MAKERERE UNIVERSITY

COLLEGE OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF FOOD TECHNOLOGY AND NUTRITION

DEVELOPMENT OF LOW-COST NUTRIENT-DENSE COMPOSITE FLOURS FROM LOCALLY AVAILABLE FOODS FOR CHILDREN AGED 1-5 YEARS IN EASTERN UGANDA

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B.Sc. FOOD SCIENCE AND TECHNOLOGY (Mak)

REG NO: 2019/HD02/25483U

A DISSERTATION SUBMITTED TO THE COLLEGE OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES IN PARTIAL FULFILMENT OF THE AWARD OF A MASTER OF SCIENCE DEGREE IN FOOD SCIENCE AND TECHNOLOGY OF MAKERERE UNIVERSITY.

APRIL 2022

DECLARATION

This research dissertation is my original work and has not been presented to any institution of higher learning for the purpose of obtaining a degree.

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DEDICATION

This work is dedicated to my parents, Mr Sajad Warugaba and Ms Grace Olive Kisembo who have loved and supported me unconditionally.

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to everyone who has helped me along this research journey. Special thanks to my academic supervisors, who provided invaluable guidance all through the research. I also want to thank the teaching and non-teaching staff and the School of Food Technology, Nutrition and Bioengineering for their support.

I am grateful to the McKnight Foundation for sponsoring my Master's education. My classmates, Soumaya Abdou Salam and Ruth Martha Mirembe provided immeasurable support during my studies for which I am thankful. I also acknowledge my friends, workmates and family for their support.

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ABBREVIATIONS AND ACRONYMS

ANOVA:	Analysis of Variance
AOAC:	Association of Official Analytical Chemists
CIAT:	International Centre for Tropical Agriculture
CIE:	Commission International de l'Eclariage
FANTA:	Food and Nutrition Technical Assistance
FAO:	Food and Agricultural Organization
FEWS NET:	Famine Early Warning Systems Network
FRA:	Food Rights Alliance
FRN:	Farmer Research Networks
GAIN:	Global Alliance for Improved Nutrition
GDP:	Gross Domestic Product
IFPRI:	International Food Policy Research Institute
IPC:	Integrated Food Security Phase Classification
MAAIF:	Ministry of Agriculture, Animal Industry and Fisheries
MOFPED:	Ministry of Finance, Planning and Economic development
MoH:	Ministry of Health
NARO:	National Agricultural Research Organization
NPA:	National Planning Authority
PHH:	Post-harvest handling
RNI:	Recommended Nutrient Intake
rpm:	revolutions per minute
RVA:	Rapid Visco Analyser

RVU:	Rapid Visco Units
Shs:	Shillings
UBOS:	Uganda Bureau of Statistics
UNICEF:	United Nations Children Fund
VAM:	Vulnerability Analysis and Mapping
VEDCO:	Volunteer Efforts for Development Concerns
WAI:	Water Absorption Index
WSI:	Water Solubility Index
WFP:	World Food Programme
WHO:	World Health Organisation

ABSTRACT

Childhood malnutrition is a common problem in Uganda. Lack of proper nutrition during the early years can have lifelong consequences on educational attainment, health and economic outcomes. Locally available foodstuffs can be used to formulate nutritionally adequate food mixtures. This study aimed to develop acceptable inexpensive nutrient-dense mixtures from locally available foods for children aged 1-5 years in eastern Uganda (Kamuli, Buyende and Pallisa districts). The five least-cost sources of energy, protein, iron and zinc in each of the two rainy seasons and two dry seasons were identified from locally available foods. The gross energy, proximate and mineral compositions of the identified foods were determined and used to formulate optimal mixtures for the different seasons. The optimal mixtures for the dry seasons contained sweet potatoes, maize, sorghum, soybeans, beans, sesame and groundnuts. The optimal mixtures for the rainy seasons contained maize, sorghum, beans, sesame and groundnuts. The most acceptable formulations had functional properties that are desirable in foods for infants and young children such as high dispersibility (77.2-76.8%), low water absorption index (WAI) (1.7-2.0g/g) and high water solubility index (WSI) (0.2-.03g/g). The pasting properties indicated that the formulations form stable low viscosity pastes that can withstand breakdown during cooking and have high resistance to retrogradation on cooling. When cooked, the most acceptable formulation for the dry seasons had gross energy of 87.2 kcal, 2.3g of sugars, 9.5g of starch, 5.8g of protein, 1.6g of crude fat, 1.7g of fiber, 0.8g of ash, 7.5mg of iron and 1.6mg of zinc per 100g. The most acceptable formulation for the rainy seasons had gross energy of 71.4 kcal, 2.6g of sugars, 7.1g of starch, 4.2g of protein, 0.9g of crude fat, 1.0g of fiber, 0.6g of ash, 8.1mg of iron and 1.4mg of zinc per 100g. The cooked samples provided more than 50% of the Recommended Nutrient Intakes (RNI) for protein, iron and zinc for children aged 1-5 years per serving. The adoption of the formulations developed in this study has the potential to reduce undernutrition in children aged 1-5 years. However, it is recommended that *in vitro* digestibility and mineral bioavailability studies of the formulations are carried out to predict the fraction of nutrients that would be absorbed by a child`s gastrointestinal tract and as such make necessary readjustments to the formulations.

CHAPTER 1

INTRODUCTION

1.1 Background

Globally, the burden of child malnutrition in all its forms remains a challenge. In 2019, 21.3% (144.0 million) of children under 5 years of age were stunted, 6.9% (47.0 million) wasted, 5.6% (38.3 million) were overweight and at least 340 million suffered from micronutrient deficiencies (FAO et al., 2020). Lack of proper nutrition during these early years can have lifelong consequences on educational attainment, health and economic outcomes (UNICEF, 2019a). In low-income countries such as Uganda, undernutrition is a common problem (Adebisi et al., 2019). The immediate causes of undernutrition are inadequate dietary intake and disease (WFP, 2012). Forty per cent of the children in Uganda do not receive adequate dietary diversity. Diet diversity and quality are particularly low in eastern Uganda (FANTA, 2010), where 51% of the households are food poor (UBOS, 2018).

There is a negative correlation between wealth and undernutrition (WFP et al., 2019). Evidence shows that low-income households purchase and consume greater amounts of cheap, energy-dense foods that are filling, but have lower nutritional quality, as compared to higher-income households (MAAIF et al., 2016). There is, therefore, an urgent need to focus on the food intake of the poorest households if Uganda is to meet its nutritional targets (FRA, 2020). Eastern Uganda is the poorest region in Uganda (Development Initiatives, 2020). The poverty rate in Eastern Uganda (24.5%) is significantly higher than the national rate (19.7%) and 27.6% of children in the eastern region live below the national poverty line (UBOS et al., 2018). A survey by NARO, Makerere University & VEDCO (2021) found that more than half of the children in Kamuli, Buyende and Pallisa districts in Eastern Uganda had inadequate diets.

