization of Orange Fleshed Sweetpotato (OFSP) as a functional ingredient in various food products due to its excellent nutritional properties (Truong & Avula, 2010). Orange fleshed sweet potato varieties are an excellent staple food because they contain high levels of beta-carotene, a fat-soluble carotenoid that the human body can easily convert into vitamin A (Stathers et al., 2013). In different regions of the globe, there have been advancements in processing technologies aimed at transforming sweetpotatoes into purees and dehydrated forms that can be used as a functional ingredients in various food products (Truong & Avula, 2010).

In recent years, a continuous flow microwave heating system that delivers fast and efficient heating has emerged as an efficient technology for aseptically processing shelf stable OFSP purees (Coronel et al., 2005; Steed et al., 2008). One major challenge with this advanced technology of processing sweet potato puree through sterilization and aseptic packaging is that it retains a high moisture content that might not be conducive to some product applications and adds cost to long-distance transportation. In contrast, OFSP that is processed into flour is a practical approach to ensure a shelf-stable product using different dehydration techniques (Padmaja, 2009). Sweetpotato flour requires less storage space, transportation cost and can be subsequently used as an ingredient in various products including bread (partial substitution for wheat), pies, reconstituted baby food, and cakes (Mbogo et al., 2021). Sweetpotato flour can retain beta-carotene effectively if packaged in aluminum foil laminates that reduce light and oxygen exposure (Chilungo et al., 2019).

Sweet potato flour can add natural sweetness, color, and flavor to processed food products. It can also serve as a source of energy and nutrients and minerals and contributes to the daily nutrient needs for beta-carotene, thiamin, iron, vitamin C, and protein (Truong & Avula, 2010). However, sweet potato flour has low protein content, ranging from 1 to 8.5% (Dansby & Bovell-Benjamin, 2003; Stathers et al., 2013; Woolfe, 1992) and would require fortification with iron, folate, and niacin to meet the micronutrient profile of fortified grains, such as wheat flour in the U.S. (Feng Godinez, 2015). Sweetpotato flour fortification with the incorporation of higher protein content flours such as soy flour, cottonseed flour, and gluten flour has been studied (Feng Godinez, 2015; Padmaja, 2009). Like sweet potato roots, sweet potato leaves, which can also be eaten, have several nutritional benefits (Stathers et al., 2013). Several studies have been conducted to evaluate the

nutritional composition of sweet potato leaves (Mwanri et al., 2011; Ooko Abong et al., 2020; Sun et al., 2014). Fresh sweetpotato leaves are an excellent source of protein, carotenoids, vitamins A, B, C, calcium, iron, and antioxidants (Mwanri et al., 2011; Ooko Abong et al., 2020; Stathers et al., 2013; Sun et al., 2014). Furthermore, sweetpotato leaves provide more bio-accessible calcium than spinach (Allen et al., 2014) and if combined with roots that are not the number 1 market grade, making flour could increase the yield of sweet potato biomass per acre as well as improve the nutritional content of the product. However, sweetpotato leaves, though a rich source of vitamins, minerals and protein have been much less used as a human food in Western countries (Padmaja, 2009).

Outside the U.S.A., edible forest insects are gaining increasing attention in the food industry as an alternative protein source to meat and a more environmentally friendly strategy for increasing the protein supply. Traditionally, the majority of insects consumed as a food source have been gathered from natural forests (Durst & Shono, 2010). Edible insects are rich sources of protein, fats, essential amino acids, and essential vitamins and minerals for the improvement of the human diet (Durst & Shono, 2010). The fats in edible insects can help with the absorption of fat-soluble nutrients, such as sweet potato beta-carotene. Furthermore, proteins from edible insects have high digestibility, between 77% and 98% (Ramos-Elorduy et al., 1997). On the same weight basis, most edible insects contain more protein and minerals (Durst & Shono, 2010). Insects are also a good source of fiber due to their high chitin (a carbohydrate polymer) content, which accounts for about 10% of the whole dried insect (Belluco et al., 2013). Therefore, the incorporation of an insect-derived ingredient into sweet potato flour or puree can help to alleviate problems associated with protein-deficient diets (Durst & Shono, 2010).

Although sweet potato is a highly nutritious crop, it alone does not supply all essential nutrients in amounts needed for health, as in an emergency ration or ready-to-use-therapeutic food (RUTF). Considering the variations in nutritional composition among the OFSP tubers, sweet potato leaves, and edible insects, there is a complementarity that can be explored.

The objectives of this study were to evaluate the nutritional composition of different varieties of sweetpotato flesh, and edible insects and to investigate the effects of different processing methods and temperature on the nutritional composition of the dehydrated products.

## 2.3. Materials and Methods

### 2.3.1. Schematic Overview of the Experimental Program

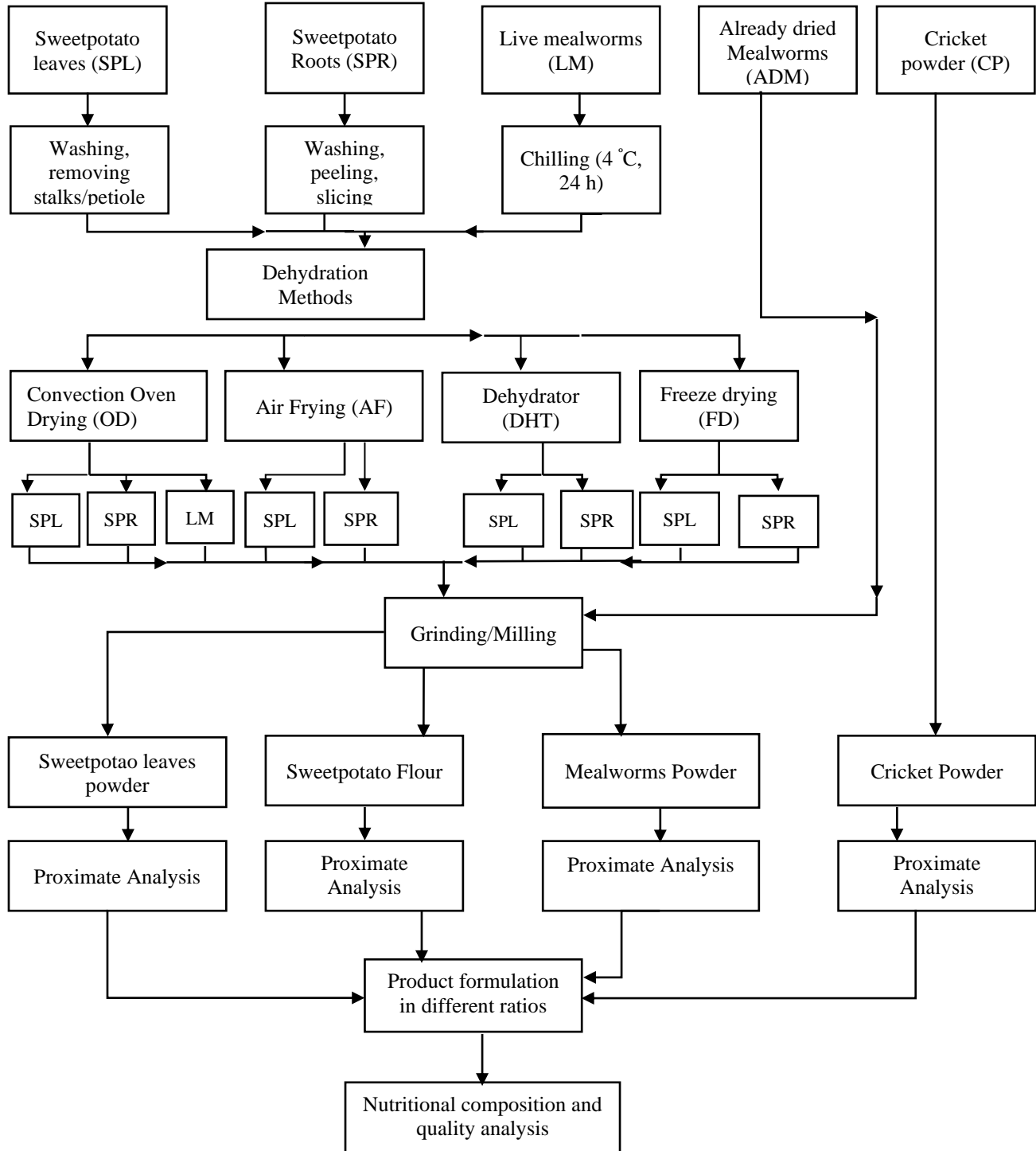


Figure 2.1. Schematic Overview of the Experimental Program.

## **2.3.2. Sample Acquisition and Preparation**

### **2.3.2.1. Collection of Sweetpotato Leaves**

Four varieties of sweetpotato leaves that were about 3 months old at the time of harvest (September 29, 2022), Bonita, Murasaki, Purple majesty, and Covington were obtained from the fields at the NC State University's research station located in Kinston, North Carolina. Covington was planted on June 17, 2022, while Purple Majesty, Bonita, and Murasaki-29 were planted on June 21, 2022. Addition Covington variety leaves were obtained from a different field at the Cunningham research station. Stems with leaves about 30 cm long from the tip were cut and transported from the field to the North Carolina State University's food science department laboratory in polyethylene plastic bags and stored at -81 °C until dried.

#### **2.3.2.1.1. Sweetpotato Leaves Dehydration and Powder Production.**

Leaves were dried within 2 days from the collection date. Stems were removed, and the leaves were then washed with running tap water, and air dried to remove the excess water on the surface. Leaves were divided into batches as per drying methods and treatments (Figure 2.1). Briefly, the leaves were dried to a constant weight at 60 and 52 °C for approximately 10 and 12 hours respectively by convection oven (25EM, Precision Scientific, Chicago, Illinois), -40 /-30 °C for 36 h by freeze dryer (GEN25XL, Genesis), 60 °C and 52 °C for approximately 8 hours by air fryer (Nuwave, LLC, Illinois, USA), and 52, and 60 °C for 12 hours by convection food dehydrator (12 M, New York, USA). The dried leaves were ground into powder using an electric blender (MB 1001, China), then packed in air-tight polythene plastic bags, wrapped in aluminum foil to minimize nutrient loss during storage (Chilungo et al, 2019) and stored at -20 °C until further analysis. Sweet potato flour (SPF) was stored at -80 °C to avoid enzymatic and chemical degradation, which could result in a visible loss of color due to the transformation or loss of the conjugated double bond structure of beta-carotene (Chilungo et al., 2019).

### **2.3.2.2. Collection of Sweetpotato Roots**

Two varieties of orange-fleshed sweetpotatoes; Covington and Beauregard were used in this study. The Beauregard variety of orange-fleshed sweetpotatoes (*Ipomoea batatas* L.) was purchased from a local supermarket in Raleigh, NC while the Covington variety (freshly harvested) was obtained from a Horticultural crops research station located in Kingston, North Carolina, USA during the

harvesting period of September to November 2022. Covington was chosen because it is one of the varieties that are most grown in the USA. To prepare the sweetpotato flour, the method described by Dansby and Bovell-Benjamin (2003) was used with slight modification. The sweet potato roots were washed with running tap water to remove any debris or soil particles. The roots were then peeled, using a stainless-steel kitchen knife, and sliced into 2-mm thick slices using a Hobart FP150 continuous feed food processor (Hobart Corp., Troy, OH, USA). The sweet potato slices were divided into batches according to the number of drying methods; (1) freeze drying, (2) convection oven drying, (3) air frying, (4) convection food dehydration.

#### **2.3.2.2.1. Convection Oven Drying of Sweetpotato Roots**

In convection oven drying, the slices were dehydrated in a tray at 60 °C for approximately 12 hours until a constant weight was reached. The dried samples were ground into powder using a Magic bullet blender (MB 1001, China). The flour was packed in polypropylene bags, wrapped in aluminum foil, and stored at -20 °C until used for proximate analysis and product formulations.

#### **2.3.2.2.2. Freeze-Drying of Sweetpotato Roots**

Three main stages were applied during the freeze-drying of the samples, which were previously frozen at -81 °C. In the first stage, the sweetpotato slices were frozen at -40 °C for 120 minutes (2 hours) and then subjected to a second stage- the primary/main drying (-30 °C at 0.040 bars) for 720 minutes (12 hours). Lastly, the third and final drying was done at 25 °C for 720 minutes (12 hours) under a vacuum pressure of 0.020 bars). After drying, the samples were weighed, and the final weight was recorded to calculate the initial moisture content and dry matter. Dried samples were processed into flour using a Magic bullet blender (MB 1001, China) and stored at -20 °C in airtight polythene bags wrapped in aluminum foil until used.

#### **2.3.2.2.3. Sweetpotato Drying by Food Dehydrator**

The sliced sweetpotatoes were dehydrated at 60 °C for approximately 12 hours in a convection food dehydrator (12 M, New York, USA) until a constant weight was reached. The dehydrated sweetpotato slices were ground in a Magic bullet blender (MB 1001, China) into flour. The sweetpotato flour was stored in a food-grade freezer at -20 °C in an airtight polythene bag wrapped in aluminum foil sheets until used.

#### **2.3.2.2.4. Sweetpotato Dehydration by Air Fryer**

Briefly, the sliced sweetpotatoes were dried at 60 °C for approximately 12 hours in a Nuwave Brio air fryer (Nuwave, LLC, Illinois, USA). The dried sweetpotato slices were ground in Magic Bullet blender (MB 1001, China) into a powder and stored at -20 °C in airtight polyethylene bags wrapped in aluminum foil sheets until used. The processing was done in duplicate.

#### **2.3.2.3. Yellow Mealworms Dehydration and Cricket Powder Processing**

Five kgs of already dried yellow mealworms (*T. Molitor*) were purchased from Superior Pet Supplies, Inc. Washington. House Crickets powder (*Acheta Domesticus*) named Bud's cricket powder was purchased from Harrison Food Group, LLC, Everett, Washington., USA. The dried yellow mealworms and cricket powder were stored at 4 °C until used. Live mealworms were purchased from local insect supplier in USA. The live mealworms were chilled at 4 °C for 24 hours prior to drying to anesthetize them. The mealworms were dried at 60 °C (convection oven drying) until a constant weight was obtained. The dried mealworms were ground into powder using electric Magic Bullet blender (MB 1001, China) and stored at 4 °C in an airtight polyethylene bag until used.

### **2.3.3. Analytical methods**

#### **2.3.3.1. Proximate Analysis**

The proximate composition of the samples was determined using standard methods (AOAC, 2012) with slight modifications; moisture (AOAC 925.09), protein (AOAC 968.06), fat (AOAC 920.39), ash (923.03), fiber (AOAC 962.09) and carbohydrates were determined by difference; Total carbohydrate (g/100g dry weight) = 100 – (% crude protein + % crude fat + % crude fiber + % ash).

##### **2.3.3.1.1. Moisture Content**

Briefly, 5 grams of sample was weighed into aluminum pans and dried in a convection oven (25EM, Precision Scientific, Chicago, Illinois) at 105 °C until a constant weight was reached for approximately 24 hours. The dried samples were then cooled in a desiccator until constant weight and weighed. Moisture content was reported as initial weight minus the dry weight.

#### **2.3.3.1.2. Crude Fat Content**

Briefly, approximately 1 gram of insect powder and 5 grams of sweetpotato leaves' powder and sweetpotato flour were weighed into 33 x 94 mm cellulose thimbles with weights recorded, then the samples were covered in glass wool to prevent sample loss due to floating during extraction. Fat was extracted from the samples in an automated Soxhlet unit, Buchi-E-816-Soxhlet (BUCHI Corporation, New Castle, DE, USA) that continuously refluxes a stream of hexanes through the sample, thereby conducting repeated extractions to remove all the fat in the sample for approximately 5 hours, including time for rinsing and drying steps to remove the residual hexane from the lipid extract. The beakers containing lipid extract were gently heated on a hotplate at 80 °C until all the remaining solvent was evaporated, then cooled to room temperature (excessive drying may oxidize fat and give high results). The weight of the extracted lipid was recorded as crude fat content since all components (most notably carotenes in sweetpotato roots and chlorophyll in sweetpotato leaves) soluble in hexanes are extracted via the Soxhlet method.

#### **2.3.3.1.3. Crude Protein Content**

The crude protein content in the samples was determined by automated nitrogen and protein analyzer (Rapid N Exceed-Elementar Americas) with autosampler. Briefly, the instrument was first calibrated using the aspartic acid standard. For the sample analysis, 250 mg of finely ground sample was weighed into tin foil boats, carefully pressed to pellets using the manual pressing tool to prevent sample loss, and then deposited into the autosampler. Analyses were run using the standard method implemented in the instrument software with analysis time of about 5 minutes per sample. Each sample analysis was conducted in duplicate. Results were expressed as % nitrogen content in the sample and a protein factor of 6.25 was used to calculate the % protein content.

#### **2.3.3.1.4. Ash Content**

A  $5 \pm 0.5$  g sample of ground material was weighed on a digital balance into ceramic crucibles that were previously labeled with a heat-resistant marker. The crucibles were then heated in a Barnstead F6018 muffle furnace (Barnstead Int., Iowa, U.S.A.) at 550 °C for 12 hours. The crucibles were cooled in the desiccator and then weighed. Ash content was reported on a dry weight basis.

#### **2.3.3.1.5. Fiber Content**

The crude fiber was determined by AOAC method 962.09 Briefly, 2 g of sample previously defatted to less than 1% fat content was boiled in 0.255N sulfuric acid for 30 minutes. The resulting insoluble residue was filtered through a Buchner funnel and washed with boiling water. The washed residue was boiled in 0.312 N sodium hydroxide for 30 minutes, filtered, and washed with 25 mL of boiling 0.255 N sulfuric acid solution, three 50 mL portions of water, and 25 mL of alcohol. The filtered and washed residue was then dried at  $130 \pm 2$  °C for 2 hours, cooled in a desiccator, and weighed. After drying, the sample was ignited at 550 °C for 30 minutes, cooled in a desiccator, and weighed to determine the weight loss. The crude fiber content was expressed relative to the dry weight of the sample.

#### **2.3.3.2. Vitamins and Minerals Analysis**

##### **2.3.3.2.1. Ascorbic Acid (Vitamin C)**

The AOAC 967.21 method with modification was used to measure the ascorbic acid (Vitamin C) in the samples. Metaphosphoric acid-acetic acid, indophenol solution, and ascorbic acid standard [(USP) Ascorbic Acid Reference Standard] were prepared as described by AOAC 967.21. Extraction of Vitamin C from the samples was done using metaphosphoric acid-acetic acid as described by AOAC 967.21 method with slight modification. Briefly, two grams of the ground sample that had been dried was weighed into 50 mL centrifuge tubes and 20 mL of metaphosphoric acid-acetic acid was added. The mixture was centrifuged at 3500 rpm for 15 minutes and the supernatant was transferred into a new centrifuge tube for analysis (or filtered where necessary). The indophenol solution was standardized by adding it to the standard ascorbic acid solution (a mixture of 5 mL metaphosphoric acid-acetic acid and 2 mL standard ascorbic acid) using an automated Thermo Scientific titrator (Orion Star T900) until the pink rose color persisted for 5 seconds and the corresponding mV value was recorded as an endpoint. For the sample analysis, 5 mL of metaphosphoric acid-acetic acid and 2 mL sample extract were pipetted into a flask and then titrated with indophenol solution using the automated Thermo Scientific titrator (Orion Star T900). The endpoint was preset as a mV value determined through the standardization step. The ascorbic acid content was reported as mg/100g.

#### **2.3.3.2.2. Mineral Content**

Approximately 0.5 g of the sample was mixed with 10 mL of concentrated nitric acid (HNO<sub>3</sub>) in Teflon microwave digestion vessel. The closed Teflon vessels containing sample and nitric acid were then subjected to MARS 6 Microwave (CEM Corporation, Matthews, NC) heating for predefined time and temperature. After the samples were digested completely resulting in a clear solution, the content was then transferred into a 25 mL volumetric flask and diluted with distilled water to the mark. After the standards were prepared, the mineral contents (Ca, Mg, K, P, Cu, Fe, Mn, Zn, Na, Sr, Al, Cd, Cr, Ni, and Pb) were determined by Perkin Elmer Ion Coupled Plasma Emission Spectrometer (Perkin Elmer, 8000 DV) in radial orientation.

#### **2.3.3.3. Color Analysis**

Hunter L\*A\*B\* color values were measured with a ColorFlexEZ colorimeter (CFEZ2636, Hunter Associates laboratories, VA, USA) at a 45°/0° optical geometry. The instrument was first calibrated against a standard black glass reference tile and then against a standard white glass reference tile. Ground samples were placed in a 45-mm clear glass sample disk with at least 25 mm of the sample (first black line) and covered with a black cover to take the measurement. Three measurements were performed for each sample, and averages of these readings are reported and used in the analysis. Results were expressed as tri-stimulus values, L\* (lightness, 0 =black, 100 = white), a\* (-a\* = greenness, + a\* = redness), and b\* (-b = blueness, +b = yellowness).

#### **2.3.4. Statistical Analysis**

Statistical analyses were carried out using JMP statistical software version 17.0 (SAS Institute, Cary, NC, USA). Results were expressed as mean and standard deviation from duplicate analyses. ANOVAs were conducted on the mean values between treatments and the mean differences from ANOVA analyses were determined using Tukey's HSD post hoc test with  $\alpha = 0.05$ .

## **2.4. Results and Discussion**

### **2.4.1. Proximate Composition**

#### **2.4.1.1. Proximate composition of Sweetpotato Leaves**

##### **2.4.1.1.1. Effect of Varieties on Proximate Composition of Sweetpotato Leaves**

The moisture and dry matter content of the four sweetpotato leaves varieties did not show any significant difference ( $p > 0.05$ ). Figure 2.2 shows the values of moisture and dry matter content (fresh weight) of sweetpotato leaves. The moisture and dry matter content of the leaves were in the range of 80.95 to 81.47 g/100g fresh weight (FW) and 18.53 to 19.05 fresh weight (FW) respectively. The moisture content obtained in this study was slightly lower and the dry matter content was slightly higher than those reported by Mwanri et al. (2011) for sweet potato leaves. Sun et al. (2014) reported moisture content in the range of 84.09-88.92 g/100g dry weight (DW) for 40 varieties of sweetpotato leaves in China which is also slightly higher than the values obtained in this study. The difference in genotype, drying methods used, the extent of drying (duration), and maturity of the sweetpotato leaves could have influenced the differences in moisture and dry matter content. The proximate composition differed significantly among the sweetpotato leaf varieties ( $p < 0.05$ ), as shown in Figure 2.3. The proximate composition of the four sweetpotato varieties (Bonita, Murasaki-29, Purple Majesty, Covington field 1 and Covington field 2) were in the range of 4.82-6.38 g/100g dry weight (DW) for moisture content, 3.0-3.59 g/100g (DW) for crude fat content, 18.53-23.32 g/100g (DW) for crude protein content, 7.91-10.34 g/100g for ash content, 7.35-8.59 g/100g for crude fiber content and 56.08-62.43 g/100g for carbohydrate content. The Covington sweetpotato leaf variety from field 2 had the highest crude fat content ( $3.59 \pm 0.5$  g/100) whereas the Covington from field 1 had the lowest crude fat content ( $3.0 \pm 0.56$  g/100g). Field 2 was harvested about 5 weeks later than field 1. The protein content was lowest in Purple Majesty (18.53 g/100g DW) while Covington from field 1 had the highest protein content (23.32 g/100g DW). Sweetpotato leaf protein is rich in lysine, and tryptophan, which are not commonly found in cereals (Mwanri et al., 2011) and therefore this makes it a good addition to diets that are predominantly based on cereals. Covington from field 2 had the highest ash content (10.34 g/100g DW) with Purple Majesty having the lowest ash content (7.91 g/100g DW). Ash content is a measure of the mineral content in food, therefore, sweetpotato leaves of Covington varieties should be targeted to increase the mineral content in food during formulation

development. Analysis of variance showed no significant differences in protein content among leaves of sweetpotato varieties of Bonita, Covington from field 1, and Covington from field 2. There was no significant difference ( $p \geq 0.05$ ) in fat content among the Covington from field 2, Bonita, Murasaki, and purple majesty sweetpotato leaf varieties. These results are similar to those reported by (Sun et al., 2014) who analyzed the nutritional quality of proximate composition and antioxidant activity of polyphenols of 40 sweetpotato cultivar leaves in China dried by freeze-drying method. The authors reported protein content in the range of 16.69-31.08 g/100g, fiber content in the range of 9.15-14.26 g/100g (DW), crude fat content in the range of 2.08-5.28 g/100g (DW), ash content in the range of 7.39-14.66 g/100g, and carbohydrate content in the range of 42.03-61.36g/100g in the sweetpotato leaves.

#### **2.4.1.1.2. Effects of Drying Methods on Proximate Composition of Sweetpotato Leaves**

For Murasaki-29, under different drying methods, the proximate composition ranged from 3.87-6.90 g/100g, 2.94-3.39 g/100g, 18.87-20.93g/100g, 8.00-8.28g/100g, 8.50-8.70g/100g, and 59.52-61.21 g/100g for moisture (DW), crude fat (DW), crude protein (DW), ash (DW), crude fiber, and carbohydrate respectively (Figure 2.5). All drying methods were not significantly different in all proximate composition parameters of the Murasaki-29 Sweet potato leaf variety ( $p > 0.05$ ) except moisture content which was significantly higher in convection dried leaves at 52 °C and significantly lower in air fried leaves at 52 °C.

The proximate composition of Bonita Sweetpotato leaf variety ranged from 5.11 (Convection oven dried 1, COD 1) to 7.34 (Convection oven dried 2, COD2) g/100g DW for moisture; 2.55 (COD 2) to 3.42 (AF 2) g/100g DW for crude fat ; 21.65 (COD 1) to 25.85 (COD 2) g/100g DW for crude protein, 8.08 (COD 1) to 9.65 (COD 2) g/100g DW for ash , 8.26 (COD 1) to 8.66 (Freeze-dried, FD) g/100g DW for crude fiber, and 53.45 (COD 2) to 58.85 (COD 1) g/100g DW for carbohydrate (Figure 2.6). All drying methods were not significantly different with respect to fat, protein, fiber, and carbohydrate ( $p > 0.05$ ). There were significant differences in moisture and ash content among the drying methods ( $p \leq 0.05$ ).

In Covington from field 1 (Figure 2.7), fat content was highest in freeze-dried leaves (3.48 g/100g DW) whereas convection oven-dried leaves at 52 °C had the lowest fat content (2.53 g/100g).

Convection oven-dried (52 °C) leaves had the highest protein content (24.93 g/100g) while freeze-dried leaves had the lowest protein content (22.48 g/100g). Although there was this variation in protein content among the drying methods, the protein content was not significantly different among the drying methods ( $p>0.05$ ). The ash content varied significantly depending on the method of drying ( $p<0.05$ ). The convection oven at 52 °C had the highest ash content (9.35 g/100g), while the lowest ash content was observed in convection oven-dried (60 °C) leaves (7.87 g/100g). The crude fiber and carbohydrate content were in the range of 7.26-7.42g/100g DW, and 55.79-59.56 g/100g DW respectively.

On different drying methods and temperatures, Covington sweetpotato leaf variety obtained from field 2 had varying proximate composition (Figure 2.8). Freeze-dried leaves were significantly higher in fat content (4.46 g/100g) while air-fried leaves at 52 °C had significantly the lowest ash content (3.15 g/100g) ( $p<0.05$ ). Moisture content was highest in freeze-dried leaves (7.81g/100g) and lowest in leaves dried by food dehydrator at 60 °C (4.30 g/100g). No significant difference ( $p<0.05$ ) in protein content among the drying methods was observed. However, leaves dried at 60 °C by food dehydrator had the highest protein content (23.19 g/100g DW) whereas air-fried leaves at 52 °C had the lowest protein content (22.10 g/100g). Ash, crude fiber and carbohydrate content ranged from 9.95-10.79 g/100g, 7.36-7.50 g/100g, 55.05-57.01 g/100g respectively.

In Purple Majesty, the proximate composition did not differ significantly among the drying methods ( $p>0.05$ ) except moisture content. Moisture content ranged from 4.40 (convection oven 60 °C) to 6.94 (Air-fried 60 °C) g/100g of dry weight. The protein content was in the range of 17.76 g/100g (convection oven at 60 °C) to 19.21 g/100g (air fried at 60 °C). Freeze-dried leaves had the highest ash content (8.08 g/100g) while ash content of 7.69 g/100g obtained from convection oven-dried leaves at 60 °C was the lowest. Fat content ranged from 3.04 (convection oven 60 °C) to 3.43 (freeze-dried) g/100g of dry weight; crude fiber ranged from 7.89 (AF 2) to 7.98 (COD 2) g/100g of dry weight; carbohydrate ranged from 61.74 (AF 1) to 63.16 (COD 1) g/100g of dry weight (Figure 2.4). These results are in agreement with results reported by several studies (Mwanri et al., 2011; Sun et al., 2014) for sweetpotato leaves. Even though there were significant differences in some proximate composition among the different drying methods, overall, the drying methods had

little effect on proximate composition of the sweetpotato leaves. Varietal difference was identified as the primary factor contributing to the variations in proximate composition of sweetpotato leaves.

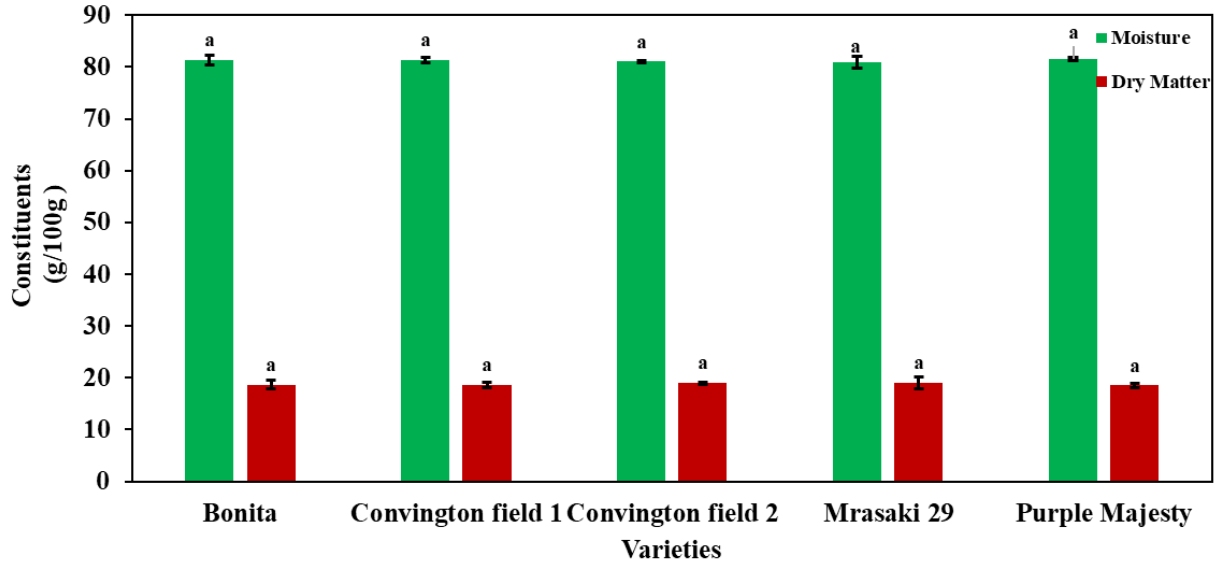


Figure 2.2. Moisture and dry matter (g/100g) of Bonita, Covington 1, Covington 2, Murasaki-29, and Purple Majesty varieties of sweetpotato leaves.

Each bar represents the mean of duplicate determinations. Bars with common letters represent no significant difference ( $p>0.05$ ) in moisture and dry matter among the varieties.

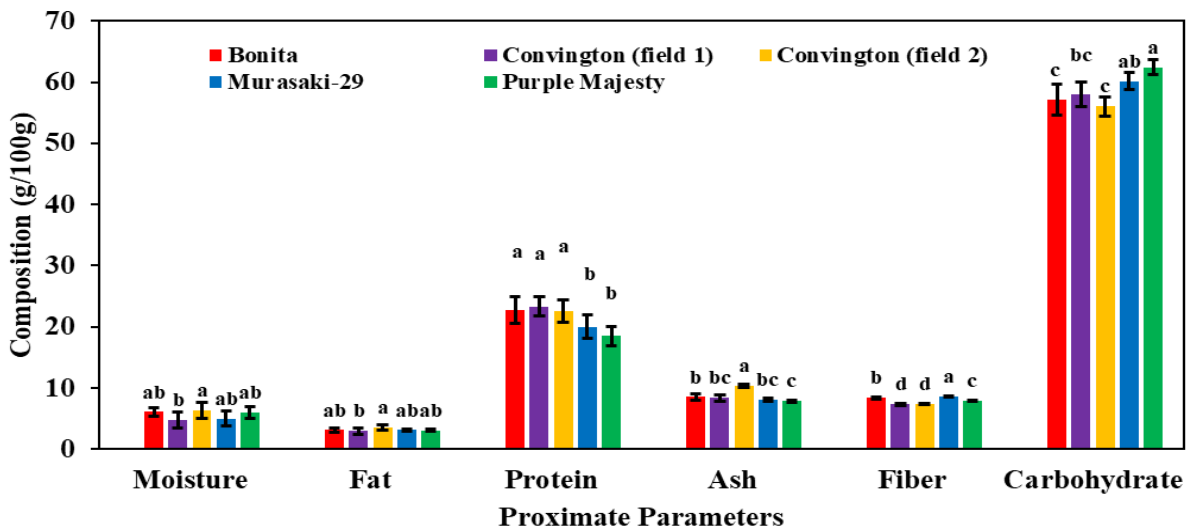


Figure 2.3. Proximate composition (g/100g) of Bonita, Covington 1, Covington 2, Murasaki-29, and Purple Majesty varieties of sweetpotato leaves.

Each bar represents the mean of duplicate analyses. Bars with common letters for each proximate composition parameter represent no significant differences ( $p>0.05$ ).

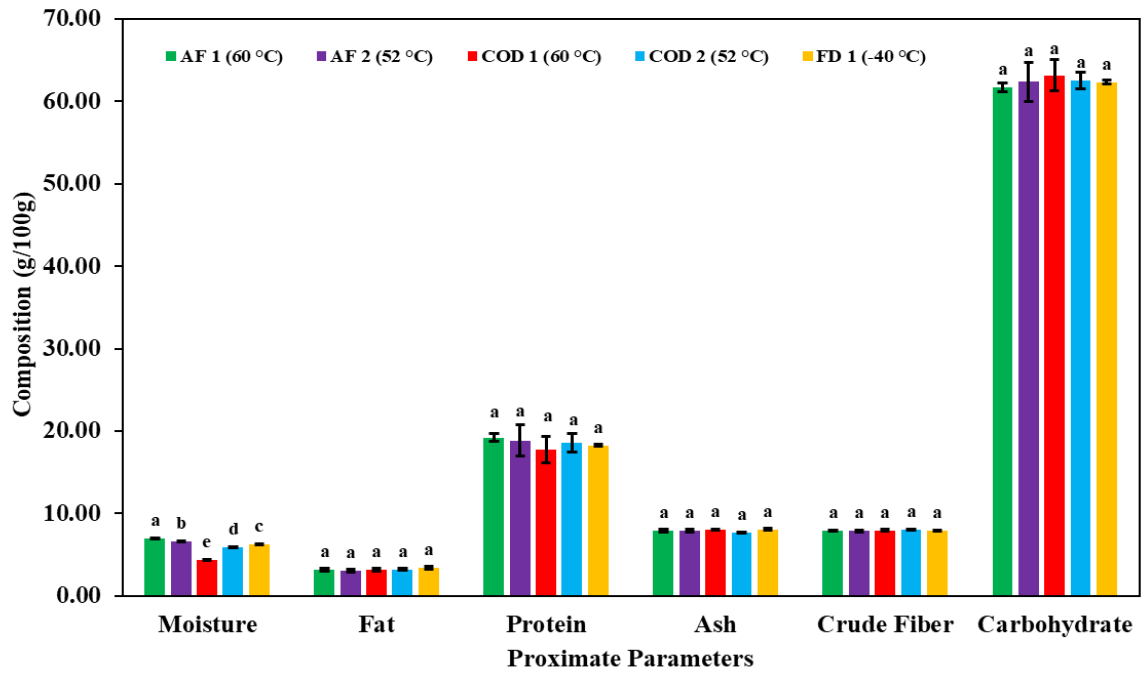


Figure 2.4. Proximate composition (g/100g) of Purple Majesty sweetpotato leaf variety on different dehydration methods and temperatures.