There are practical constraints to meeting dietary diversity requirements, including distance to and frequency of market days, inability to keep fresh foods cool and availability of time to prepare and feed frequent, balanced meals for young children (de Pee, 2015). In order to fill the nutrition gap, it is important to consider the availability, physical access and affordability of nutritious foods required for adequate nutrient intake (WFP et al., 2019). Proper selection and combination of locally available or household foodstuff can be used to formulate multi mixes that are nutritious, acceptable and affordable (Abamecha, 2020). Mothers are willing to adopt nutritious formulations prepared from local foods as they are culturally appropriate and acceptable (Mbela et al., 2018). The use of locally available food items also ensures availability and affordability (Abamecha, 2020). The foods commonly consumed in eastern Uganda include millet, soybeans, maize, beans, cassava, sorghum, sweet potatoes, groundnuts and sesame (NARO et al., 2021). Of these, cassava, maize, millet, and sorghum are the highest produced crops (FEWS NET, 2017). These can potentially be used for the formulation of nutrient-dense composite flours.

1.2 Problem statement

Good nutrition enables children to grow, develop, learn, play and contribute to their communities (UNICEF et al., 2017). Uganda has one of the youngest populations in the world with more than half of the population being under 15 years (MoFPED, 2019). Children aged 0-5 years constitute 21.4% of the total population (UBOS, 2018). However, 3 in 10 children under 5 are not growing well due to malnutrition (UNICEF, 2019b). Twenty-nine per cent of Ugandan children under 5 years are stunted (9% are severely stunted), 11% are underweight (2% are severely underweight), and 4% are wasted (1% are severely wasted) (UBOS & ICF, 2018). In addition, 53% of children under the age of 5 percent are anaemic and unlikely to reach their full mental and physical potential (WFP et al., 2019).

In Uganda, diets for children below 5 years are predominantly starch-based and lack the critical nutrients that children's brains and bodies need to grow (Mulenga, 2019). Such deprivation in early childhood affects cognitive development, which affects school performance and lifetime earnings (MoFPED, 2019). There is a need to develop more nutritious and diverse meals while keeping in mind the resources available to the community, their tastes and preferences, and the cost of the eventual diets (Ekesa et al., 2019). Families make better food choices when nutritious options are affordable, convenient, and appealing (UNICEF, 2019b).

Seasonality is a major factor in accessibility to a healthy diet year-round (SNV, 2020). The availability and prices of different foods change across the cropping seasons (Gilbert et al., 2017; Musumba & Zhang, 2016). Consumers substitute between foods according to price fluctuations (FAO et al., 2020) which has dietary implications and can cause episodes of nutritional deficiencies (Gilbert et al., 2017). Common staples such as beans, millet, cassava, sweet potatoes and maize can be blended to enhance the energy and nutrient density of children's diets (Kikafunda et al., 2006; Mbela et al., 2018; Ndagire et al., 2015; Tibagonzeka, 2014). Several studies on the utilization of local foods to make nutrient-dense mixtures have been carried out (Kikafunda et al., 2006; Ndagire et al., 2015; Tibagonzeka, 2014; Tumwine et al., 2019). However, low-cost nutritionally adequate mixtures for the different seasons of the year were unexplored. As such, this study sought to develop acceptable inexpensive, nutritionally adequate flours from locally available foods for children aged 1-5 years in Pallisa, Kamuli, and Buyende districts.

1.3 Objectives

1.3.1 Main Objective

Utilisation of locally available, inexpensive food crops to improve the nutritional status of children in selected Eastern Ugandan districts.

1.3.2 Specific Objectives

1. To identify the five least expensive sources of different nutrients available to households in selected Eastern Ugandan districts during different seasons in the year
2. To determine the nutritional value of the identified least expensive sources
3. To formulate least-cost acceptable composite flours for different seasons in the year
4. To determine the functional and nutritional properties of the most acceptable composite flours

1.4 Research Questions

1. What are the five least expensive sources of different nutrients that are available to households in selected Eastern Ugandan districts during different seasons of the year?
2. What is the nutritional value of the identified least expensive sources?
3. What are the least-cost acceptable composite flours for the different periods of the year?
4. What are the functional and nutritional properties of the most acceptable composite flours?

CHAPTER 2

LITERATURE REVIEW

2.1 Malnutrition

Malnutrition is an abnormal physiological condition, typically due to eating the wrong amount and/or kinds of foods (von Grebmer et al., 2014). Malnutrition can arise in three forms:

- undernutrition, which is defined as dietary energy intakes below the minimum levels necessary to achieve and maintain a healthy weight;
- overnourishment, which is defined as dietary energy intake which exceeds requirements for maintenance of a healthy body weight; and
- micronutrient deficiencies, which is defined as a lack of essential vitamins and minerals required in small amounts by the body for proper growth and development (Ritchie & Roser, 2017).

The greatest burden of all forms of malnutrition is shouldered by children and young people from the poorest and most marginalized communities, perpetuating poverty across generations (UNICEF, 2019a). At least 1 in 3 children under 5 years globally is undernourished or overweight and 1 in 2 suffers from micronutrient deficiency. These are the children who are not growing well (UNICEF, 2019b). Malnutrition results in poor physical and mental development in children, vulnerability or exacerbation of disease, mental retardation, blindness and general losses in productivity and potential (Ritchie & Roser, 2017).

Malnutrition is caused by the poor quality of children's diets. Forty-four per cent of children aged 6 to 23 months worldwide are not fed fruits or vegetables and 59% are not fed eggs, dairy, fish or meat (UNICEF, 2019a). Fruits and vegetables are rich in micronutrients (FAO & WHO, 2004). Eggs, dairy, fish and meat are good sources of high-quality protein as well as bioavailable iron and zinc (WHO, 2003). Only 1 in 5 children aged 6 to 23 months from the poorest households and rural areas is fed the minimum recommended variety of foods for healthy growth and brain development. Poor families are more likely to choose low-cost, low-quality meals. The most disadvantaged children are at the highest risk of malnutrition due to poverty and marginalization

(UNICEF, 2019b). In addition, the health and socio-economic impacts of COVID-19 are likely to worsen the nutritional status of the most vulnerable population groups (FAO et al., 2020).

In Uganda, 29% of Ugandan children aged 6-59 months are stunted, 4% are wasted, 11% are underweight, and 4% are overweight (UBOS & ICF, 2018). Malnutrition is the leading cause of mortality in these children under 5 years of age (Adebisi et al., 2019). Malnourished children who survive into adulthood are relatively weaker and their contribution to total productivity is impaired (MAAIF et al., 2016). However, the rate of decline of malnutrition in the country has been very slow for the last 15 years and it is still far from being over (Adebisi et al., 2019). Various foods rich in nutrients are available but malnutrition still occurs due to inadequate intake, uptake and, or utilization of nutrients composed in the food. This may be a consequence of poor processing of food, poor food handling and preparation methods and/or impaired absorption capacity of the body (FRA, 2020).

2.1.1 Hidden hunger

Hidden hunger is a deficiency in essential vitamins and minerals (UNICEF, 2019a). It is also known as micronutrient deficiency (WFP, 2012). Essential micronutrients include (but are not limited to): iron, zinc, calcium, iodine, vitamin A, B-vitamins, and vitamin C (Ritchie & Roser, 2017). Micronutrient deficiency can coexist with adequate or even excessive consumption of dietary energy from macronutrients, such as fats and carbohydrates. It can, therefore, affect overweight and obese individuals. This is why it is known as hidden hunger (von Grebmer et al., 2014).

Hidden hunger is an important global health issue (Ritchie & Roser, 2017; UNICEF, 2019a; von Grebmer et al., 2014) that affects more than an estimated 2 billion people globally (von Grebmer et al., 2014). Worldwide, the most widespread micronutrient deficiencies are in iron, zinc, vitamin A, iodine and folate, but deficiencies in vitamin B12 and other B vitamins also commonly occur (Muthayya et al., 2013). Micronutrient deficiencies are widespread among populations of developing countries who mostly consume cereal-based, monotonous diets (CABI & FAO, 2011). The typical diet in Uganda is based on mostly stable crops such as maize, wheat, rice, and cassava, which provide a large share of energy but relatively low amounts of essential vitamins and minerals, frequently resulting in hidden hunger (von Grebmer et al., 2014). The urban poor, who mainly reside in slums, are more vulnerable to micronutrient deficiencies given their low purchasing power as a result of limited income (Chege et al., 2019).

Uganda is ranked 37th in the countries affected by micronutrient deficiencies with a global hidden hunger index of 34.7. A high Hidden Hunger Index score strongly correlates with a low Human Development Index score (Muthayya et al., 2013). The Human Development Index score is a compound measure of three basic dimensions of human development: development: health, education and income (Salas-Bourgoin, 2014). This highlights the urgency with which hidden hunger must be addressed (Muthayya et al., 2013). One way of reducing micronutrient deficiencies is dietary diversity (Chege et al., 2019; von Grebmer et al., 2014). Micronutrient-rich foods such as fruits and vegetables, meat and dairy, pulses, seafood, nuts and seeds must be included in the diet (Ritchie & Roser, 2017).

According to recent global estimates, at least 340 million children under the age of five (one in every two) suffer from hidden hunger (UNICEF, 2019b). These vitamin and mineral deficits can have serious and long-term consequences (von Grebmer et al., 2014). Even mild to moderate deficiencies of micronutrients in new borns and young children lead to impaired physical and cognitive development, poor physical growth, increased morbidity from infectious diseases and decreased work productivity in adulthood (Muthayya et al., 2013). Unfortunately, hidden hunger is rarely noticed until it is too late to do anything (UNICEF, 2019a). The world is not on track to achieve the global nutrition targets on child stunting, wasting and overweight by 2030. The current level of effort is not anywhere near enough to end malnutrition in the next decade (FAO et al., 2020).

2.2 Complementary feeding

Complementary feeding refers to foods that are consumed in addition to breastfeeding (de Pee, 2015). Breast milk contains all of the nutrients needed by children in the first 6 months of life (UBOS & ICF, 2018). After 6 months, an infant's need for energy and nutrients starts to exceed what is provided by breast milk, and complementary foods are necessary to meet those needs. An infant of this age is also developmentally ready for other foods (UNICEF, 2005). The introduction of complementary food at six months is to fill the gap between nutritional needs and the amounts provided by breastmilk (Saleem et al., 2014). However, meeting the additional nutrient needs from the complementary feeding diet is challenging, because the child's food intake is small compared with his or her nutrient needs (de Pee, 2015). Complementary feeding that is insufficient in quality and quantity contributes to childhood malnourishment (Ekholuenetale et al., 2020).

Complementary feeding plays an important role in infant growth, intellect, and development (Saleem et al., 2014). If complementary foods are not introduced around the age of 6 months, or if they are given inappropriately, an infant’s growth may falter (UNICEF, 2005). Appropriate complementary feeding should include feeding children a variety of foods to ensure that requirements for nutrients are met (UBOS & ICF, 2018). However, there are practical constraints to meeting dietary diversity requirements such as distance to and frequency of market days, inability to keep fresh foods cool, and unavailability of time to prepare and feed frequent, balanced meals to young children (de Pee, 2015).

2.2.1 Complementary feeding in Uganda

In Uganda, millet porridge is a major complementary food for infants and young children (Tumwine et al., 2019). Finger millet is recommended as a complementary food because it is one of the most nutritious cereals and is easy to digest (Isingoma et al., 2019). However, the porridge is thick and children cannot obtain adequate nutrition from the volumes that their small stomachs are able to accommodate. Thinning the porridge requires the addition of large volumes of water which reduces the nutrient density (Tumwine et al., 2019). In addition, being plant-based millet is limited in lysine which is an essential amino acid and has low energy and nutrient density (WHO, 2000).

Nutritious, acceptable and affordable complementary foods for infants can be formulated by combining locally available food items, which can be comparable to the conventional proprietary infant formulations (Abamecha, 2020; Kikafunda et al., 2006; Mbela et al., 2018; Ndagire et al., 2015; Tibagonzeka, 2014). In eastern Uganda, locally available foods such as millet, soybeans, maize, sorghum, silverfish, cassava, sweet potatoes, rice, beans, grain amaranth groundnuts and sesame have been utilized to make complementary foods (NARO et al., 2021). Cassava, maize, millet, and sorghum are the highest produced crops in eastern Uganda with annual productions of 1,061,185, 1,108,556, 106,841 and 133,310 megatonnes respectively (FEWS NET, 2017). In 2019, Pallisa District Local Government reported that maize was the highest produced crop (over 42,000 megatonnes) followed by cassava (over 33,000 megatonnes).

NARO et al. (2021) found that there are challenges faced in household production of nutrient-dense composite flours in eastern Uganda namely limited knowledge on the right ingredients and mixing ratios, cost of ingredients and seasonality of ingredients. Low-income households rely on the cheapest available foods. Therefore, the cost of the eventual formulations needs to be taken into consideration (GAIN & UNICEF, 2021). The low-cost complementary foods should also be easy to prepare in home and community kitchens (Kulkarni et al., 1991).

2.3 Food Security

Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 1996). Household food security is the application of this concept to the family level, with individuals within households as the focus of concern (FAO, 2003). Household access to food is realised through various means namely:

- own food production by the households;
- purchase of food from the markets;
- exchange of food for other resources;
- food aid or donations; and
- any other sources such as food collected from the wild (Yikii et al., 2017).