AF (Air fried), COD (convection oven dried), FD (freeze-dried). Each bar represents the mean of duplicate analyses. Bars with common letters for each proximate composition represent no significant differences ( $p>0.05$ ).

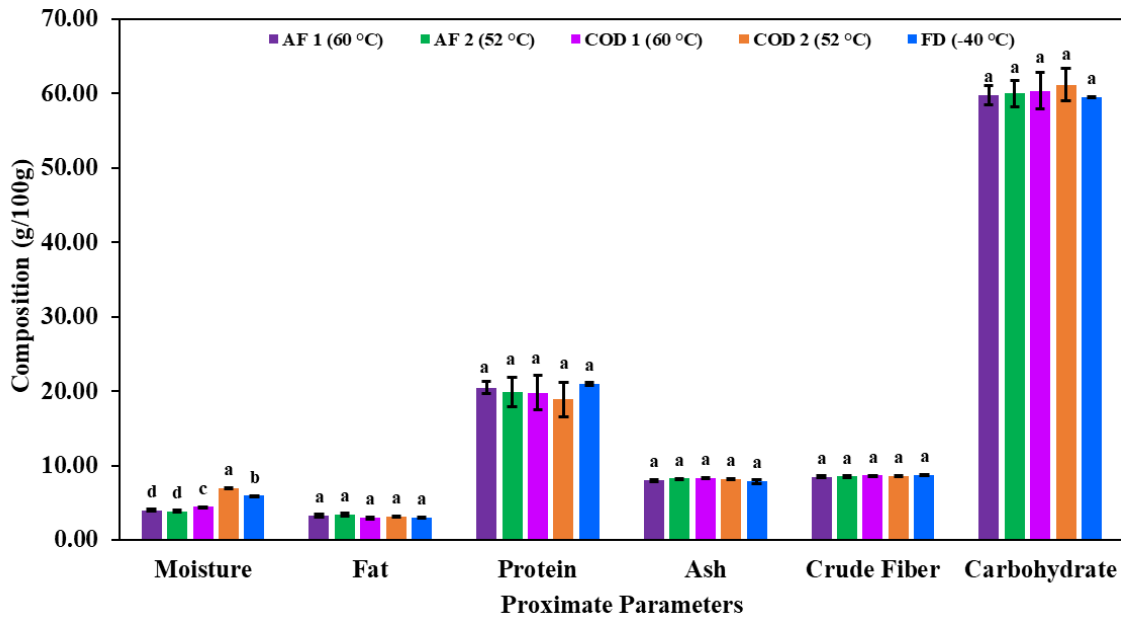


Figure 2.5. Proximate composition (g/100g) of Murasaki-29 sweetpotato leaf variety on different dehydration methods and temperatures.

AF (Air fried), COD (convection oven dried), FD (freeze dried). Each bar represents the mean of duplicate analyses. Bars with common letters for each proximate composition parameter represent no significant difference ( $p > 0.05$ ).

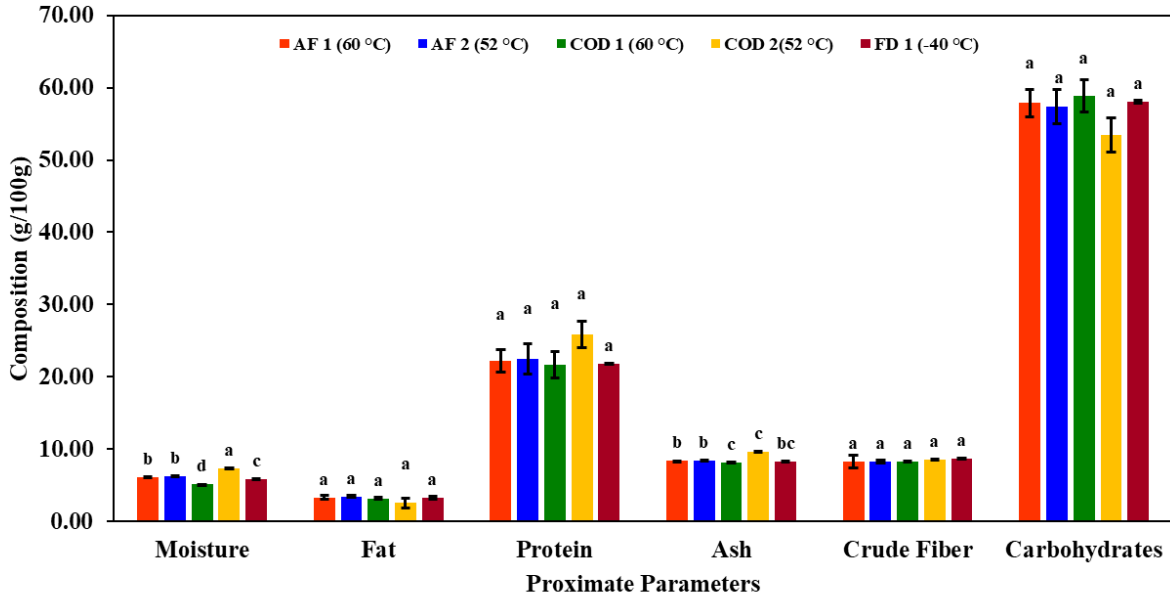


Figure 2.6. Proximate composition (g/100g) of Bonita sweetpotato leaf variety on different dehydration methods and temperatures.

AF (Air fried), COD (convection oven dried), FD (freeze-dried). Each bar represents the mean of duplicate analyses. Bars with common letters for each proximate composition parameter represent no significant differences ( $p > 0.05$ ).

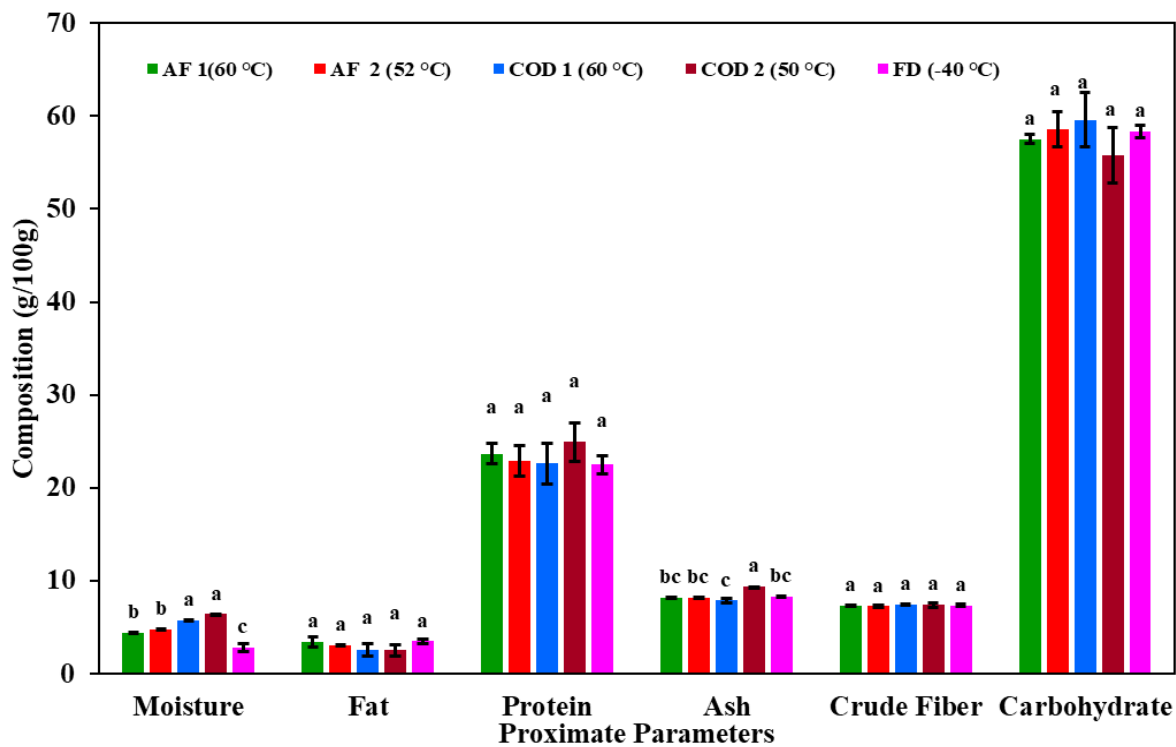


Figure 2.7. Proximate composition (g/100g) of Covington sweetpotato leaf (field 1) variety on different dehydration methods and temperature. AF (Air fried), COD (convection oven dried), FD (freeze-dried). Each bar represents the mean of duplicate analyses. Bars with common letters for each proximate composition parameter represent no significant differences ( $p>0.05$ ).

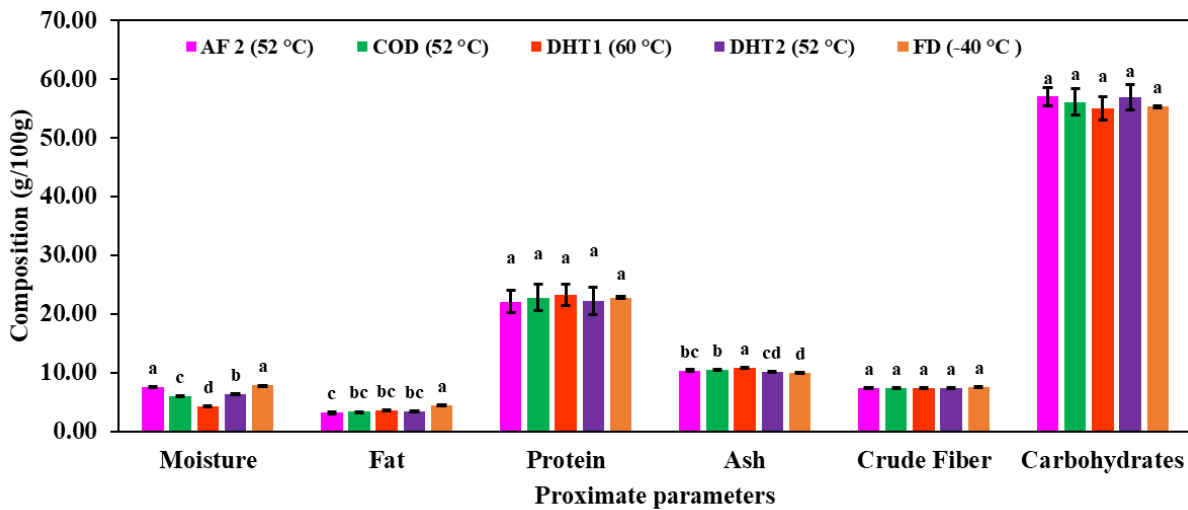


Figure 2.8. Proximate composition (g/100g) of Covington sweetpotato leaf (field 2) variety on different dehydration methods and temperature. AF (Air fried), COD (convection oven dried), FD (freeze-dried). Each bar represents the mean of duplicate analyses. Bars with common letters for each proximate composition parameter represent no significant differences ( $p>0.05$ ).

## 2.4.1.2. Proximate Composition of Orange Fleshed Sweetpotato Flour.

### 2.4.1.2.1. Effect of Varieties and Drying Methods on Proximate Composition of Orange Fleshed Sweetpotato Flour.

Figure 2.9 shows moisture and dry matter content (g/100g of fresh weight of sample) and the proximate composition (g/100g dry weight le) of the two OFSP flour varieties are shown in Figure 2.10. The two varieties did not differ significantly ( $p>0.05$ ) in moisture and dry matter content. However, moisture was slightly higher in Covington (78.08 g/100g FW) than in Beauregard (77.96 g/100g FW), whereas the dry matter content was slightly higher in Beauregard (22.04 g/100g FW) than in Covington (21.92 g/100g FW). These values are comparable to those reported by Yencho et al. (2008) for Covington and Beauregard orange fleshed sweetpotato varieties. The authors reported dry matter content of 20.0 g/100g for Covington and 18.7 g/100g for Beauregard roots when the harvested roots were cured at 30 °C, 80% to 90% relative humidity for 7 days. Dry matter content of Covington storage roots is typically 1 to 2 percent higher than that of Beauregard (Yencho et al., 2008). However, results obtained in this study showed that Beauregard had slightly higher dry matter content than Covington. This difference could be attributed to high moisture content in Covington variety as freshly harvested roots were used whereas the roots of Beauregard variety were purchased from the market which were previously cured and therefore might have contained less moisture.

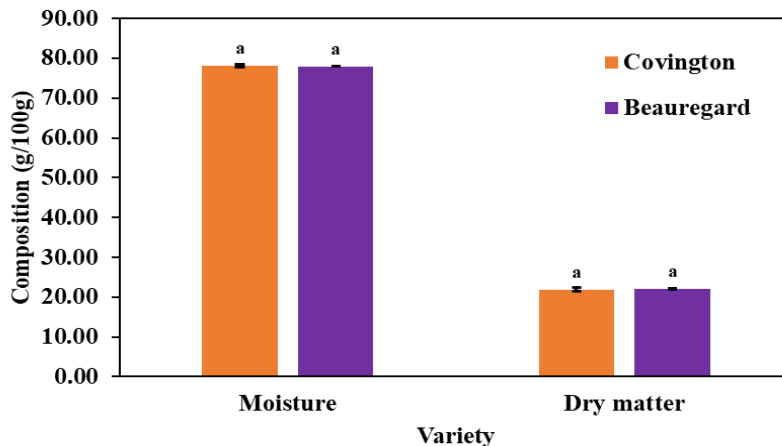


Figure 2.9. Moisture and dry matter (g/100g) of Covington and Beauregard sweetpotato varieties. Each bar represents the mean of duplicate analyses.

Bars with common letters represent no significant differences ( $p>0.05$ ) in moisture and dry matter between the varieties.

In Covington sweetpotato flour and with respect to drying methods, freeze-dried and air fried flour had lower moisture content of 6.13 and 6.12 g/100g DW respectively, whereas dehydrator dried flour had the highest moisture content (7.50 g/100g DW). The slight variations in moisture content among the drying methods could be attributed to the differences in drying time and degree to which the sample is dried during its preparation stage (Van Hal, 2000). Flour with moisture content of 2-3% can be obtained using artificial dryers, while in solar drying, a moisture content as low as 8% can be obtained. Crude fat content ranged from 0.55 (Dehydrator dried-DHT) to 0.74 (Freeze-dried-FD) g/100g. Protein content ranged from 7.43 g/100g (DHT) to 8.91 g/100g (FD). Ash content ranged from 3.23 (DHT) to 4.54 (COD) g/100g; crude fiber ranged from 2.70 (AF) to 2.93 g/100g (COD); carbohydrate ranged from 83.08 (FD) to 84.77 g/100g (AF).

In Beauregard sweetpotato flour, the proximate composition values were 6.40 (DHT) and 7.48g/100g (COD) for moisture; 0.42 (COD) and 0.55 (DHT) g/100g for crude fat; 5.17 (COD) and 6.72 g/100g (DHT) for crude protein; 4.18 (DHT) and 4.23 g/100g (COD) for ash; 3.09 (COD) and 3.15g/100g (DHT) for fiber; 85.42 (DHT) and 87.08 g/100g (COD) for carbohydrate. The majority of sweetpotato flour is made up of carbohydrates, which ranges between 84.6 g/100g to 94.8 g/100g on a dry weight basis (Van Hal, 2000), which is similar to the range of values obtained in this study for sweetpotato flour. Analysis of variance showed no significant differences ( $p>0.05$ ) in proximate composition among the drying methods in Beauregard sweetpotato flour except in moisture content.

It can be seen from Figure 2.10 of proximate composition of the two OFSP flour varieties as affected by variety and drying methods that the two varieties differed significantly ( $p<0.05$ ) in some parameters such as moisture and ash content. Samples were not significantly different ( $p>0.05$ ) in crude fat, crude protein, crude fiber, and carbohydrate content between the two varieties. The moisture contents obtained in this study were within the range for sweetpotato flour (4.4 -13.2 g/100g DW) reported by Van Hal (2000) and 6.23-6.61 g/100g reported by Mitiku and Teku (2017). Olatunde et al. (2016) reported moisture content of 8.06-12.86 g/100g DW in their evaluation of quality attributes of sweetpotato flour as influenced by variety, pretreatment and drying method, which is slightly higher than values obtained in this study. Drying method and duration of drying are the main factors that influence the moisture content (Van Hal, 2000). The moisture content of sweetpotato flour is considered a quality characteristic where storage is

concerned, since water can accelerate chemical or microbiological deterioration (Van Hal, 2000). Lower moisture content obtained in this study indicates that the flour could have a longer shelf-life.