One of the main global challenges is how to ensure food security for a world growing population while ensuring sustainability (ACF, 2014). Food insecurity can worsen diet quality and consequently increase the risk of various forms of malnutrition, potentially leading to undernutrition as well as overweight and obesity (FAO et al., 2020). Household food security is constrained by three factors:

- Food availability. Prolonged dry cells, crop and livestock diseases result in poor harvests and low food stocks at household level
- Food access. High food prices coupled with low household incomes reduce purchasing power thus limiting access to food
- Food utilization. Poor food preparation practices, food preferences based on culture and poor hygiene practices constrain physical and biological utilisation of food (Uganda IPC Technical Working Group, 2017).

In 2019, close to 750 million people or one in ten people in the world were exposed to severe levels of food insecurity (FAO et al., 2020). People experiencing severe food insecurity have typically run out of food and, at worst, gone a day (or days) without eating (FAO et al., 2019). Two billion people, or 25.9% of the global population, experienced hunger or did not have regular access to nutritious and sufficient food in 2019. This is known as moderate food insecurity (FAO et al., 2020). Food supply disruptions and a lack of income as a result of the loss of livelihoods and remittances caused by COVID-19 mean that households around the world are having more difficulty accessing nutritious foods. This has made it even more difficult for the poorer and vulnerable populations to access healthy diets (FAO et al., 2020).

The government of Uganda has several sector policies and legal frameworks that guide food security. However, malnutrition remains a prominent national challenge with a big proportion of the population not being able to access adequate food (FRA, 2020). The demand for food in the country has outstripped the supply because of the rapid population growth rate at 3% per annum outpacing food production, at 2% for over a decade (NPA, 2018).

2.3.1 Cost of food

A key reason why millions of people around the world suffer from hunger, food insecurity and malnutrition is that they cannot afford the cost of healthy diets (FAO et al., 2020). Healthy diets tend to come at a higher cost. Yet, to be sustainable or even feasible, healthy diets must be affordable (Hess et al., 2019). The cost and affordability of diets vary around the world, across regions and in different development contexts. They also vary within countries due to temporal and geographical factors (FAO et al., 2020). Thus, measuring food prices quarterly and at the market level, instead of national annual measures, may better indicate the effect of prices on food choices (Todd et al., 2010).

In Uganda, overall, food purchases contribute the largest share (57%) to Dietary Energy Consumption (UBOS, 2018). Farm households produce some of the food they consume, but most do not produce an adequate diversity of food and have to buy some of their food from the market (SNV, 2020). Food prices are thus crucial for economic modelling of consumer food choices and dietary patterns (Todd et al., 2010). The WFP cost of the diet study found that it costs seven times more for a household to purchase a nutritious diet, compared to a diet that meets only their energy requirements, because fresh foods such as milk, dried fish and green leafy vegetables are more expensive (WFP et al., 2019).

2.3.2 Seasonality of food prices

Food prices vary during the year (SNV, 2020). The prices of food crops change across seasons and regions given the agro-ecological zones, consumption patterns, and religious and social events (Musumba & Zhang, 2016). Agricultural production in Uganda is almost entirely rain-fed and is as such dependent on the rainfall patterns (Sridharan et al., 2019). Most parts of Uganda experience bimodal rainfall. Karamoja however, experiences unimodal rainfall (Sridharan et al., 2019). According to FEWS NET (2021), in areas with bimodal rainfall, there is a dry season from December to February before the first rainy season which starts in March and ends in June. There is also a second dry season from July to mid-August before the second rainy season that runs from mid-August to November. In Karamoja, which experiences unimodal rainfall, the rainy season starts in April and ends in October (FEWS NET, 2021).

The availability of two rainy seasons in most parts of the country allows for two cropping seasons for staples such as maize, beans, millet, and sorghum. For these crops, seasonality plays a major role in food availability and trade (FEWS NET, 2017). However, due to climate change, the rainfall pattern is sometimes irregular which disrupts farmers' plans (Uganda IPC Technical Working

Group, 2017). Inconsistent rains also affect yields resulting in increased prices of foods (SNV, 2020). The prices of seasonal crops typically peak just before the harvest, when supplies are scarce, and drop substantially immediately after harvest (Gilbert et al., 2017). The prices of perishable foods such as fruits and vegetables show particularly high seasonality (Todd et al., 2010). Vegetables are scarce during the dry seasons and as such cost more in such seasons (SNV, 2020). Consumers substitute between foods according to price fluctuations (FAO et al., 2020). As such, quarterly estimates are preferred to annual estimates when modelling food choices (Todd et al., 2010). Seasonal prices of foods can be obtained from local retailers as it is the retailers that sell to the end consumers (WFP, 2017). WFP VAM (2009) developed a Market Analysis Tool that can be used to conduct a trader survey.

Prices are an overarching indicator of the food security situation in an area (WFP VAM, 2017). The seasonality of food prices has dietary and nutritional outcomes and can cause episodes of nutritional deficiencies (Gilbert et al., 2017). Increasing cross-border demand coupled with the excessive sale of food crops has also affected food price stability in Uganda (Uganda IPC Technical Working Group, 2017). There is a global challenge of transforming food systems to ensure that no one is constrained by the high prices of nutritious foods or the lack of income to afford a healthy diet (FAO et al., 2020).

2.3.3 Least-cost formulation

Least-cost formulation is the combination of a variety of ingredients in specific quantities to deliver a balanced nutritious diet to a target group at the lowest feasible cost (Rossi, 2008). It is used by modern food processors to put together a formula at the lowest cost, where that formula needs to meet certain technical parameters and constraints and where there is flexibility in ingredient use in meeting those parameters (De Carvalho et al., 2015). Least-cost formulation is a mathematical solution and is based on linear programming (Rossi, 2008).

Linear programming is a mathematical modelling technique used to optimize several variables to achieve an objective, subject to restrictions called constraints (Russell & Taylor, 2011). Linear programming has proven to be a useful technique in the development of food-based recommendations and has been widely used to develop population and individual specific recommendations (De Carvalho et al., 2015). Linear programming can also be used by food technologists to develop product formulations. The ‘trial and error’ method, which has commonly been used in developing formulations is time consuming and requires numerous repetitions (Sheibani et al., 2018).

Although least-cost formulation is based on linear programming, it requires the expertise of nutritionists to examine the nutrient requirements of the target group. Formulations produced using linear programming are only as good as the nutrient and component specifications entered (Rossi, 2008). The sensory and consistency characteristics of the designed formulations also need to be taken into consideration, especially for foods meant to be used for malnourished children or children at risk of malnutrition. To keep costs low and ensure that the resulting formulation is culturally acceptable, formulations should preferably be based on locally accessible ingredients (De Carvalho et al., 2015).

In least-cost formulation, the cost of raw materials used in the formulation can be acquired from current market prices through a survey (Olorunfemi et al., 2006). Proximate constituents and mineral constituents can then be obtained from standard tables and sources (Olorunfemi, 2007) or through laboratory analyses of the foods in question. A linear programming model consisting of decision variables, an objective function, and model constraints is then used to design the formulation (Russell & Taylor, 2011). Cultural constraints may be used to ensure palatability of the formulations, but they do not guarantee that the optimizations will result in quantities of ingredients that could be used to construct a food with an acceptable structure (De Carvalho et al., 2015).

2.4 Functional properties of food

Functional properties describe the behaviour of food components during preparation and cooking, as well as how they affect finished food products in terms of how it feels, looks and tastes (Godswill et al., 2019). Functional properties of food include swelling capacity; water absorption capacity; oil absorption capacity; emulsion capacity and stability; foam capacity and stability; gelatinisation capacity and temperature; bulk density; and dextrinization among others (Godswill et al., 2019). Functional properties determine the application and use of food material in various food products (Adebowale et al., 2009). The functional properties of foods and flours are dependent on the components of the food material such as carbohydrates, proteins, fats and oils, moisture, fibre, ash, and other ingredients or food additives added to the food (flour), as well as the structures of these components (Godswill et al., 2019). Functional properties of carbohydrates in foods include sweetening, thickening, stabilizing, gelation and fat replacement. Functional properties of proteins in foods include solubility, thickening, binding, gelation, foaming, and emulsifying capacity (Vaclavik & Christian, 2008).

2.4.1 Water Absorption Index and Water Solubility Index

Water Absorption Index (WAI) and Water Solubility Index (WSI) are a measure of the hydration properties of flour (Mahgoub et al., 2020). The WAI is a measure of a flour's capacity to absorb water and swell providing a desired consistency and body to a food system (Choi et al., 2012). WAI determines the volume occupied by the granule or starch polymer after swelling in excess water (Yousf et al., 2017). Different products and food formulations require different levels of water absorption in order to achieve a desirable consistency and finished product characteristics (Godswill et al., 2019). WSI determines the amount of polysaccharides released from the granule on the addition of excess water. High WSI is an indicator of good starch digestibility (Yousf et al., 2017). Devraj et al (2020) found that the WAI of selected rice varieties ranged from 2.08 to 2.42 g/g. For multigrain composite mixtures, the WAI ranged from 2.3 to 2.4 g/g and the WSI from 0.05 to 0.06 g/g (Itagi & Singh, 2012). For composite flours from teff fortified with soybean and orange-fleshed sweet potato, Tenagashaw et al. (2016) reported that the WAI ranged from 2.20 to 4.85 g/g and the WSI from 0.08 and 0.17 g/g. The WSI for complementary foods produced from blends of orange-fleshed sweet potato, sorghum, and soybeans ranged from 0.028 to 0.031 g/g (Alawode et al., 2017).

2.4.2 Gelatinisation temperature

Gelatinisation is a process of breaking down intermolecular bonds of starch molecules in the presence of heat and water, allowing the hydrogen bonding sites to absorb more water (Godswill et al., 2019). It results in granular swelling, crystallite melting, loss of birefringence, viscosity development, and solubilisation (Liu et al., 2009). Gelatinisation is responsible for the thickening of food systems (Vaclavik & Christian, 2008) and is thus important in the formulation of various products (Iwe et al., 2016). Starch gelatinisation increases the availability of starch for hydrolysis by amylase. This is used in the food industry to make starch digestible and also to thicken/bind water in products such as sauces and soups (Godswill et al., 2019).

Flours differ in their gelatinisation characteristics (Iwe et al., 2016). Gelatinisation is influenced by the type of starch, water, temperature, stirring and presence of other ingredients like sugar, fat, acids and protein among others. Starch from different sources will exhibit different thinking and water-binding properties. Starch with more amylopectin often has a higher thickening ability and the root starches are generally more effective than cereal starches (Godswill et al., 2019). The relative ratio of protein, carbohydrates and lipids that make up a flour and the interaction between such components in the products also affect the gelation characteristics (Iwe et al., 2016). As such, the granules in food products occur in different modified forms due to various stages of gelatinisation and swelling (Sikorski & Piotrowska, 2007).

The gelatinisation temperatures of unmodified starches usually range from 55°C to 85°C (Belitz et al., 2009). Chandra et al. (2015) found flours containing wheat, rice, green gram and potato had gelatinisation temperatures ranging from 56.22°C to 60.56°C. Flours containing sweet potatoes and wheat exhibited gelatinisation temperatures ranging from 60.25 to 70.25°C (Etudaiye et al., 2015).

2.4.3 Emulsion activity and stability

An emulsion is a combination or mixture of two or more liquids that are normally immiscible (Godswill et al., 2019). The emulsion activity reflects the capacity of a protein to aid in the formation of an emulsion and is related to the protein's ability to adsorb to the interfacial area of oil and water in an emulsion (Sreerama et al., 2012). Emulsion stability is the ability of the emulsion system of foods to resist the changes and alterations in its physicochemical properties over time (Godswill et al., 2019). Chandra et al. (2015) found flours containing wheat, rice, green gram and potato had emulsion activity ranging from 41.49 to 44.69% and emulsion stability ranging from 38.38 to 48.65%. Composite flours containing wheat, mushroom, black gram, soybeans, and sorghum exhibited emulsion activity ranging from 40.00 to 81.48% and emulsion stability ranging from 50.51 to76.10%.

2.4.4 Bulk Density

Bulk density is the ratio of mass to volume (Wani et al., 2013) measured without the influence of any compression (Chandra et al., 2015). Bulk density is greatly affected by particle size (Adebowale et al., 2009) and starch content of the food product (Godswill et al., 2019). Bulk density of a flour is important in the determination of its suitability for food applications (Adebowale et al., 2009). Flour with high bulk density suggests suitability for use in food preparation as a thickener whereas a low bulk density suggests suitability for use as a complementary food (Chandra et al., 2015). Bulk density is also important in determining the packaging requirement of a flour (Adebowale et al., 2009). Flours with a higher bulk density can easily be compressed into a pouch, allowing for a smaller pouch than flours of the same weight with a lower bulk density (Leonhard, 2018).

Chandra et al. (2015) found that composite flours containing wheat, rice, green gram and potato had bulk densities ranging from 0.762 to 0.820 g/ml. Alawode et al. (2017) reported values ranging from 0.57 to 0.6 g/ml for composite flours containing orange-fleshed sweet potato, sorghum, and soybeans. Composite flours formulated from maize and African yam bean were found to have bulk densities ranging from 0.86 to 1.43 g/ml by Anosike et al. (2020).

2.4.5 Dispersibility

Dispersibility is a measure of the reconstitution of flour or flour blends in water (Adebowale et al., 2005). It describes the ease with which flour samples may be distributed as single particles over the surface and throughout the bulk of the constituting water (Anosike et al., 2020). The higher the dispersibility, the better the flour reconstitutes in water. An optimum distribution of particle sizes is essential to a good dispersion. Fine powders tend to make more lumps whereas very large particles give a gritty dispersion (Kulkarni et al., 1991).