The protein content range of 5.17 g/100g (Beauregard) to 8.91 g/100g (Covington ) is higher than the protein content values of  $(2.07 \pm 0.13- 2.76 \pm 0.34 \text{ g/100g})$  reported by Mitiku and Teka (2017) and 0.55 to 5.87 g/100g reported by Olatunde et al. (2016) for sweetpotato flour. Depending on the duration and the intensity (temperature) of heat exposure, heat processing treatments have a negative effect on protein quantity and quality (Van Hal, 2000). Drying temperatures below 80 °C which were used in this study are considered less destructive to protein (van Hal 2000). This effect can be seen in freeze-dried (FD) sweetpotato flour of Covington sweetpotato variety which had the highest protein content (8.91g/100g) while the lowest protein content (7.43g/100g) was recorded in dehydrator-dried (60 °C) sweetpotato flour. Freeze drying technology is expensive in terms of processing costs, hence, use of inexpensive technologies is recommended to lower the processing costs provided that the quality of the flour remains acceptable (Van Hal, 2000). The differences in protein content may be predominantly due to differences in sweetpotato varieties, geographical location, and soil. Furthermore, the chemical composition and nutritional quality of sweet potato flour are mainly determined by the chemical composition of the sweetpotato roots, which is related to the time of harvest (Van Hal, 2000). Protein is a vital macronutrient required for human growth and development. Although sweetpotato is a low-protein food that is high in energy, it has been reported that its protein in both fresh and flour form is of good biological quality (Van Hal, 2000). Sweetpotato flour intake would contribute only 10% of recommended daily intake (RDA) for protein (Van Hal, 2000). Results of protein content obtained in this study for the two sweetpotato varieties confirm that sweetpotato tubers alone do not provide sufficient protein to meet the protein requirement of a diet during formulation of a complete meal, so fortification with other protein-rich ingredients is necessary to increase the protein content of the final product. The fat content values obtained in this study are comparable to those reported by Olatunde et al. (2016) (0.04-1.45 g/100g) for orange fleshed sweetpotato flour but are lower than the fat content reported by Mitiku and Teka (2017) ( $1.52 \pm 0.16-1.25 \pm 0.06$ ) for white and yellow fleshed sweetpotato flour. This indicates that the difference in sweetpotato variety could have influenced the variation in fat content values reported in this study. Naturally, sweetpotato is a low-fat food, so fortification with other ingredients such as edible insects, which are rich in fats (Ramos-

Elorduy, 2005) can help with absorption of fat-soluble nutrients present in sweetpotato such as beta-carotene. The ash content values for this study are higher than the ash content reported by (Olatunde et al., 2016) (0.15-2.09 g/100g) for sweetpotato flour. Yenchou et al., (2008) reported ash content of 0.91% for Beauregard and 0.88% for Covington sweetpotato varieties. A study by Mitiku and Teka (2017) reported ash content values of  $3.38 \pm 0.01$  g/100g and 5.32 g/100g for flour made from white and yellow sweetpotato varieties respectively, which are similar to the ash content values obtained in this study. Ash content is used as a measure of the amount of total minerals present in a biomass and it is an important quality parameter (Liu, 2019). Variations in ash content can be attributed to differences in varieties (Van Hal, 2000).

In general, the differences observed in proximate composition could be attributed to the differences in cultivars rather than the drying methods used. This is in agreement with results of a study conducted by Olatunde et al. (2016) that evaluated the quality attributes of sweet potato flour as influenced by variety, pretreatment, and drying method and found that variety was a dominant factor influencing attributes of sweet potato flour and so should be targeted at specific end uses.

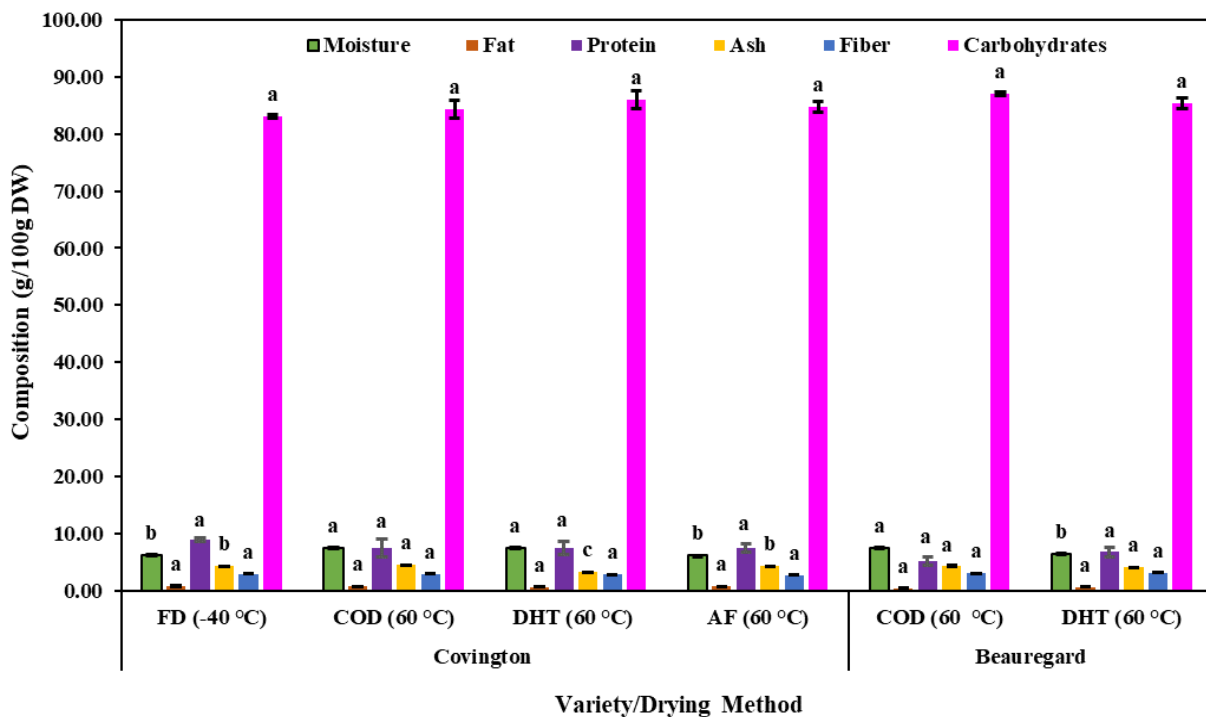


Figure 2.10. Proximate composition (g/100g) of Covington and Beauregard sweetpotato flour. Each bar represents the mean of duplicate determinations. Bars with different letters represent significant differences ( $p < 0.05$ ) among the samples for each proximate composition.

### 2.4.1.3. Proximate Composition of Edible Insects

The removal of moisture through dehydration enhances the shelf life of insects being stored for food or feed. Furthermore, it is considered necessary as a precondition and/or preliminary measure for certain ingredient production extraction methods (Hernández-Álvarez et al., 2021). In this study, insects were dehydrated in a convection oven at 60 °C and analysis on proximate composition was conducted. Figure 2.11 shows moisture and dry matter content (100 g/100 DW) of two groups of oven-dried mealworms purchased at different times from different suppliers. As it can be seen from the results, the two groups of mealworms were not significantly different ( $p>0.05$ ) in moisture and dry matter content. The moisture content was 59.85 g/100g and 58.28 g/100g FW for mealworms 1 and mealworms 2 respectively. Dry matter content values were 40.16 g/100g (fresh weight) for mealworms 1 and 41.72 g/100g FW for mealworms 2 respectively.

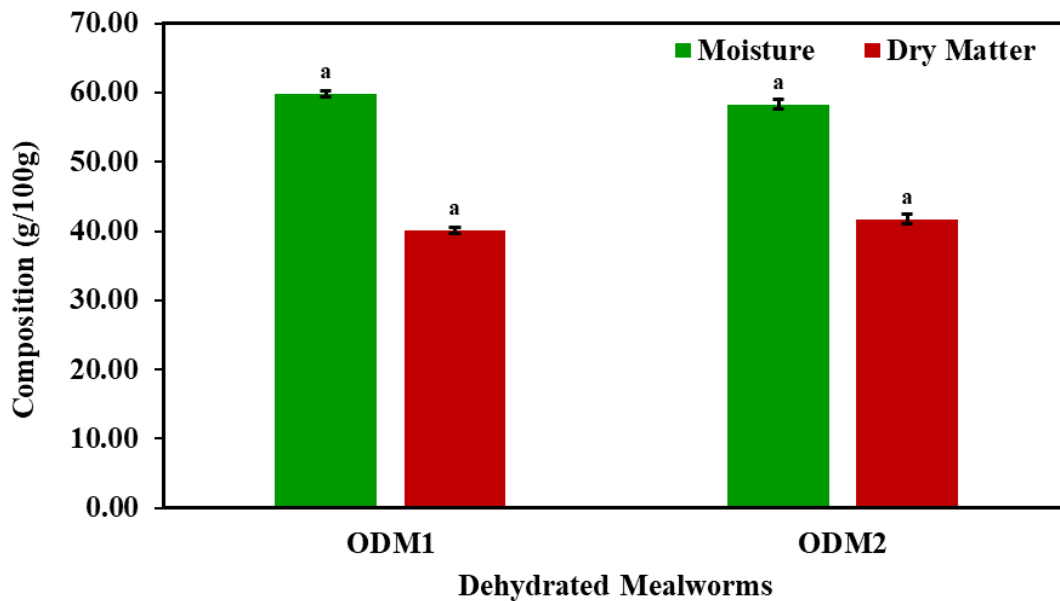


Figure 2.11. Moisture and dry matter (g/100g) of mealworms; live oven-dried mealworm 1 (LODM 1) and live oven-dried mealworms 2 (LODM 2).

Each bar represents the mean of duplicate analyses. Bars with common letters represent no significant differences ( $p>0.05$ ) in moisture and dry matter between the samples.

In this study, the proximate composition of the oven-dried mealworms was compared to the proximate composition of already dried mealworms (ADM) and Cricket powder (CP) that were

purchased from insect suppliers in the US. The proximate composition of the oven-dried mealworms (ODM), already dried mealworms (ADM), and Cricket powder (CP) are shown in Figure 2.12. The results of one-way ANOVA revealed significant differences in all proximate composition parameters except ash content among the edible insects' powders ( $p \leq 0.05$ ). The moisture content was significantly lowest in convection oven dried mealworms 2 -ODM2 (2.70 g/100g dry-weight) and ODM1 (3.50 g/100g dry-weight). Moisture was significantly highest in already dried mealworms, ADM (6.2 g/100g dry weight) followed by Cricket powder, CP (4.30 g/100g). The moisture results obtained in this study are similar to results obtained in one study by Krzyżaniak et al. (2022) where the authors determined the extent to which the application of blanching, different drying temperatures and times, and different drying methods influenced selected physical and chemical parameters of yellow mealworms. The authors reported moisture content in the range of 3.15% (blanched for 180 min then dried at 80 °C in convection oven) to 5.47% (blanched for 60 min then freeze-dried -30/-40 °C). Kröncke et al. (2019) used rack oven drying, vacuum drying and freeze-drying methods to dehydrate mealworms. Their results for moisture content ranged from 0.87% (rack oven drying) to 9.83% (freeze drying) which are within the range of results obtained in this study. The crude fat content obtained in this study ranged from 27.85 g/100g dry weight (ODM2) to 31.69 g/100g dry weight (ODM1). The fat content values in this study are slightly lower than those reported by Alves et al. (2016) for yellow mealworms powder who reported values ranging from 39.05 g/100g DW to 40.45 g/100g DW. Krzyżaniak et al. (2022) reported crude fat content values in the range of 29.5 g/100g to 39.9 g/100g for mealworms powder, which are similar to the fat content values obtained in this study. Edible Insects have a significant amount of fat, which is the second largest component of their nutrient profile (Ramos-Elorduy, 2005). The average fat content varies by order, with Orthoptera (grasshoppers, crickets, locusts) being protein-rich but containing only 13.41%, while Coleoptera (beetles, grubs) contain the highest fat content at 33.40%. Other insects such as Hemiptera (bugs), Isoptera (termites), Blattodea (cockroaches), and some Lepidoptera (caterpillars) also have high fat content, ranging from 30.26, 32.74, 29.90, and 27.66% on average respectively (Rumpold & Schlüter, 2013). The protein content was highest in cricket powder (58.58 g/100g DW) while the lowest protein content was observed in already dried mealworms (50.50 g/100g DW). The protein content differed significantly among the samples ( $p < 0.05$ ). The protein values obtained in this study are similar to the protein values reported in many studies 44.83 g/100g to 50.07 g/100g (Alves et

al., 2016); 47.10 g/100g to 54.50 g/100g (Krzyżaniak et al., 2022); 50.96 g/100g to 51.51 g/100g (Selaledi & Mabelebele, 2021); 52.23 g/100g to 56.30 g/100g (Kröncke et al., 2019) for yellow mealworms. The ash content in the samples ranged from 2.68 g/100g (CP) to 4.07 g/100g (ADM). The ash content values are comparable to those reported for mealworms (2.77 g/100g to 3.55 g/100g) by Krzyżaniak et al. (2022) and (4.15 to 4.23 g/100g) reported by Selaledi and Mabelebele (2021). The fiber content was in the range of 5.92 g/100g DW (CP) to 7.58 g/100g DW (ODM 2). Most edible insects have exoskeletons composed of chitin that are the good sources of fiber. The crude fiber content values are in agreement with results of several studies (Alves et al., 2016; Kröncke et al., 2019; Krzyżaniak et al., 2022; Selaledi & Mabelebele, 2021) for mealworms. Fombong et al. (2017) evaluated the influence of freeze-drying and oven-drying post blanching on the nutrient composition of the edible insect longhorn grasshopper (*Ruspolia differens*) in Kenya. The authors' results revealed that there was no significant difference in protein content of freeze-dried and oven-dried grasshoppers and that there was slight variation in proximate composition, mineral and fatty acid. In this study, the variation in the proximate composition in oven-dried mealworms, already dried mealworms and the cricket powder could be attributed to differences in insect species (mealworms vs. crickets), or the insects' rearing conditions (farm-dried mealworms vs. live mealworms dried in lab). The diet could contribute to variation because oven dried mealworms that were purchased from different suppliers might have not been fed the same diet and we do not know what they were fed. This is in agreement with results reported by Alves et al. (2016) who analyzed the nutritional composition of mealworms grown on different artificial diets with bocaiuva pulp flour. Depending on the diet, their results revealed both significant increase and decrease in moisture, protein, lipid, ash and carbohydrates in the mealworms. The developmental stage of the insects which also affects the nutritional composition of edible insects was ruled out as a contributing factor to the slight variation observed in this study as both mealworms were purchased in their adult stage.

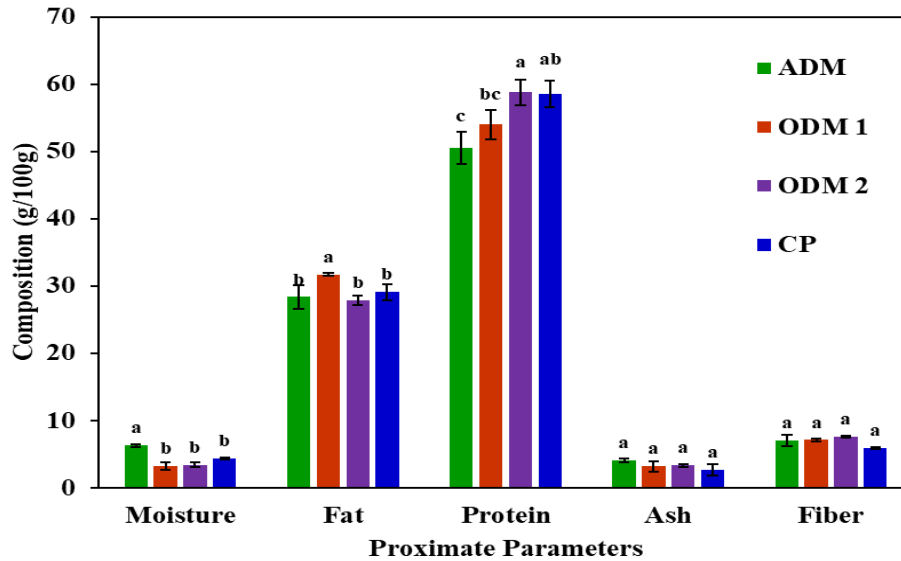


Figure 2.12. Proximate composition (g/100g) of already dried mealworms (ADM), oven-dried mealworms type 1 (ODM 1), oven-dried mealworms type 2 (ODM2), and Cricket powder (CP).

Each bar represents the mean of duplicate determinations. Bars with different letters represent significant differences ( $p < 0.05$ ) among the samples for each proximate composition.

## 2.4.2. Color Results

### 2.4.2.1. Color Results of Dehydrated Sweetpotato Leaves

Color measurements for the dried sweetpotato leaves powder as affected by variety and drying methods are shown in Figure 2.13. Three measurements were performed for each sample and averaged to obtain representative color values for each treatment. Sweetpotato leaf powder  $L^*$ ,  $a^*$ , and  $b^*$  values were affected by drying method and temperature.  $L^*$  and  $a^*$  values were higher in freeze-dried leaves of all varieties than those of oven-dried and air-fried. Among the freeze-dried leaves, the  $L^*$  value ranged from 46.16 (Bonita) to 50.84 (Covington field 2). The lowest  $L^*$  value was observed in Bonita (36.74) that was air-fried at 52 °C. The  $a^*$  value which indicates the greenness (-a) or redness (+a) ranged from -7.54 (Murasaki, FD) to -1.00 (Covington field 1, COD 52 °C). Within each variety, all freeze-dried leaves had the lowest  $a^*$  value. The range of  $b^*$  value was from 21.32 for Bonita, Air-fried 52 °C to 29.94 for Bonita Air-fried 52 °C and Covington field 2 freeze-dried. These results show that freeze-dried leaves were lighter ( $L^*$  value), greener ( $a^*$  value) and slightly yellow ( $b^*$  value). The retention of green color ( $a^*$  value) in freeze-dried leaves can be attributed to drying at lower temperatures which might have prevented pigment degradation due to heating.

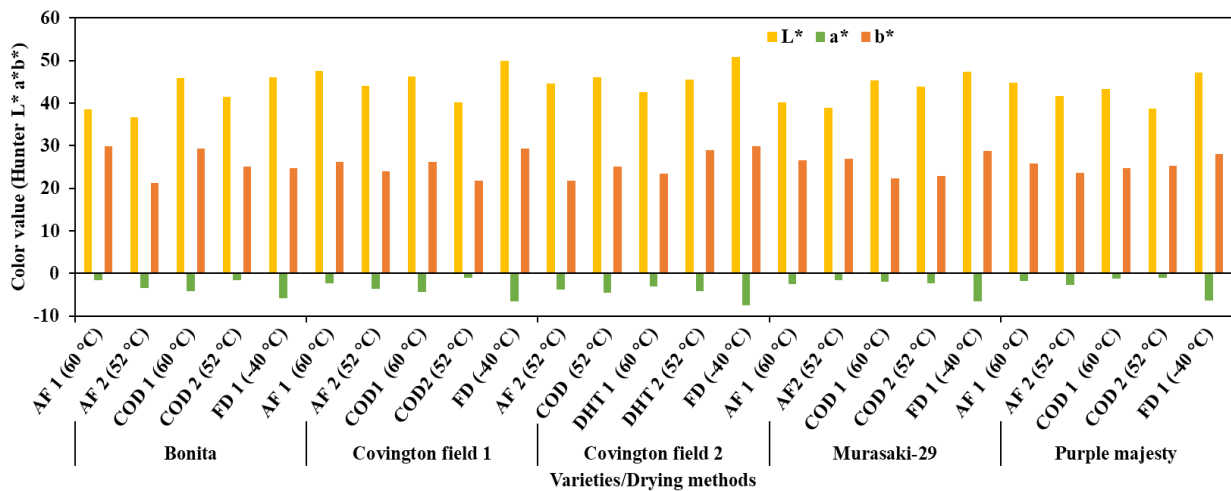


Figure 2.13. Effect of drying methods on sweetpotato leaf powder color.