Composite flours formulated from maize and African yam bean have been found to have dispersibility ranging from 66 to 72% by Anosike et al. (2020). Alawode et al. (2017) reported values ranging from 69 to 86% for composite flours containing orange-fleshed sweet potato, sorghum, and soybeans. Dispersibility of composite flour containing maize, yellow cassava, sweet potato, defatted soybean and groundnut ranged from 69.00 to 81.25% (Eke-Ejiofor & Mbaka, 2018).

2.5 Pasting properties

The pasting properties of a food refer to the changes that occur in the food as a result of the application of heat in the presence of water. These changes affect the texture, digestibility, and end-use of the food product (Ocheme et al., 2018). Starch granules when heated become hydrated and swell forming a paste. The granule structure collapses due to the melting of crystallites, unwinding of double helices and breaking of hydrogen bonds (Wang & Copeland, 2013). These changes are collectively referred to as starch gelatinisation and are accompanied by the loss of characteristic birefringence of intact granules. On cooling, the disaggregated starch chains retrograde gradually into partially ordered structures that differ from those in native granules (Ojo et al., 2017). Gelatinisation and retrogradation are the key functional properties of starch that determine the quality and nutritional value of starchy foods (Wang & Copeland, 2013).

Pasting properties can be determined using a Rapid Visco Analyser (RVA). This involves subjecting a flour suspension to a controlled heating-and-cooling cycle under constant sheer (Julianti et al., 2017). Properties such as peak viscosity, peak temperature, breakdown, final viscosity, setback, peak time, trough viscosity, and pasting temperature can be read from the pasting profile (Ndagire et al., 2015). Peak viscosity is the maximum viscosity developed during after sample heating (Choi et al., 2012). It is proportional to the degree of granule swelling upon heating. Flour with a higher swelling capacity will have a higher peak viscosity (Choi et al., 2012). High peak viscosity is an indication of the suitability of the blends for products requiring high gel strength and elasticity (Ojo et al., 2017). Adeola et al. (2017) reported peak viscosities ranging from 24.75 to 60.84 RVU for composite flours containing sorghum, pigeon pea, and soybean flour.

Peak viscosities of composite flours containing maize, yellow cassava, sweet potato, defatted soybean and groundnut flours ranged from 158.18 to 620.54 RVU (Eke-Ejiofor & Mbaka, 2018).

Trough viscosity is the point at which the viscosity reaches its minimum during either the heating or cooling processes. It measures the ability of the paste to withstand breakdown during cooling (Eke-Ejiofor & Mbaka, 2018; Iwe et al., 2016). It is the most commonly used parameter to determine the quality of a starch-based sample. It gives an idea of the ability of the product to gel after cooking (Eke-Ejiofor & Mbaka, 2018). The difference between peak viscosity and trough viscosity is termed breakdown viscosity. Adeola et al. (2017) reported trough viscosities ranging from 23.38 to 57.59 RVU for composite flours containing sorghum, pigeon pea, and soybean flour. Trough viscosities of composite flours containing maize, yellow cassava, sweet potato, defatted soybean and groundnut flour ranged from 92.90 to 241.48 RVU (Eke-Ejiofor & Mbaka, 2018).

Breakdown is regarded as the measure of the degree of disintegration of the granules or paste stability (Kumar & Khatkar, 2017). A low breakdown value suggests stability of starches under hot conditions (Ojo et al., 2017). Adeola et al. (2017) reported breakdown viscosities ranging from 0.67 to 3.25 RVU for composite flours containing sorghum, pigeon pea, and soybean flour. Breakdown viscosities of composite flours containing maize, yellow cassava, sweet potato, defatted soybean and groundnut flour ranged from 63.43 to 419.38 RVU (Eke-Ejiofor & Mbaka, 2018).

Final viscosity is a measure of the ability of a flour to form a viscous paste after cooking. A low final viscosity indicates a flour will form a low viscous paste on cooking and cooling (Anosike et al., 2020). Adeola et al. (2017) reported final viscosities ranging from 52.71 to 140.29 RVU for composite flours containing sorghum, pigeon pea, and soybean flour. Final viscosities of composite flours containing maize, yellow cassava, sweet potato, defatted soybean and groundnut flour ranged from 157.00 to 310.72 RVU (Eke-Ejiofor & Mbaka, 2018).

Setback viscosity is the difference between peak and final viscosity (Kumar & Khatkar, 2017). Pasting properties (except pasting temperature) decrease with an increase in the protein content of a food (Ocheme et al., 2018). Adeola et al. (2017) reported setback viscosities ranging from 29.33 to 82.71 RVU for composite flours containing sorghum, pigeon pea, and soybean flour. Setback viscosity of composite flours containing maize, yellow cassava, sweet potato, defatted soybean and groundnut flour ranged from 50.12 to 113.25 RVU (Eke-Ejiofor & Mbaka, 2018).

2.6 Sensory evaluation

Sensory evaluation is a scientific method used to evoke, measure, analyse, and interpret those responses to products as perceived through the senses of sight, smell, touch, taste, and hearing (Stone et al., 2012). Sensory evaluation is very important for assessing the acceptability of developed, improved or modified foods (Mbela et al., 2018). Food acceptability is not easy to measure as it is very subjective (Vaclavik & Christian, 2008). Every time consumers select or eat a food, they make subjective judgements using one or more of the five senses (Vaclavik & Christian, 2008). Acceptability and consumption of a food are largely determined by the desirability of its sensory attributes. Infants and young children consume less of foods with inferior sensory characteristics than those with superior sensory characteristics (Ndagire et al., 2015).

Sensory evaluation is carried out by taste panels, comprising groups of people that taste food samples under controlled conditions and evaluate them in different ways depending on the particular sensory test being conducted. This is the only type of testing that can measure consumer preference and acceptability (Vaclavik & Christian, 2008). Panellists are asked to score the acceptability of different sensory attributes such as colour, aroma, taste, texture, and overall acceptability (Mbela et al., 2018). Acceptability of the developed food product is often compared with a related commercial product that is commonly consumed (Akande et al., 2017). The acceptability of food developed for young children is evaluated by the caretakers (Mbela et al., 2018). Children are too young to make rational judgements about the sensory attributes of food. In addition, it is the caretakers that decide whether or not they will offer the food to their child (Buzigi et al., 2020). Tibagonzeka (2014) reported that caretakers of children aged 6-59 months had found complementary foods containing wheat, sesame, millet, grain amaranth, groundnuts and cassava highly acceptable. Complementary foods comprising maize, sorghum and mungbean malt were also considered acceptable (Onwurafor et al., 2017). Complementary food formulated from rice, faba beans, sweet potato flour, and peanut oil has also been considered acceptable (Mahmoud & El Anany, 2014).

2.7 Colour

Foods have an infinite variety of appearance characteristics. They might have diffuse, glossy, uneven, porous, or flat surfaces. They may be transparent, hazy, translucent or opaque and their colours may be uniform, patchy or multi-layered (Macdougall, 2010). The interactive role of pigment absorption with light scatter from food structure can have massive effects on colour and visual appearance (Völz, 2003). When light strikes food, it is reflected, absorbed, or transmitted. Reflected light determines the colour of food. The appearance can change depending on the amount of light, the light source, the observer's angle of view, size, and background differences (Giese, 2003).

Colour can be determined using the human eye where a person describes the colour of a sample using their perception and experience. This method is fast but produces inconsistent results (Hasnul Hadi et al., 2021). Visual colour judgements can be affected by individual differences in colour perception, lighting conditions and angle of view. Instrumentation to measure colour provides a subjective and consistent method of colour quality control (Giese, 2003). Colour can be measured using photoelectric colour measuring instruments. These are divided into two classes, trichromatic colorimeters and spectrophotometers (Macdougall, 2010). Colorimeters measure the colour of primary radiation sources, which emit light, and secondary radiation sources, which are those that reflect or transmit external light. Spectrophotometers measure the spectral distribution of transmittance or reflectance of the sample (Pathare et al., 2013). However, it is impossible to eliminate the lack of precision in colour measurement (Tan et al., 2004).

2.7.1 The Lovibond colour scale

The Tintometer® colorimeter was invented by Joseph Lovibond in the late 19th century. It uses a series of gradient red, yellow, blue and neutral (RYBN) coloured glasses. This is known as the Lovibond colour scale (Umbreit & Russel, 2013). Each colour has a unit range (Table 1) and the colour of a sample is determined by matching different units of these colours to obtain a match (Hasnul Hadi et al., 2021). Results are reported as Lovibond values of red, yellow, blue and neutral required for a visual match (Tan et al., 2004).

Table 1: Lovibond colour scale

Colour	Range
Red	0-79.9
Yellow	0-79.9
Blue	0-39.9
Neutral	0-39.0

(Hasnul Hadi et al., 2021)

The colour of a sample can also be described as bright or dull (Umbreit & Russel, 2013). A dull sample is one where red, yellow and blue are required to make a match. The value of the smallest colour is expressed as dullness. A sample is described as bright when the nearest possible match appears dull in comparison. When this occurs, neutral values are added and recorded as the sample brightness (Hasnul Hadi et al., 2021). The Lovibond Tintometer is simple to use. However, it is slow and tedious to operate. Automatic Lovibond instruments that can complete colour measurements in less than 25 seconds while overcoming the subjectivity of visual methods have been developed (Choudhury, 2014).

There are several other colour systems are used to describe colour in the food industry (Giese, 2003). These include:

- The Munshell colour system,
- Hunter L a b,
- Commission Internationale de l'Eclairage (CIE) L*a*b*,
- CIE XYZ,
- CIE L*u*v*,
- CIE Yxy, and
- CIE LCH (Fairchild, 2005).

These differ in the symmetry of the colour space and in the coordinate system used to define points within that space (Pathare et al., 2013). According to CIE principles, all colours are mixtures of red, green and blue colours. The quantities of red, green, and blue required to create any given colour are known as tristimulus values and are symbolized by the letters X, Y, and Z, respectively (Pathare et al., 2013). The Munsell colour system on the other hand is a colour space that specifies colours based on three colour dimensions: hue, value (lightness), and chroma (Moody & Needles, 2004).

CHAPTER 3

MATERIALS AND METHODS

3.1 The Study Area

The study was conducted in three districts of Eastern Uganda namely Pallisa, Kamuli and Buyende (Figure 1).

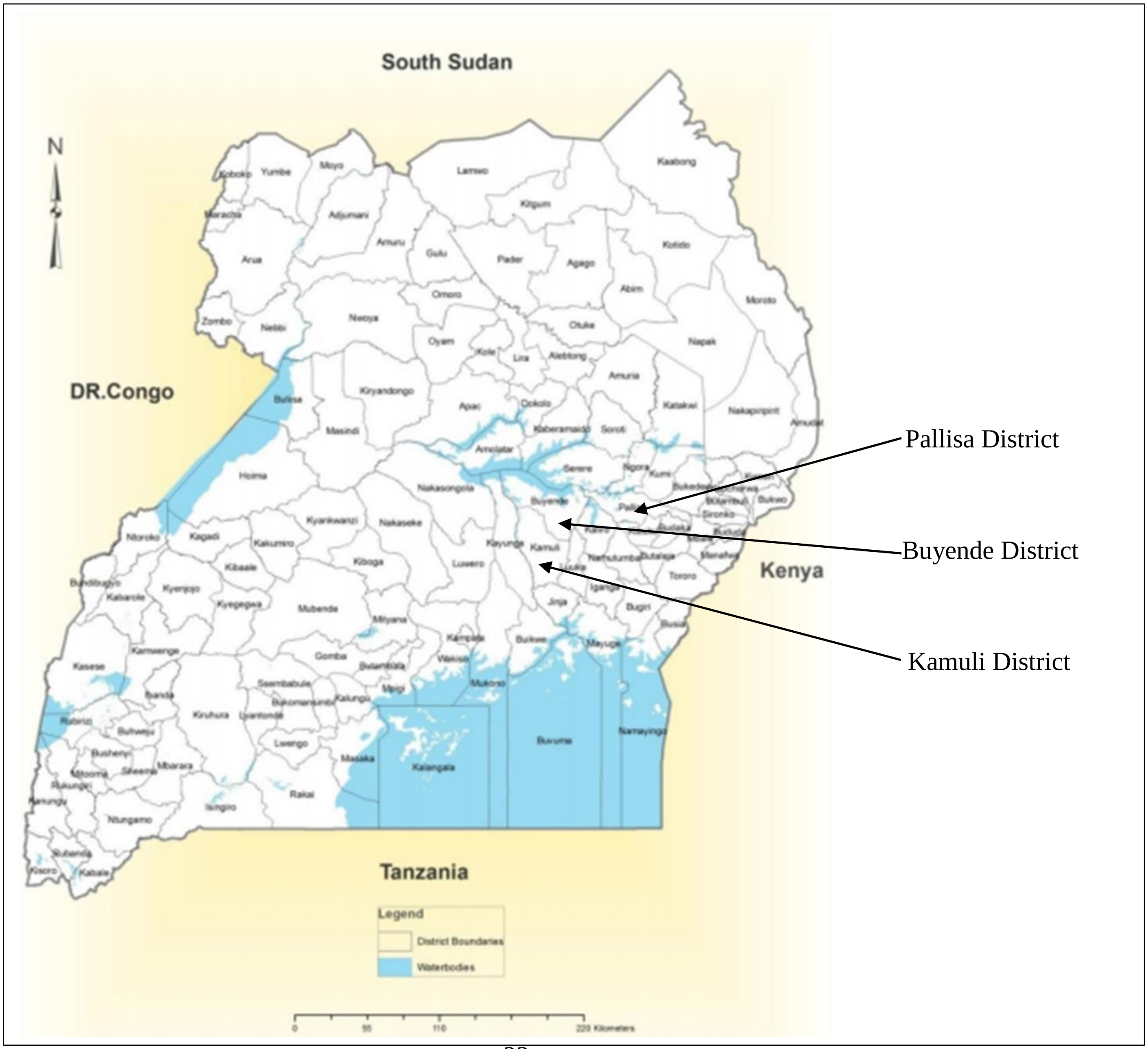

Figure 1: A map of Uganda showing the study area (UBOS, 2017)

Kamuli, Buyende and Pallisa are found in the Kioga plains agro-ecological zone (MAAIF et al., 2016; Nassary et al., 2020). The Kioga plains have a fast-growing population with a growth rate of 4% - 6% with the poverty and food security situation worse than the national average (Chombo et al., 2018). Kamuli, Pallisa and Buyende districts are characterised by high malnutrition and high food insecurity (NARO, Makerere University & VEDCO, 2019).