Each bar represents mean of triplicate measurements. Abbreviations: FD, freeze-dried; COD, convection oven dried; DHT, dehydrator dried; AF, air fryer dried.

#### 2.4.2.2. Color of Dehydrated Sweetpotato Flour.

The Hunter L\* a\* b\* color values of sweetpotato flour as affected by variety and drying methods are shown in Figure 2.14. The mean L\* values ranged from 74.23-83.19, a\* ranged from 8.11-22.16 and b\* ranged from 21.5-29.13 for all sweetpotato flour. In terms of variety, the mean L\* values ranged from 74.23-81.73, a\* ranged from 9.75-22.16, b\* ranged from 21.5-29.13 for Covington sweetpotato flour while L\*, a\*, and b\* values for Beauregard sweetpotato flour ranged from 80.83-83.19, 8.11-13.99, and 23.5-29.01 respectively. The mean L\*, a\*, and b\* values showed greater variability between the two varieties and among the drying methods. With respect to variety and drying method, the order of L\* values were 83.19 (Beauregard, DHT) > 81.73 (Covington, DHT) > 81.44 (Covington, COD) > 80.83 (Beauregard, COD) > 78.28 (Covington, FD) > 74.23 (Covington, AF) > 56.59 (Covington, Raw). The order for a\* values were 29.55 (Covington, Raw) > 22.16 (Covington, FD) > 13.99 (Beauregard, COD) > 12.49 (Covington, COD) > 12.47 (Covington, AF) > 9.75 (Covington, DHT) > 8.11 (Beauregard, DHT). Dehydrator dried flour was lighter (higher L\* values) than the freeze dried and air-fried flour (Lower L\* values). However, the whiteness of the flour cannot be used as a measure of color retention after processing as this is not always directly related to the flesh color of the roots, rather this is an indication of level of browning that occurs during drying and processing of the flour (Van Hal,

2000). The L\* and b\* values obtained in this study are in agreement with values reported for sweetpotato by Olatunde et al., (2016).

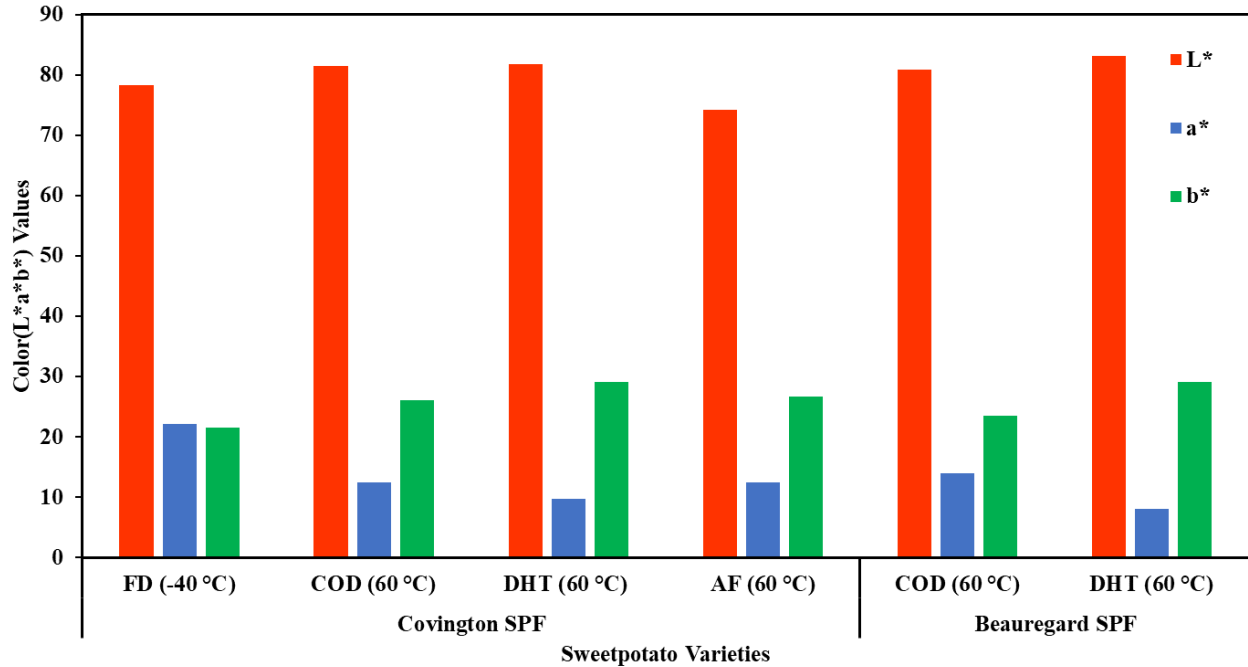


Figure 2.14. Effect of drying methods on Covington and Beauregard sweetpotato flour color.

Each bar represents mean of triplicate measurements. Abbreviations: FD, freeze-dried; COD, convection oven dried; DHT, dehydrator dried; AF, air fryer dried. The numbers in brackets are drying temperatures.

### 2.4.3. Ascorbic Acid (Vitamin C) in Dehydrated Sweetpotato Leaves and Roots.

Table 2.2 shows the ascorbic acid content in four varieties of sweetpotato leaves and two varieties of sweetpotato flesh flour. Ascorbic acid content in both leaves and roots varied significantly ( $p < 0.05$ ) among the drying methods. Freeze-dried leaves and roots showed significantly higher vitamin C content compared with air fried, convection oven dried and dehydrator dried leaves and roots. The vitamin C content in leaves ranged from 9.5 to 18.0 mg/100g (Bonita), 10.3 to 15.1 mg/100g (Covington field 1), 12.1 to 30.6 mg/100g (Covington field 2), 14.8 to 24.5 mg/100g (Murasaki-29) and 9.4 to 20.9 mg/100g (Purple Majesty) while in the sweetpotato flesh ranged from 12.35 to 18.16 mg/100g (Covington) and 9.90 to 10.08 mg/100g (Beauregard). Difference in drying temperature for each method caused little variation in the vitamin C content. The dominant factor in variations observed was the varietal difference and the type of drying method used as it can be seen from results in Table 2.1 that at the same drying temperature using the same drying

method, there was a considerable variation in vitamin C content among the varieties. Cooking leafy vegetables decreases the vitamin C content due to its high water solubility and loss through oxidation during cooking and the loss ranges from 30-93% (Sreeramulu et al., 1983). Sreeramulu et al. (1983) suggested that cooking with little water and for short time is necessary for high vitamin C retention.

Table 2.1. Vitamin C (mg/100g) content of the four varieties of sweetpotato leaves (1) and two varieties of sweetpotato roots (2) as affected by drying methods.

1							
Variety	Drying methods						
	AF1 (60 °C)	AF2 (52 °C)	COD1 (60 °C)	COD2 (52 °C)	FD (-40 °C)	DHT1 (60 °C)	DHT2 (52 °C)
Bonita	11.0 ± 0.28 <sup>bc</sup>	12.3 ± 0.54 <sup>b</sup>	9.5 ± 0.68 <sup>c</sup>	10.4 ± 0.30 <sup>bc</sup>	18.0 ± 0.56 <sup>a</sup>	-----	-----
Covington F1	12.0 ± 0.52 <sup>b</sup>	11.6 ± 0.81 <sup>b</sup>	10.3 ± 0.11 <sup>b</sup>	10.8 ± 0.77 <sup>b</sup>	15.1 ± 0.21 <sup>a</sup>	-----	-----
Covington F2	-----	17.8 ± 1.26 <sup>b</sup>	-----	17.4 ± 0.69 <sup>b</sup>	30.6 ± 1.17 <sup>a</sup>	12.1 ± 0.42 <sup>c</sup>	13.0 ± 0.32 <sup>c</sup>
Murasaki-29	14.8 ± 0.01 <sup>c</sup>	14.9 ± 0.16 <sup>c</sup>	17.8 ± 0.53 <sup>b</sup>	18.1 ± 0.09 <sup>b</sup>	24.5 ± 0.42 <sup>a</sup>	-----	-----
Purple Majesty	9.7 ± 0.79 <sup>b</sup>	10.5 ± 0.38 <sup>b</sup>	9.4 ± 0.73 <sup>b</sup>	10.0 ± 1.41 <sup>b</sup>	20.9 ± 1.29 <sup>a</sup>	-----	-----

2				
Variety	Drying methods			
	AF (60 °C)	COD (60 °C)	FD (-40 °C)	DHT (60 °C)
Covington	12.35 ± 0.75 <sup>b</sup>	14.25 ± 0.92 <sup>b</sup>	18.16 ± 0.40 <sup>a</sup>	13.60 ± 0.51 <sup>b</sup>
Beauregard	-----	9.90 ± 0.05 <sup>a</sup>	-----	10.08 ± 0.20 <sup>a</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same row, do not differ significantly (p >0.05). Abbreviations: AF, Air fried; COD, convection oven dried; DHT, dehydrator dried; FD, freeze-dried; Covington F1, Covington field 1; Covington F2, Covington field 2. Numbers in brackets after abbreviations are temperatures.

----- = sample not measured (drying method not used to dry the sample due to less sample availability)

#### 2.4.4. Mineral Content

The mineral content analysis was done on selected samples which included oven dried mealworms 1 (ODM1), freeze-dried Covington SPF, Dehydrator dried Covington SPF, Fresh Covington sweetpotato, Convection oven dried Beauregard SPF, Dehydrator dried Covington sweetpotato leaf from field 2, and freeze-dried Covington sweetpotato leaf from field 2. The mineral contents of the selected samples are shown in Table 2.2. Sweetpotato leaves were highest in calcium, potassium, magnesium, iron, and manganese while zinc, phosphorus, and sodium were highest in mealworm powder. However, there were slight variations in potassium, phosphorus, and sodium contents between the sweetpotato flour and the sweetpotato leaf powder. This shows that the variations in mineral contents among the samples can complement each other during product formulation.

*Table 2.2. Mineral composition (mg/100g) of selected sweetpotato flour, sweetpotato leaf, oven dried mealworms.*

Minerals	Samples						
	ADM	CV-SPF- FD	CV-SPF- DHT	CV-SP- Fresh	BG-SPF- COD	CV-SPL- DHT	CV- SPL-FD
Calcium (Ca)	41.64	141.80	156.08	16.65	115.23	1592.14	1521.35
Potassium (K)	712.04	1571.9	1733.9	309.1	1584.6	1763.3	1794.4
Phosphorus (P)	679.7	152.3	161.3	34.5	143.2	203.3	199.8
Zinc (Zn)	9.4	1.1	2.0	0.4	1.1	1.8	1.9
Iron (Fe)	5.4	1.8	2.5	0.8	2.5	13.5	11.3
Manganese (Mn)	0.97	0.43	0.42	0.08	0.87	4.61	3.89
Magnesium (Mg)	238.74	110.86	119.46	17.48	77.97	884.80	798.58
Sodium (Na)	111.79	11.18	18.31	6.20	9.12	11.81	13.12

**Abbreviations:** *Already dried mealworms (ADM); Covington sweetpotato flour freeze-dried (CV-SPF-FD); Covington sweetpotato flour dehydrator dried-52 °C (CV-SPF-DHT); Covington sweetpotato fresh (CV-SP-Fresh); Beauregard sweetpotato flour convection oven dried (BG-SPF-COD); Covington sweetpotato leaf dehydrator dried 52 °C (CV-SPL-DHT); Covington sweetpotato leaf freeze-dried (CV-SPL-FD).*

## 2.5. Conclusion

This study confirmed that sweetpotato roots were low in both fat and protein content. On the other hand, sweetpotato leaves were found to be rich in protein content while the edible insects were found to be rich in both protein and lipids. Since OFSP is rich in  $\beta$ -carotene, which is a fat-soluble pro-vitamin A, in this regard, fortification with edible insects can help with absorption of the nutrient while improving its protein content. The protein content in sweetpotato leaves (18.24-25.85g/100g DW) was more than twice that of sweetpotato roots (5.17-8.91g/100g DW) whereas the protein content of edible insects (50.50-58.81 g/100g DW) was more than twice that of sweetpotato leaves. In sweetpotato leaves, the Covington variety exhibited superior nutritional composition with respect to protein content, and vitamin C content and should be targeted as a suitable cheaper option for protein and vitamin C sources in sweetpotato leaves. Freeze drying resulted in sweetpotato leaf powders and sweetpotato flours with good appearance due to high color retention as measured by Hunter L\*a\*b\* values. But, due to high operational costs associated with this technology, the use of freeze-drying should be encouraged only when the product's color or appearance is a priority. Overall, this study revealed that the four different drying methods at a temperature of 60 °C or below had little effect on the nutritional composition of the sweetpotato leaves, sweetpotato roots and edible insect indicating that the temperature and extent of drying (duration) used was at a reasonable level to prevent significant nutrient loss.

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**CHAPTER 3: PRODUCT FORMULATION: USE OF SWEETPOTATO FLOUR,  
SWEETPOTATO LEAF POWDER, AND EDIBLE INSECT POWDER**

### 3.1. Abstract

The prevalence of malnourished children in Sub-Saharan Africa is high with approximately 15 million children in Sub-Saharan Africa (SSA) affected by severe acute malnutrition (SAM). Ready-to-use therapeutic foods (RUTF) are distributed in the region to help treat malnutrition. While RUTFs are nutritionally dense and an ideal product for treating malnutrition, they are inadequate due to the high cost and unreliable supply. The aim of this study was to develop an affordable sweetpotato based product fortified with locally available and familiar ingredients to treat malnutrition in young children. A product from sweetpotato flour, sweetpotato leaf powder, and mealworm powder was developed. Analyses on proximate composition, vitamin C, and mineral contents of the formulated product were conducted and compared with WFP standard (CSB). Proximate composition results for all the formulated flour ranged from 3.28-3.64 g/100g for moisture, 4.19- 6.74 g/100g for crude fat, 15.69-20.16 g/100g for protein, 4.70-5.63 g/100g for ash, 2.44-3.18 g/100g for crude fiber, and 65.32 g/100g for carbohydrate while mineral content ranged from 1563.7-2848.2 mg/100g for potassium, 218.4-383.1 mg/100g for phosphorus, 397.4-464.9 mg/100g for calcium, 2.0-3.3 mg/100g for zinc, 6.2-8.0 mg/100g for iron, 284.7-330.6 mg/100g for magnesium, and 22.55-44.78 mg/100g for sodium. Statistical analysis results showed that variation in proportions of SPF, MP, and SPL significantly ( $p < 0.05$ ) influenced the nutrient contents of the formulated product. Formulation with proportions of 60% SPF, 20% MP and 20% SP was able to meet the nutritional composition specified by World Food Program, although ash, vitamin C, and zinc were slightly lower in the formulated flour. Overall, the results of this study revealed that the formulated products are rich in mineral contents. The findings of this study provide important insight showing that an affordable and nutritious product with potential to combat malnutrition can be made from locally available ingredients. The formulated product can be used as a cheaper alternative to RUTF's and other commercial products such as CSB to prevent malnutrition among young children in SSA.

### **3.2. Introduction**

Malnutrition is a major public health problem that affects people globally, but is more prevalent in developing countries where there are high levels of undernutrition and deficiencies in micronutrients (Matiza Ruzengwe et al., 2022). Globally, there are more than 2 billion people suffering from micronutrient deficiency (WHO, 2021). In 2020, 149.2 million children under the age of five were stunted while 45.4 million were stunted, and an estimated 462 million adults were underweight (WHO, 2021). The global nutrition targets to be met by 2025 and 2030 for Sustainable Development Goal (SDG) 2 (end hunger, achieve food security, and improved nutrition and promote sustainable agriculture) endorsed by the World Health Assembly includes reducing stunting by 40 percent and 50 percent by 2025 and 2030 respectively (WHO, 2021).

One of the interventions aimed at reducing the occurrence of stunting in children under the age of five is food fortification (Homann, 2015; Kairiza et al., 2020). According to World Health Organization (WHO) (WHO, 2020), Asia and Africa have the highest levels of malnutrition globally. Praharaj et al. (2021) reported that the high prevalence of undernutrition and micronutrient deficiency in Africa and Asia is largely due to the consumption of diets that are not diverse, consisting mainly of cereal-based foods that lack fruits, vegetables legumes, pulses, and animal-based foods. Most cereals lack lysine and tryptophan, which are essential amino acids, but sweetpotato leaves contain high amounts of these amino acids (Mwanri et al., 2011). Additionally, sweetpotato leaves have been reported to contain high amounts of proteins, minerals such as calcium, iron, potassium, vitamins B, C, and antioxidants but their utilization as human food have been very little (Padmaja, 2009). Increased world population that is expected to reach 9 billion by 2050 has increased the demand for animal protein, which in turn has resulted in increases in cost of animal protein (Van Huis et al., 2013). The high cost of animal protein has led to a reduction in its consumption, resulting in a quest for more affordable animal-based protein sources, such as edible insects (Van Huis, 2013).

This study is aimed at formulating and evaluating the nutritional composition of sweetpotato based product fortified with sweetpotato leaf and edible insect powders that can be used as a cheaper alternative to commercial RUTFs and other products to combat malnutrition in children, especially

in developing countries such as those in Sub-Saharan Africa (SSA). The study used the WFP product Corn Soya Blend (CSB) as a standard.

### **3.3. Materials and Methods**

#### **3.3.1. Formulation of the product**

Flours from oven-dried Covington sweetpotato, oven-dried Covington sweetpotato leaves, and oven-dried mealworms were used to formulate the product in different ratios as shown in Table 2. Oven-dried ingredients were chosen because, in the previous study, the results obtained revealed that the drying methods had little or no effect on the nutritional composition of sweetpotato leaf powder, sweetpotato flour, and edible insect powder. The predominant factor that influenced the variation in nutritional composition observed was the variety in sweetpotato leaves and roots, and insect type in edible insects. Even though the freeze-dried sweetpotato roots and leaves showed a better appearance in terms of color, the method has limited usage in the food industry because of its expensive operation cost. Currently, it is the sole technology implemented on an industrial level to dehydrate coffee, spices, meats, food ingredients, and other high-value food products (Ratti, 2001). Formulation ratios (Table 3.1) were developed using the Pearson square method and linear programming was employed to optimize the formulation ratios that would result in nutrient content that meets the applicable standards. Nutritional specifications for WFP's CSB, a product prepared from heat-treated maize and soya beans, sugar, vitamins, and minerals, were used as a standard. The product is consumed as porridge by children and adults and is also distributed in schools in Sub-Saharan Africa including Malawi as part of school feeding programs to combat malnutrition. The nutritional specifications of CSB are shown in table 3.2. The macronutrients and micronutrients targeted by our formulation were protein, energy, fat, crude fiber, vitamin C, vitamin A, iron, zinc, calcium, and potassium.

*Table 3.1. Formulation ratios of sweetpotato flour, mealworm powder, and sweetpotato leaf powder.*

Formulation	Sweetpotato flour (SPF) (%)	Mealworm powder (MP) (%)	Sweetpotato leaf powder (SPL) (%)
1A	77	14	9
4A	67	10	23
7A	60	20	20

**Control sample:** Commercial Corn soya blend (CSB), WFP

### **3.3.2. Proximate Composition of the Formulated Product**

AOAC (2012) standard methods with slight modifications were used to determine the proximal composition of the formulated product. Moisture was analyzed by AOAC 925.09, protein (AOAC 968.06), fat (AOAC 920.39), ash (923.03), crude fiber (AOAC 962.09), and carbohydrates (g/100g) were determined by difference =  $100 - (\text{Crude fat g/100g} + \text{crude protein g/100g} + \text{ash g/100g} + \text{crude fiber g/100g})$ . For moisture content, 5 grams of sample was weighed and dried at 105 °C in a convection oven (25EM, Precision Scientific, Chicago, Illinois) to a constant weight, cooled in desiccator and weighed. The moisture content was expressed on a dry weight basis. Fat content was measured by extracting 5 grams of finely ground sample with hexane in an automated Soxhlet unit, Buchi-E-816-Soxhlet (BUCHI corporation, New Castle, DE, USA). The weight of extracted lipid was recorded and expressed as crude fat content in the sample. Crude protein content was measured by nitrogen and protein analyzer (Rapid N Exceed- Elementar Americas) which works on the principle of DUMAS method. A 250-mg portion of ground sample was weighed and deposited into the autosampler for analysis. The protein factor of 6.25 was used to calculate the % protein content. Ash content was determined by burning 5 grams of sample in a pre-weighed crucible in muffle furnace (Barnstead Int., Iowa, U.S.A.) at 550 °C for 12 hours. The crucibles were cooled in desiccators and weighed. The ash content was reported on a dry weight basis. Fiber content was determined using a previously defatted sample. Briefly, 2 g of sample was boiled in 1.25% sulfuric acid for 30 minutes, then filtered and washed. The insoluble particles were boiled in 1.25% sodium hydroxide for 30 minutes, filtered, and washed. The residue was then dried at 130 °C for 2 hours, cooled and weighed. The dried residue was ignited at 550 °C for 30

minutes to determine weight loss and calculate the crude fiber content relative to the dry weight of the sample.

### **3.3.3. Energy Content**

The energy content of the formulated product was calculated by using the conversion factors of 4 kcal/g for carbohydrate, 4 kcal/g for protein, and 9 kcal/g for fat (Marcel et al., 2022).

### **3.3.4. Vitamin C, Beta-Carotene, and Mineral Analysis**

#### **3.3.4.1. Vitamin C (Ascorbic acid)**

Vitamin C in samples was determined by titration of extracted sample with indophenol solution (AOAC 967.21). Briefly, vitamin C was extracted from  $3 \pm 0.2$  grams of sample mixed with approximately 30 mL of metaphosphoric acid-acetic acid in a 50 mL centrifuge tube and centrifuged at 3500 rpm for 15 minutes. The supernatant was transferred into new centrifuge tubes after being filtered. Indophenol solution was standardized with standard ascorbic acid by titration until pink rose color persisted for 5 seconds and corresponding volume of indophenol used was recorded. Blank was run the same way as standard ascorbic acid but using distilled water and volume in mL of indophenol solution used was recorded. Samples were analyzed by pipetting 2 mL of sample extract into a 50 mL conical flask and adding 5 mL of metaphosphoric acid-acetic acid and titrating with indophenol solution until a pink rose color persisted for 5 seconds. The ascorbic acid was calculated using the following formula:

$$\text{Ascorbic acid (mg/100g)} = [(X-B) \times (F / E) \times (V / Y)] \times 100$$

where X is the volume in mL of the indophenols solution used for the sample titration, B is the average volume in mL of indophenol used for blank titration, F is the mass in mg of ascorbic acid equivalent to 1.0 mL indophenol standard solution, E is the volume in mL of sample extract assayed, V is the total volume in mL of extract, Y is the total volume in mL of sample aliquot titrated (sample extract plus metaphosphoric acid-acetic acid).

#### **3.3.4.2. Beta-carotene analysis**

Extraction of  $\beta$ -carotene was done using a mixture of hexane and acetone solvents (50:50 ratio) and spectrophotometrically quantified. Briefly, 5 grams of finely ground sample was first mixed

with 25 mL of methanol in a 50 mL conical centrifuge tube and vortexed for 2 minutes. The mixture was then centrifuged at 5000 rpm for 10 minutes to separate the solid and liquid phases. The liquid phase was transferred into a separatory funnel while the solid phase was returned for re-extraction. The 25-mL hexane–acetone (50:50) mixture was added back to the solid phase in the 50 mL conical centrifuge tube, vortexed, and centrifuged again. The colorless residue in the centrifuge tube was re-extracted two more times with 25 mL of the hexane–acetone mixture. All of the extracts were combined in a 250 mL separatory funnel and washed with 15 mL of water. Five mL of saturated sodium chloride solution was added to the funnel to facilitate phase separation. The aqueous phase was discarded, the upper layer (extract) was collected, and the volume was measured using a graduated cylinder and recorded. Absorbance was measured using a spectrophotometer (Genesys 150 UV-Vis spectrophotometer) at 450 nm and readings were recorded.  $\beta$ -carotene concentration in the sample was determined as follows:

$$A = E^{1\% \text{ cm}^{-1}} * c * l \quad \text{where,}$$

A = absorbance reading from the spectrophotometer

$E^{1\% \text{ cm}^{-1}} = 2592$  (extinction coefficient for  $\beta$ -carotene at 450 nm).

c = concentration in g/100mL

l = The pathlength of the cuvette (1cm)

### 3.3.4.3. Mineral Analysis

A 0.5-g portion of the sample was mixed with 10 mL of concentrated nitric acid ( $\text{HNO}_3$ ) in Teflon microwave digestion vessels that were then subjected to MARS 6 Microwave (CEM Corporation, Matthews, NC) heating for predefined time and temperature. After digestion, the resulting clear solution was transferred into a 25-mL volumetric flask and diluted with distilled water to the mark. Standards of the analyzed minerals were prepared. The mineral contents (Ca, Mg, K, P, Cu, Fe, Mn, Zn, Na, Sr, Al, Cd, Cr, Ni, and Pb) were determined by Perkin Elmer Ion Coupled Plasma Emission Spectrometer (Perkin Elmer, 8000 DV) in radial orientation but only selected results are reported for comparison with CSB data.

Table 3.2. Nutritional specifications for Corn Soya Blend (CSB).

<b>A</b>	
<b>Macronutrients</b>	<b>Specifications/ 100g flour (DW)</b>
Energy	380 kcal minimum
Protein	14.0 % (N x 6.25) minimum
Fat	6.0 % minimum
Crude Fiber	5.0 % maximum
Ash	4.1 % maximum
<b>B</b>	
<b>Micronutrients</b>	<b>Specifications/ 100g flour (DW)</b>
Vitamin A	3460 IU
Vitamin C	90 mg
Iron	4 mg
Zinc	5 mg
Calcium	362 mg
Potassium	140 mg
Phosphorus	280 mg
Vitamin D	441.6 IU
Iodine	40 µg
Folate	110 µg

**Source:** WFP (2020)

### 3.4. Results and Discussion

#### 3.4.1. Proximate Composition

##### 3.4.1.1. Moisture

The moisture content was not significantly different ( $p > 0.05$ ) among the formulated flour samples (Figure 3.1). The moisture content was  $3.38 \pm 0.035$  g/100g for 7A,  $3.57 \pm 0.523$  g/100g for 4A, and  $3.64 \pm 0.212$  for 1A. These moisture content values were significantly lower ( $p < 0.05$ ) than the specified limits (10.0 g/100g or lower) for standard flour (CSB) that we compared in this study (WFP, 2020). Lower moisture content obtained in this study suggests that the flour would have

extended shelf-stability as the moisture content of flour is used as an indicator of quality, since it is one of the factors that impacts storage, shelf-life, and safety of foods by accelerating chemical or microbiological deterioration (Van Hal, 2000). Moisture content of flour is influenced by several factors such as drying method, drying time, and period and condition of storage (Van Hal, 2000). Moisture content obtained in this study are also lower than values (4.90-6.10g/100g) reported by Marcel et al., (2022) for soybeans, amaranth grains, pumpkin seeds and orange-fleshed sweetpotato composite flour.

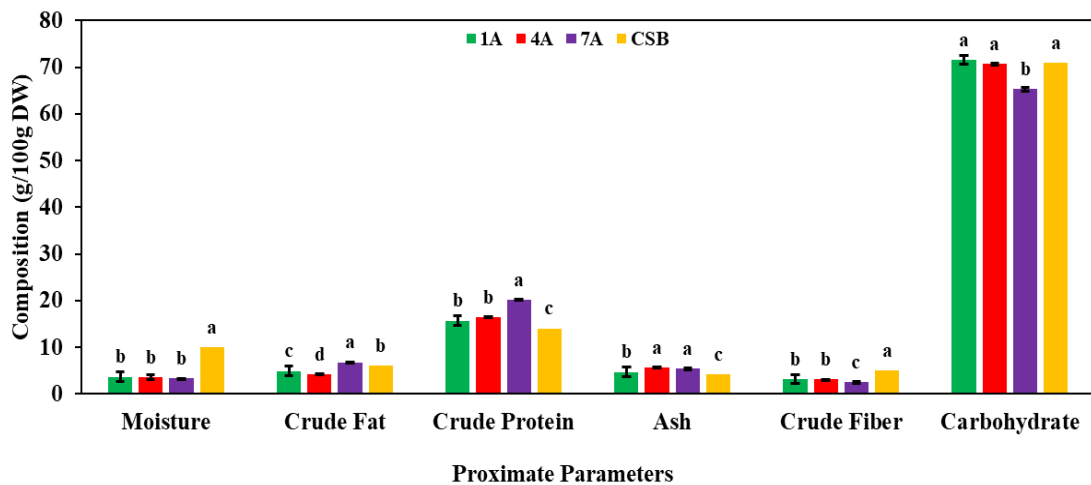
#### **3.4.1.2. Crude Fat**

The crude fat content of the formulated flour ranged from  $4.19 \pm 0.092$  g/100g DW to  $6.74 \pm 0.007$  g/100g (Figure 3.1). The crude fat content was highest in formulation 7A (6.74 g/100g) while the lowest fat content was in formulation 4A (4.19 g/100g) The difference in fat content is attributed to the varying proportions of the constituting ingredients (Table 3.1), most notably the increased proportion of mealworm powder in formulation 7A relative to 4A from 10% to 20% while decreasing the proportion of sweetpotato flour and sweetpotato leaf powder by 7% and 3% respectively, since mealworms are rich in fat which is the second largest component of their nutrition profile (Rumpold & Schlüter, 2013). The higher fat content in 7A indicates that the flour would have higher energy since oil provides higher energy density. The fat content in 7A meets the fat content value specified by WFP for CSB flour while the fat content in 1A and 4A were significantly lower than fat content of the standard flour (CSB). High proportion of sweetpotato flour, which is low in fat, typically 0.05 to 0.30% ((Woolfe, 1992) in 1A and 4A might have contributed to the lower fat content values. This suggests that fortification with mealworms as a fat-rich ingredient is a better option to enhance the energy density of the formulated flour and help with the absorption of vitamin A. Overall, according to the WFP standard, 7A can be considered as good source of fat.

#### **3.4.1.3. Crude Protein**

The protein content of the formulated flour was significantly higher ( $p < 0.05$ ) compared with the standard Corn Soya Blend (CSB) flour as shown in Figure 3.1. The utilization of sweetpotato leaves and mealworms as protein-rich ingredients increased the protein content of the sweetpotato flour which is typically low ranging from 1.0-8.5% (Van Hal, 2000). CSB is a carbohydrate-rich

ingredient made of up to 55% maize and 24% soybeans as its main protein source (WFP, 2020). The protein content of the formulated flour ranged from  $15.69 \pm 0.488$ g/100g DW (1A) to  $20.16 \pm 0.051$  g/100g DW (7A). The highest protein content in 7A (20.16g/100g) is undoubtedly due to the high proportion of mealworms (20%) compared with lower proportions in 1A (14%) and 4A (10%). Since the ingredients with the protein content of approximately 22 g/100g (sweetpotato leaves), 7 g/100g (sweetpotato flour), and 55 g/100g (mealworms) were used, then it can be seen that the major contributor of protein content in the formulated flour was mealworms. Based on the formulation proportions, protein content contribution of each ingredient can be estimated to be 8 g/100g (mealworms), 5 g/100g (sweetpotato flour), 2 g/100g (sweetpotato leaves) for formulation 1A; 6 g/100g (mealworms), 5 g/100g (sweetpotato flour), 5 g/100g (sweetpotato leaf powder) for formulation 4A; 11 g/100g (mealworms), 4 g/100g (sweetpotato flour), 4 g/100g (sweetpotato leaf powder) for formulation 7A. The protein content values obtained in this study are higher than protein content values (10.82 g/100g to 13.19 g/100g) reported by Olatunde et al. (2020) for composite flour formulated using different ratios of millet flour, sweetpotato flour, and soybeans flour. Gemede (2020), reported protein content of (14.92-20.99g/100g) for complementary food formulated from maize flour, pea flour, and Anchote flour, which are similar to results obtained in this study. Edible insects present a complete protein, providing all the essential amino acids. Therefore, the formulated flour can provide adequate protein to human diet.



*Figure 3.1. Proximate composition (g/100g) of formulated flours (1A, 4A, 7A) and standard (CSB). Each bar represents the mean of triplicate analyses. Bars with different letters represent significant differences ( $p < 0.05$ ) among the samples for each proximate parameter. 1A (77% sweetpotato flour + 14% mealworm flour + 9% sweetpotato leaf powder); 4A (67% sweetpotato flour + 10% mealworm flour + 23% sweetpotato leaf powder); 7A (60% sweetpotato flour + 20% mealworm powder + 20% sweetpotato leaf powder); CSB (Corn Soya Blend).*

#### **3.4.1.4. Ash**

The formulated flour differed significantly ( $p < 0.05$ ) in ash content. Interestingly, all the formulated flours were significantly higher in ash content compared with CSB standard flour (Figure 3.1). The ash content was highest in 4A which had the highest proportion (23%) of sweetpotato leaf powder while the lowest ash content was observed in 1A which had the lowest proportion of sweetpotato leaf powder. This shows that the higher values of ash content of the formulated flour were significantly influenced by the incorporation of sweetpotato leaf powder in greater proportions, which is also an indication that sweetpotato leaf powder would provide the essential minerals needed for the body development since ash content represents the amount of total mineral in the biomass (Liu, 2019). Many studies (Mwanri et al., 2011; Sun et al., 2014) have reported higher ash content values for sweetpotato leaves than for edible insects (Krzyżaniak et al., 2022; Rumpold & Schlüter, 2013) and sweetpotato flour (Mitiku & Teka, 2017; Olatunde et al., 2016; Van Hal, 2000; Yencho et al., 2008).

#### **3.4.1.5. Crude Fiber**

All the formulated flours had significantly lower ( $p < 0.05$ ) Crude fiber content than the standard CSB flour (5.0 g/100g). However, among the formulated flours, 1A (3.18 g/100g) and 4A (3.06 g/100g) had significantly higher crude fiber contents than 7A (2.44g/100g), which had lower crude fiber content. The significant differences in crude fiber content among the formulated flours might be attributed to the varying formulation proportions of ingredients which have varying crude fiber content. Even though insects are good sources of fiber, in this study the higher proportions of sweetpotato flour and sweetpotato leaf powder in 1A and 4A were the major contributors of crude fiber. The crude fiber contents obtained in this study were higher than crude fiber values (1.13-2.19 g/100g) reported by Olatunde et al. (2020) for complementary foods made using millet flour, sweetpotato flour, and soybean flour but similar to crude fiber content values (2.75 g/100g-3.41g/100) reported by Gemede (2020) who formulated complementary flour from maize flour, pea flour, and Anchote flour. Codex Alimentarius Commission (2011) requires crude fiber content of less than 5% in complementary foods which agrees with results obtained in this study. High fiber content makes the food bulky and may induce flatulence depending in fiber type (Codex Alimentarius Commission, 2011).

#### **3.4.1.6. Carbohydrates**

The range of carbohydrate content of the three formulated flours was from 65.32 g/100g to 71.55 g/100g. Formulation 1A, having the proportions of 77% sweetpotato flour (SPF), 14% mealworm powder (MP), and 9% sweetpotato leaf powder (SLP), was the highest in carbohydrate (71.55 g/100g) while the lowest carbohydrate content (65.32 g/100g) was observed in formulation 7A with the proportions of 60% sweetpotato flour, 20% mealworm powder, and 20% sweetpotato leaf powder (Figure 3.1). The carbohydrate content was decreased with decreasing sweetpotato flour proportions. Increasing sweetpotato leaf powder while decreasing sweetpotato flour proportions resulted in slight decrease in carbohydrate content (4A). This finding revealed that in these formulations, SPF is considered as the main source of carbohydrate followed by the sweetpotato leaf powder. Carbohydrate accounts for the bulk of sweetpotato flour which ranges between 84.6% and 94.8% on a dry weight basis. The carbohydrate contents of the formulated flour were similar to the carbohydrate content of the standard (CSB).

#### **3.4.2. Energy Content of the Formulated Flour**

Energy values of the formulated flour are shown in Figure 3.2. The metabolizable energy content of the formulated flour differed significantly ( $p < 0.05$ ) and ranged from 386.2 to 402.52 kcal/100g. All the formulated flour met the energy content specified by WFP for the control (CSB) flour. The highest energy content (402.52 kcal/100g) was in 7A which had the formulation proportion of 60% sweetpotato flour, 20% mealworm powder, and 20% sweetpotato leaf powder. While carbohydrate plays a key contribution to the energy values in foods, in this study, the incorporation of fat-rich ingredient such as mealworm powder played a significant contribution to energy content of the formulated flour. For instance, formulation 1A had the highest carbohydrate content (71.55 g/100g) than 7A which had the lowest carbohydrate content (65.32 g/100g), but formulation 7A with 6.74 g/100g fat content was found to be higher in energy than formulation 1A with 4.19 g/100g fat content.

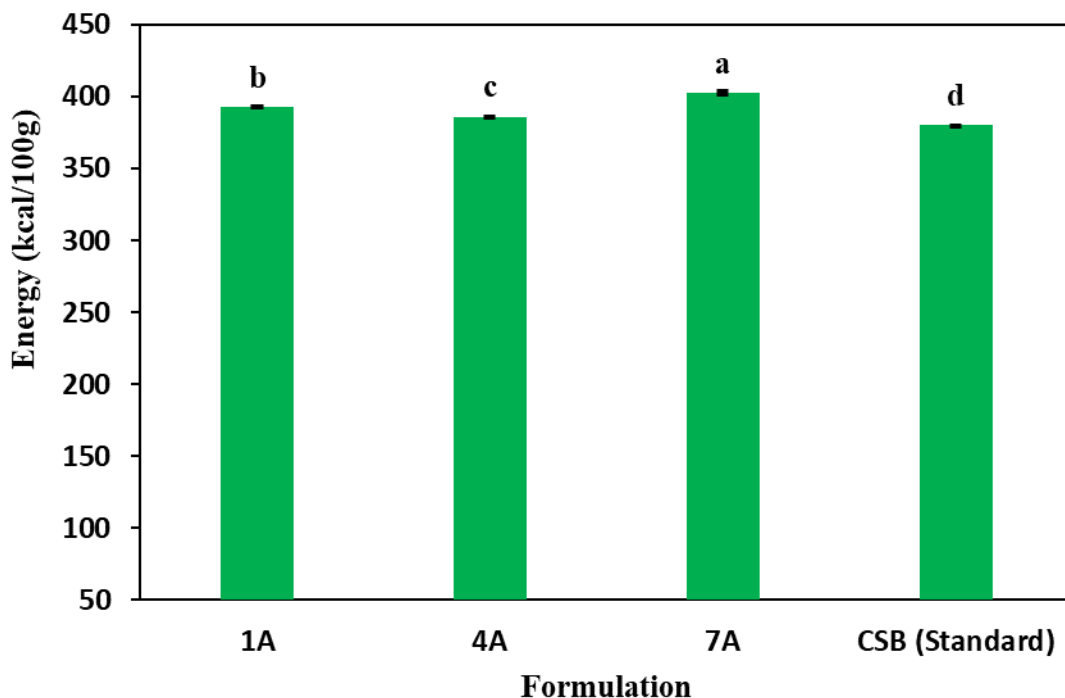


Figure 3.2 Energy values (kcal/100g) of the formulated products compared with the standard (CSB).

### 3.4.3. Color Analysis

#### 3.4.3.1. Results of L\* Color Values

Hunter L\*a\*b\* color values of the formulated flour are shown in Figure 3.2. L\* values were significantly different ( $p < 0.05$ ) among the formulated flours. The L\* value ( $62.43 \pm 0.18$ ) was highest in formulation 1A, which had the formulation proportions of 77% SPF, 14% MP, and 9% SPL while the lowest L\* value ( $52.07 \pm 0.10$ ) was observed in 7A which had the formulation proportions of 60% SPF, 20% MP, and 20% SPL. The L\* value decreased with the decreasing proportion of SPF. L\* is the tristimulus color parameter which indicates the lightness of the flour (0=black, 100=white). Hence, the results of L\* values in this study revealed that decreasing the proportion of SPF while increasing the proportions of MP and SPL flours resulted in darker flour.

#### 3.4.3.2. Results of a\* Color Values

The a\* value of the formulated flours was highest ( $p < 0.05$ ) in formulation 1A ( $4.63 \pm 0.023$ ), which had the formulation proportions of 77% SPF, 14% MP, and 9% SPL while the lowest a\*

value was in 7A ( $-0.66 \pm 0.46$ ), which had the formulation proportions of 60% SPF, 20% MP, and 20% SPL. The  $a^*$  color parameter indicates greenness ( $-a^*$ ) or redness ( $+a^*$ ). Flour from formulation 4A and 7A were slightly greener ( $a^* = -0.86$  and  $a^* = -0.66$ , respectively). This might be due to incorporation of SPL in higher proportions compared with 1A which had lower (9 %) SPL proportion.

### 3.4.3.3. Results of $b^*$ Color Values

The  $b^*$  color value, which indicates blueness ( $-b$ ) or yellowness ( $+a$ ) in flour, was significantly different among the formulated flour samples. The  $b^*$  value was highest in 1A ( $30.29 \pm 0.33$ ) and lowest in 4A ( $28.71 \pm 0.26$ ). Slightly higher yellowness (higher  $b^*$  values) in 1A and 7A could be attributed to higher proportions of SPF and MP compared with 4A which had lower proportions of SPF (67%) and MP (10%) but high in proportion of SPL (23%).

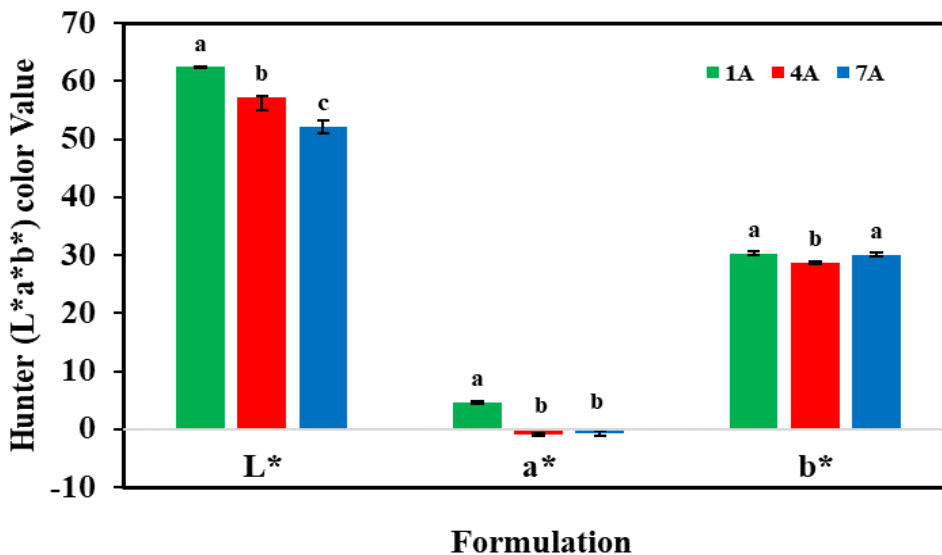


Figure 3.3. Formulated flour color (Hunter  $L^*a^*b^*$ ).

Each bar represents mean of triplicate measurements. Bars with different letters in the common column, represent significant differences ( $p < 0.05$ ). 1A (77% sweetpotato flour + 14% mealworm flour + 9% sweetpotato leaf powder); 4A (67% sweetpotato flour + 10% mealworm flour + 23% sweetpotato leaf powder); 7A (60% sweetpotato flour + 20% mealworm powder + 20% sweetpotato leaf powder); CSB (Corn Soya Blend).

### 3.4.4. Vitamin C, Beta-Carotene, and Mineral Content

#### 3.4.4.1. Vitamin C Content

Figure 3.4 shows vitamin C content in 3 formulated flours and in standard (CSB) as specified by WFP. The vitamin C content of all the three formulated flour differed significantly ( $p < 0.05$ ) from the standard (90 mg/100g). The vitamin C content in formulated flour ranged from 18.7 mg/100g (7A) to 22.8 mg/100g (4A). Formulation 4A and 7A were significantly different in their vitamin C content while 1A was not significantly different from 4A and 7A in vitamin C content. This result revealed that the vitamin C in the formulated flour is lower than the specified limits for vitamin C content in flour by WFP and may not be an adequate source of vitamin C as they only contribute approximately 24% of the specified limits, hence the flour may still require fortification with other vitamin C-rich ingredients or a vitamin premix.

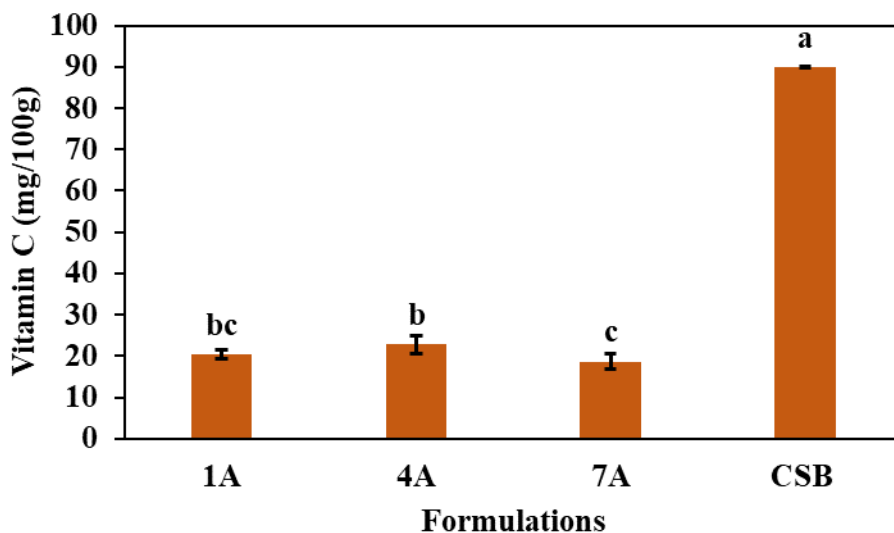


Figure 3.4. Vitamin content (mg/100g) of formulated products (1A, 4A, 7A) and CSB (standard).

Each bar represents the mean of triplicate measurements. Bars with different letters represent significant differences. 1A (77% sweetpotato flour + 14% mealworm flour + 9% sweetpotato leaf powder); 4A (67% sweetpotato flour + 10% mealworm flour + 23% sweetpotato leaf powder); 7A (60% sweetpotato flour + 20% mealworm powder + 20% sweetpotato leaf powder); CSB (Corn Soya Blend).

#### 3.4.4.2. Beta-Carotene Content

Beta-carotene levels of the formulated flour are shown in table 3.3. The beta-carotene content ranged from 10562  $\mu\text{g}/100\text{g}$  (1A) to 11442  $\mu\text{g}/100\text{g}$  (4A). These results indicate that the

formulated flour has beta-carotene concentration that when converted to vitamin A (IU/100g) can almost match the vitamin A requirements (3460 IU/100g) for CSB flour. Decreasing the sweetpotato flour proportions in the formulated flour had little effect on beta-carotene content indicating that sweetpotato leaf and edible insect powders might have also contributed to the beta-carotene content obtained in the formulated flour.

*Table 3.3. Beta-Carotene ( $\mu\text{g}/100\text{g}$ ) content of formulated flour.*

<b>Sample</b>	<b>Beta-Carotene</b>
1A	10562
4A	11442
7A	10871

1A (77% sweetpotato flour + 14% mealworm flour + 9% sweetpotato leaf powder); 4A (67% sweetpotato flour + 10% mealworm flour + 23% sweetpotato leaf powder); 7A (60% sweetpotato flour + 20% mealworm powder + 20% sweetpotato leaf powder).

#### **3.4.4.3. Mineral content**

Table 3.4 shows the selected mineral composition of the formulated product and the standard (CSB). All the formulated flour met the mineral content requirements for WFP's standard (CSB) flour except zinc, which was slightly lower than the control. Phosphorus was lower in 4A (218.4 g/100g) compared with that in the control (CSB) flour (280.0 mg/100g) and this could be due to lower formulation proportion of mealworm powder (10%) which was higher in phosphorus than sweetpotato flour and sweetpotato leaf powder. In all formulated flour, the mineral content ranged from 1563.7-2848.2 mg/100g for potassium, 218.4-383.1 mg/100g for phosphorus, 397.4-464.9 mg/100g for calcium, 2.0-3.3 mg/100g for zinc, 6.2-8.0 mg/100g for iron, 284.7-330.6 mg/100g for magnesium, and 22.55-44.78 mg/100g for sodium. The results of mineral content observed in this study are similar to the results of mineral content reported by Marcel et al. (2022) for complementary flour made using Orange-fleshed sweetpotato, pumpkin seeds, amaranth grains, and soybeans.

Table 3.4 Mineral composition (mg/100g) of the formulated flour compared with standard (CSB).

Mineral	Sample			
	1A	4A	7A	CSB
Potassium	2848.2	1577.0	1563.7	140.0
Phosphorus	383.1	218.4	277.3	280.0
Calcium	407.2	464.9	397.4	262
Zinc	3.3	2.0	2.6	5.0
Iron	8.0	6.2	6.8	4.0
Magnesium	330.6	290.7	284.7	N/A
Sodium	44.78	22.55	29.99	N/A

1A (77% sweetpotato flour + 14% mealworm flour + 9% sweetpotato leaf powder); 4A (67% sweetpotato flour + 10% mealworm flour + 23% sweetpotato leaf powder); 7A (60% sweetpotato flour + 20% mealworm powder + 20% sweetpotato leaf powder).

### **3.5. Summary**

The main objective of this study was to develop a dehydrated sweetpotato product fortified with edible insects and sweetpotato leaf powder that has a potential to combat malnutrition among children. It was hypothesized that, incorporating insect and sweetpotato leaf powders will increase the formulated product's protein, fats, vitamins, and mineral density for more complete nutrition.

From the results, the combination of sweetpotato flour, mealworm powder, and sweetpotato leaf powder showed that a product that is high in energy, fats, protein, pro-vitamin A, and minerals, and viable for local production can be easily made. The protein and fat contents increased with increasing proportion of mealworm powder while carbohydrate decreased with decreasing proportion of sweetpotato flour. Ash content which reflects the total amount of minerals present in the biomass was high in formulations with high proportions of sweetpotato leaf powder. Sweetpotato leaves that are often used as animal feed or ploughed back into the soil after harvesting of sweetpotato roots can therefore help to increase the mineral density in the formulation. Overall, the nutritional composition of the formulated flour met the nutrients requirement indicated by WFP for CSB flour for children. Hence, the product can provide adequate nutrition in developing countries, for example in sub-Saharan Africa (SSA) where levels of malnutrition are very high, and especially in areas where distribution of commercial ready-to-eat therapeutic foods used to combat the malnutrition among children is a challenge. Since sweet potatoes used in this study as a base to formulate the product can be grown in SSA, this nutritionally balanced flour can be produced locally from an accepted and familiar crop. Furthermore, aflatoxin contamination of sweet potatoes is of much less concern than with the current bases used for commercial RUTFs, such as corn or peanuts.

However, the product was found to contain lower amounts of vitamin C and slightly lower amount of zinc. Therefore, more research is needed to increase these micronutrients to adequate amounts in a formulated product. Furthermore, investigation on functional properties and sensory evaluation of the formulated product is needed prior to implementation and consumption.

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## APPENDICES

Appendix A. Complete proximate composition and mineral content of ingredients used, and formulated product.

Moisture and dry matter content (g/100g) of four varieties of sweetpotato leaves.

Variety	Initial Moisture	Dry Matter
Bonita	81.3 ± 0.896 <sup>a</sup>	18.698±0.896 <sup>a</sup>
Covington field 1	81.35 ± 0.464 <sup>a</sup>	18.646± 0.464 <sup>a</sup>
Covington field 2	81.01± 0.195 <sup>a</sup>	18.986± 0.195 <sup>a</sup>
Murasaki-29	80.95±1.115 <sup>a</sup>	19.052±1.115 <sup>a</sup>
Purple Majesty	81.47±0.332 <sup>a</sup>	18.53 ±0.332 <sup>a</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly (p >0.05).

Proximate composition (g/100g of sample) of dehydrated sweetpotato leaves.

Varieties	Proximate composition			
	Moisture	Fat	Protein	Ash
Bonita	6.11 ± 0.76 <sup>ab</sup>	3.13 ± 0.4 <sup>ab</sup>	22.79 ± 2.20 <sup>a</sup>	8.55 ± 0.59 <sup>b</sup>
Covington field 1	4.82 ± 1.30 <sup>b</sup>	3.00±0.56 <sup>b</sup>	23.32 ± 1.57 <sup>a</sup>	8.38 ± 0.54 <sup>bc</sup>
Covington field 2	6.38 ± 1.33 <sup>a</sup>	3.59 ± 0.50 <sup>a</sup>	22.61 ± 1.83 <sup>a</sup>	10.34 ± 0.3 <sup>a</sup>
Murasaki-29	5.02 ± 1.25 <sup>ab</sup>	3.14 ± 0.22 <sup>ab</sup>	19.99 ± 1.90 <sup>b</sup>	8.11 ± 0.20 <sup>bc</sup>
Purple Majesty	6.02 ± 0.93 <sup>ab</sup>	3.12 ± 0.18 <sup>ab</sup>	18.53 ± 1.54 <sup>b</sup>	7.91 ± 0.17 <sup>c</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly (p >0.05).

Proximate composition (g/100g) of Murasaki-29 sweetpotato leaves on different dehydration methods.

Treatment	Proximate composition					
	Moisture	Fat	Protein	Ash	Crude fiber	Carbohydrates
AF (60 °C)	4.00 ± 0.17 <sup>d</sup>	3.26 ± 0.24 <sup>a</sup>	20.46 ± 0.78 <sup>a</sup>	8.00 ± 0.15 <sup>a</sup>	8.50 ± 0.09 <sup>a</sup>	59.79 ± 1.26 <sup>a</sup>
AF (52 °C)	3.87 ± 0.08 <sup>d</sup>	3.39 ± 0.21 <sup>a</sup>	19.88 ± 1.96 <sup>a</sup>	8.24 ± 0.02 <sup>a</sup>	8.51 ± 0.08 <sup>a</sup>	59.99 ± 1.80 <sup>a</sup>
COD (60 °C)	4.43 ± 0.02 <sup>c</sup>	2.94 ± 0.17 <sup>a</sup>	19.80 ± 2.35 <sup>a</sup>	8.28 ± 0.07 <sup>a</sup>	8.64 ± 0.01 <sup>a</sup>	60.34 ± 2.46 <sup>a</sup>
COD (52 °C)	6.90 ± 0.04 <sup>a</sup>	3.12 ± 0.10 <sup>a</sup>	18.87 ± 2.30 <sup>a</sup>	8.17 ± 0.02 <sup>a</sup>	8.63 ± 0.06 <sup>a</sup>	61.21 ± 2.16 <sup>a</sup>
FD	5.92 ± 0.04 <sup>b</sup>	3.01 ± 0.08 <sup>a</sup>	20.93 ± 0.23 <sup>a</sup>	7.84 ± 0.24 <sup>a</sup>	8.70 ± 0.02 <sup>a</sup>	59.52 ± 0.07 <sup>a</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly ( $p > 0.05$ ).

Abbreviations: AF, Air fried; COD, convection oven dried; FD, freeze-dried. Numbers in brackets after abbreviations are temperatures

Proximate composition (g/100g) of Bonita sweetpotato leaves on different dehydration methods.

Treatment	Proximate composition					
	Moisture	Fat	Protein	Ash	Crude fiber	Carbohydrates
AF (60 °C)	6.10 ± 0.01 <sup>b</sup>	3.28 ± 0.26 <sup>a</sup>	22.19 ± 1.50 <sup>a</sup>	8.35 ± 0.03 <sup>b</sup>	8.28 ± 0.92 <sup>a</sup>	57.90 ± 1.88 <sup>a</sup>
AF (52 °C)	6.22 ± 0.01 <sup>b</sup>	3.42 ± 0.13 <sup>a</sup>	22.47 ± 2.14 <sup>a</sup>	8.43 ± 0.05 <sup>b</sup>	8.31 ± 0.19 <sup>a</sup>	57.38 ± 2.42 <sup>a</sup>
COD (60 °C)	5.11 ± 0.04 <sup>d</sup>	3.17 ± 0.18 <sup>a</sup>	21.65 ± 1.85 <sup>a</sup>	8.08 ± 0.06 <sup>c</sup>	8.26 ± 0.13 <sup>a</sup>	58.85 ± 2.22 <sup>a</sup>
COD (52 °C)	7.34 ± 0.05 <sup>a</sup>	2.55 ± 0.66 <sup>a</sup>	25.85 ± 1.76 <sup>a</sup>	9.65 ± 0.04 <sup>a</sup>	8.50 ± 0.05 <sup>a</sup>	53.45 ± 2.43 <sup>a</sup>
FD	5.81 ± 0.07 <sup>c</sup>	3.22 ± 0.21 <sup>a</sup>	21.81 ± 0.10 <sup>a</sup>	8.25 ± 0.06 <sup>bc</sup>	8.66 ± 0.04 <sup>a</sup>	58.06 ± 0.22 <sup>a</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly ( $p > 0.05$ ).

Abbreviations: AF, Air fried; COD, convection oven dried; FD, freeze-dried. Numbers in brackets after abbreviations are temperatures.

Proximate composition (g/100g) of Covington sweetpotato leaves from field 1 on different dehydration methods.

Treatment	Proximate composition					
	Moisture	Fat	Protein	Ash	Crude fiber	Carbohydrates
AF (60 °C)	4.40 ± 0.03 <sup>b</sup>	3.42 ± 0.57 <sup>a</sup>	23.65 ± 1.10 <sup>a</sup>	8.15 ± 0.05 <sup>bc</sup>	7.30 ± 0.09 <sup>a</sup>	57.49 ± 0.49 <sup>a</sup>
AF (52 °C)	4.73 ± 0.07 <sup>b</sup>	3.03 ± 0.09 <sup>a</sup>	22.95 ± 1.65 <sup>a</sup>	8.20 ± 0.02 <sup>bc</sup>	7.26 ± 0.10 <sup>a</sup>	58.55 ± 1.86 <sup>a</sup>
COD (60 °C)	5.74 ± 0.01 <sup>a</sup>	2.55 ± 0.64 <sup>a</sup>	22.61 ± 2.18 <sup>a</sup>	7.87 ± 0.20 <sup>c</sup>	7.42 ± 0.09 <sup>a</sup>	59.56 ± 2.92 <sup>a</sup>
COD (52 °C)	6.40 ± 0.04 <sup>a</sup>	2.53 ± 0.60 <sup>a</sup>	24.93 ± 2.07 <sup>a</sup>	9.35 ± 0.03 <sup>a</sup>	7.40 ± 0.26 <sup>a</sup>	55.79 ± 2.95 <sup>a</sup>
FD	2.82 ± 0.41 <sup>c</sup>	3.48 ± 0.23 <sup>a</sup>	22.48 ± 1.00 <sup>a</sup>	8.33 ± 0.05 <sup>bc</sup>	7.36 ± 0.13 <sup>a</sup>	58.35 ± 0.70 <sup>a</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly ( $p > 0.05$ ).

Abbreviations: AF, Air fried; COD, convection oven dried; FD, freeze-dried. Numbers in brackets after abbreviations are temperatures

Proximate composition (g/100g) of covington sweetpotato leaves from field 2 on different dehydration methods.

Treatment	Proximate composition					
	Moisture	Fat	Protein	Ash	Crude fiber	Carbohydrates
AF (52 °C)	7.57 ± 0.05 <sup>a</sup>	3.15 ± 0.18 <sup>c</sup>	22.10 ± 1.88 <sup>a</sup>	10.36 ± 0.12 <sup>bc</sup>	7.38 ± 0.01 <sup>a</sup>	57.01 ± 1.56 <sup>a</sup>
COD (52 °C)	5.96 ± 0.06 <sup>c</sup>	3.34 ± 0.02 <sup>bc</sup>	22.77 ± 2.24 <sup>a</sup>	10.48 ± 0.02 <sup>b</sup>	7.40 ± 0.03 <sup>a</sup>	56.12 ± 2.22 <sup>a</sup>
DHT (60 °C)	4.30 ± 0.09 <sup>d</sup>	3.62 ± 0.10 <sup>bc</sup>	23.19 ± 1.79 <sup>a</sup>	10.79 ± 0.02 <sup>a</sup>	7.36 ± 0.10 <sup>a</sup>	55.05 ± 1.97 <sup>a</sup>
DHT (52 °C)	6.27 ± 0.06 <sup>b</sup>	3.38 ± 0.09 <sup>bc</sup>	22.19 ± 2.26 <sup>a</sup>	10.13 ± 0.10 <sup>cd</sup>	7.38 ± 0.05 <sup>a</sup>	56.93 ± 2.12 <sup>a</sup>
FD	7.81 ± 0.04 <sup>a</sup>	4.46 ± 0.09 <sup>a</sup>	22.80 ± 0.18 <sup>a</sup>	9.95 ± 0.01 <sup>d</sup>	7.50 ± 0.09 <sup>a</sup>	55.30 ± 0.17 <sup>a</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly (p >0.05).

Abbreviations: AF, Air fried; COD, convection oven dried; DHT, dehydrator; FD, freeze-dried. Numbers in brackets after abbreviations are temperatures.

Moisture and dry matter (g/100g of sample) of Covington and Beauregard sweetpotato varieties

Variety	Moisture	Dry m
Covington	78.08 ± 0.42 <sup>a</sup>	21.92 :
Beauregard	77.96 ± 0.17 <sup>a</sup>	22.11 :

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly (p >0.05).

Proximate composition (g/100g) of Covington sweetpotato variety on different dehydration methods.

Treatment	Proximate Composition					
	Moisture	Fat	Protein	Ash	Crude fiber	Carbohydrates
FD	6.13 ± 0.10 <sup>b</sup>	0.74 ± 0.17 <sup>a</sup>	8.91 ± 0.29 <sup>a</sup>	4.39 ± 0.01 <sup>b</sup>	2.88 ± 0.12 <sup>a</sup>	83.08 ± 0.34 <sup>a</sup>
COD (60 °C)	7.38 ± 0.07 <sup>a</sup>	0.71 ± 0.14 <sup>a</sup>	7.45 ± 1.51 <sup>a</sup>	4.54 ± 0.06 <sup>a</sup>	2.93 ± 0.10 <sup>a</sup>	84.37 ± 1.50 <sup>a</sup>
DHT (60 °C)	7.50 ± 0.02 <sup>a</sup>	0.55 ± 0.18 <sup>a</sup>	7.43 ± 1.24 <sup>a</sup>	3.23 ± 0.02 <sup>c</sup>	2.77 ± 0.11 <sup>a</sup>	86.02 ± 1.56 <sup>a</sup>
AF (60 °C)	6.12 ± 0.02 <sup>b</sup>	0.68 ± 0.12 <sup>a</sup>	7.49 ± 0.75 <sup>a</sup>	4.36 ± 0.00 <sup>b</sup>	2.70 ± 0.04 <sup>a</sup>	84.77 ± 0.91 <sup>a</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly (p > 0.05).

Abbreviations: AF, Air fried; COD, convection oven dried; DHT, dehydrator; FD, freeze-dried. Numbers in brackets after abbreviations are temperatures.

Proximate composition (g/100g) of Beauregard sweetpotato variety on different dehydration methods.

Treatment	Proximate Composition					
	Moisture	Fat	Protein	Ash	Crude fiber	Carbohydrates
COD (60 °C)	7.50 ± 0.02 <sup>a</sup>	0.42 ± 0.19 <sup>a</sup>	5.17 ± 0.79 <sup>a</sup>	4.23 ± 0.23 <sup>a</sup>	3.09 ± 0.03 <sup>a</sup>	87.08 ± 0.40 <sup>a</sup>
DHT (60 °C)	6.40 ± 0.02 <sup>b</sup>	0.55 ± 0.17 <sup>a</sup>	6.72 ± 0.81 <sup>a</sup>	4.17 ± 0.02 <sup>a</sup>	3.15 ± 0.09 <sup>a</sup>	85.42 ± 0.88 <sup>a</sup>

Values are means ± standard deviation of duplicate analyses. Means with the same letters in the same column do not differ significantly (p > 0.05).

Abbreviations: COD, convection oven dried; DHT, dehydrator. Numbers in brackets after the abbreviation are temperatures.

Color (Hunter L\*a\*b\* values) of sweet potato leaf varieties under different drying methods.

Variety	Treatment	Color (L*a*b*)		
		L*	a*	b*
<b>Bonita</b>	AF 1 (60 °C)	38.49	-1.64	29.94
	AF 2 (52 °C)	36.74	-3.44	21.32
	COD 1 (60 °C)	45.9	-4.24	29.26
	COD 2(52 °C)	41.44	-1.62	25.13
	FD	46.16	-5.82	24.79
<b>Covington field 1</b>	AF 1 (60 °C)	47.56	-2.22	26.21
	AF 2 (52 °C)	44.08	-3.69	24.09
	COD 1 (60 °C)	46.27	-4.3	26.19
	COD 2 (52 °C)	40.25	-1	21.78
	FD	50.04	-6.53	29.26
<b>Covington field 2</b>	AF 2 (52 °C)	44.66	-3.84	21.78
	COD 2 (52 °C)	46.01	-4.6	25.12
	DHT (60 °C)	42.68	-3.1	23.45
	DHT (52 °C)	45.62	-4.12	28.99
	FD	50.84	-7.54	29.94
<b>Murasaki-29</b>	AF 1 (60 °C)	40.17	-2.58	26.57
	AF2 (52 °C)	38.98	-1.64	26.97
	COD 1 (60 °C)	45.34	-1.88	22.33
	COD 2 (52 °C)	43.89	-2.22	22.89
	FD	47.34	-6.62	28.84
<b>Purple Majesty</b>	AF 1 (60 °C)	44.76	-1.68	25.88
	AF 2 (52 °C)	41.72	-2.77	23.57
	COD 1 (60 °C)	43.28	-1.12	24.65
	COD 2 (52 °C)	38.72	-1.09	25.29
	FD	47.15	-6.28	28.06

Values are the mean of triplicate measurements.

Abbreviations: AF, Air fried; COD, convection oven dried; DHT, dehydrator; FD, freeze-dried. Numbers in brackets after abbreviations are temperatures.

Proximate composition (g/100g) of Purple Majesty sweetpotato leaf variety on different drying methods.

AF 1 (60 °C)	6.94 ± 0.04 <sup>a</sup>	3.19 ± 0.18 <sup>a</sup>	19.21 ± 0.47 <sup>a</sup>	7.94 ± 0.16 <sup>a</sup>	7.93 ± 0.08 <sup>a</sup>	61.74 ± 0.53 <sup>a</sup>
AF 2 (52 °C)	6.57 ± 0.04 <sup>b</sup>	3.04 ± 0.17 <sup>a</sup>	18.84 ± 1.87 <sup>a</sup>	7.87 ± 0.18 <sup>a</sup>	7.89 ± 0.13 <sup>a</sup>	62.37 ± 2.35 <sup>a</sup>
COD 1 (60 °C)	4.40 ± 0.03 <sup>e</sup>	3.14 ± 0.15 <sup>a</sup>	17.76 ± 1.63 <sup>a</sup>	7.99 ± 0.05 <sup>a</sup>	7.96 ± 0.09 <sup>a</sup>	63.16 ± 1.92 <sup>a</sup>
COD 2 (52 °C)	5.92 ± 0.06 <sup>d</sup>	3.19 ± 0.14 <sup>a</sup>	18.61 ± 1.14 <sup>a</sup>	7.69 ± 0.06 <sup>a</sup>	7.98 ± 0.04 <sup>a</sup>	62.52 ± 1.02 <sup>a</sup>
FD	6.29 ± 0.06 <sup>c</sup>	3.43 ± 0.17 <sup>a</sup>	18.24 ± 0.11 <sup>a</sup>	8.08 ± 0.11 <sup>a</sup>	7.90 ± 0.03 <sup>a</sup>	62.35 ± 0.20 <sup>a</sup>

Complete mineral composition (mg/100g) of selected sweetpotato flour, sweetpotato leaf, and mealworm powders.

Mineral	Samples						
	ADM	CV-SPF-FD	CV-SPF-DHT	CV-SP-Fresh	BG-SPF-COD	CV-SPL-DHT	CV-SPL-FD
Calcium (Ca)	41.64	141.80	156.08	16.65	115.23	1592.14	1521.35
Potassium (K)	712	1571.9	1733.9	309.1	1584.6	1763.3	1794.4
Phosphorus (P)	679.7	152.3	161.3	34.5	143.2	203.3	199.8
Zinc (Zn)	9.4	1.1	2.0	0.4	1.1	1.8	1.9
Iron (Fe)	5.4	1.8	2.5	0.8	2.5	13.5	11.3
Manganese (Mn)	0.97	0.43	0.42	0.08	0.87	4.61	3.89
Magnesium (Mg)	238.74	110.86	119.46	17.48	77.97	884.80	798.58
Sodium (Na)	111.79	11.18	18.31	6.20	9.12	11.81	13.12
Strontium (Sr)	0.40	0.30	0.27	<0.05	0.17	1.97	1.83
Aluminum (Al)	1.56	0.46	0.84	1.19	6.03	16.33	13.91
Cadmium (Cd)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium (Cr)	0.09	0.05	0.06	0.05	0.06	0.22	0.21
Nickel (Ni)	<0.05	<0.05	<0.05	<0.05	0.68	0.27	0.38
Lead (Pb)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper (Cu)	3.46	0.62	1.05	0.65	1.73	0.90	1.14

**Abbreviations:** *Already dried mealworms (ADM); Covington sweetpotato flour freeze-dried (CV-SPF-FD); Covington sweetpotato flour dehydrator dried-52 °C (CV-SPF-DHT); Covington sweetpotato fresh (CV-SP-Fresh); Beauregard sweetpotato flour convection oven dried (BG-SPF-COD); Covington sweetpotato leaf dehydrator dried 52 °C (CV-SPL-DHT); Covington sweetpotato leaf freeze-dried (CV-SPL-FD).*

Complete mineral content (mg/100) of formulated flour.

Mineral	Sample			
	1A	4A	7A	CSB (Standard)
Potassium (K)	2848.2	1577.0	1563.7	140.0
Phosphorus (P)	383.1	218.4	277.3	280.0
Calcium (Ca)	407.2	464.9	397.4	262
Zinc (Zn)	3.3	2.0	2.6	5.0
Iron (Fe)	8.0	6.2	6.8	4.0
Magnesium (Mg)	330.6	290.7	284.7	-
Sodium (Na)	44.78	22.55	29.99	-
Manganese (Mn)	1.42	1.39	1.35	-
Strontium (Sr)	0.71	0.64	0.62	-
Aluminum (Al)	3.62	4.96	4.67	-
Cadmium (Cd)	<0.01	<0.01	<0.01	-
Chromium (Cr)	0.16	0.14	0.14	-
Nickel (Ni)	0.92	0.81	0.78	-
Lead (Pb)	<0.01	<0.01	<0.01	-
Copper (Cu)	1.47	0.96	1.21	-

1A = 77% sweetpotato flour + 14% mealworm powder + 9% sweetpotato leaf powder

4A = 67% sweetpotato flour + 10% mealworm powder + 23% sweetpotato leaf powder

7A = 60% sweetpotato flour + 20% mealworm powder + 20% sweetpotato leaf powder