3.2 Research Design

The study combined both observational and experimental research methods. A cross-sectional research design covering 3 districts and 15 sub-counties that were randomly selected was used to determine the least-cost sources of energy, protein, iron and zinc. The nutritional value of these foods was determined by laboratory analysis. A quasi-experimental design was then used to evaluate the possibility of developing acceptable nutrient-dense mixtures. The nutritional value and functional properties of the two most acceptable formulations were determined using laboratory analysis.

3.3 Identification of least expensive available sources of different nutrients

The guidelines in WFP VAM (2009) Market Analysis Tool were used to conduct a mini-survey in order to identify least-cost sources of energy, protein, iron and zinc. Mini-surveys generate quantitative data that can often be collected and analysed quickly (USAID, 2010). Seasonal prices (Uganda shillings), availability and units of measurement of foods were obtained from retailers in local markets who were purposively selected. Retailers in local markets usually reveal the food prices that the most vulnerable households are facing across seasons (WFP VAM, 2017). The markets were visited during a quiet time of the day so that the business of the retailers was not disrupted (Deptford et al., 2017). An interviewer-administered market questionnaire (Annex 1) developed using the WFP VAM (2009) Market Analysis Tool was used to collect the data.

3.3.1 Determination of sample size

According to the WFP VAM (2009) Market Analysis Tool, a coverage ratio of at least 25% of the total markets in an area is sufficient to provide a picture that is representative of the local markets the target population uses. Markets were considered at sub-county level. The minimum number of markets to be visited for a 25% coverage ratio was calculated as follows:

- Kamuli = 25/100*20 markets = 5 markets
- Buyende = 25/100*7 markets = 1.75 markets
- Pallisa = 25/100*21 markets = 5.25 markets

Six markets were visited in Kamuli, 3 in Buyende and 6 in Pallisa districts thus meeting the Market Analysis Tool recommendation. All food retailers in each market were visited. A total of 268 retailers were visited.

3.3.2 Selection of least-expensive sources

The average prices and availability of common foods in Kamuli, Buyende and Pallisa were calculated from the data. For foods that are sold as different varieties, the cheaper varieties were selected. The cost per 1000 kcal of energy, 1g of protein, 1mg of iron and 1mg of zinc for available foods were calculated using the HarvestPlus food composition tables by Hotz et al (2012).

The least-cost sources of target nutrients were selected using nutrient cost values. Nutrient costs of energy, protein, iron and zinc for each food were calculated using the HarvestPlus food composition tables by Hotz et al. (2012). The 5 lowest nutrient costs were selected as the least expensive sources.

3.4 Determination of nutritional content of candidate foods

3.4.1 Preparation of food samples for analysis

Selected least expensive foods were purchased from local markets in Pallisa, Kamuli and Buyende districts. Collected foods were washed, thinly sliced to 4mm, dried in an air drier at 60°C for 24 hours (Mercer, 2007) and separately milled into flours. The flours were stored in airtight containers and kept out of the light before analysis (Julianti et al., 2017).

3.4.2 Determination of gross energy, proximate and mineral content

Moisture content, protein, ash, and crude fat contents were determined using standard AOAC methods (AOAC, 2000). Moisture content was determined using the Air Oven Method, AOAC Method No. 925.10 using an air forced laboratory oven (MRC Model: DFO-150). Ash was determined using AOAC method 923.03 using a laboratory chamber furnace (Carbolite™ CWF 1300). Crude fat was determined using the soxhlet method, AOAC Method 922.06 using a Tecator 1043 Soxtec System. Protein content was determined based on the Kjeldahl method, AOAC Method No. 920.87 using a Kjeltec™ 8200 Auto Distillation Unit. Jones (1941) nitrogen-to-protein factors were used to convert nitrogen content to protein content.

Gross energy was determined by the combustion of a sample in a bomb calorimeter (Miller & Payne, 1959). Sugars and starch were determined using the phenol–sulphuric acid method (Nielsen, 2010). Dietary fibre was determined gravimetrically using acid detergent fibre reagent (Kirk & Sawyer, 1991). Iron and zinc were determined using an Atomic Absorption Spectrophotometer (AOAC, 2000).

3.5 Formulation of nutritionally adequate mixtures

Design-Expert® (Stat Ease, Version 13.0.5.1) and Nutrisurvey (2007) software were used to generate optimal mixture formulations from the candidate foods for each season. The target composition of the mixtures is illustrated in Table 2.

According to WFP (2018), the minimum requirement for a complementary food is to meet 100% of the RNI for nutrients except energy per 100g of flour. In addition, the energy contribution from protein should not be less than 6% of the total energy and should not exceed 15% (Joint FAO/WHO Codex Alimentarius Commission, 2017).

Table 2: Target nutrient content per 100g

Nutrient content per 100g of flour	Target	RNI for children aged 1-3 years per day	RNI for children aged 4-5 years per day
Energy (kcal)	525 (6-15% from protein)	1,230	1,715
Protein (g)	19.7	14.5	19.7
Iron (mg)	12.6	11.6	12.6
Zinc (mg)	4.8	4.1	4.8

Sources: FAO & WHO (2004), WHO (2003)

3.6 Consumer acceptability, nutritional value and functional properties of developed composite flours

3.6.1 Sensory evaluation

The developed composite flours were subjected to sensory evaluation by an untrained panel as described by Lawless & Heymann (2010). The composite flours were prepared as recommended by WFP (2018). Flour (400g) was mixed with 2000 ml of hot water (100^{o}C) in a clean saucepan to make a smooth paste (soup). The soup was cooked for 45 minutes and stored in a thermos flask. A panel of 43 students and staff from the School of Food Technology, Nutrition and Bioengineering, Makerere University aged 20-50 years were selected to represent the caregivers of children aged 1-5 years. The panellists ranked the appearance, colour, aroma, taste, mouthfeel and overall acceptability of the mixtures using a 9-point hedonic scale (9=like extremely, 8=like very much, 7=like moderately, 6=like slightly, 5=neither like nor dislike, 4=dislike slightly, 3=dislike moderately, 2=dislike very much, 1=dislike extremely). The panellists were asked to give any comments about the samples (Appendix 3). Water was provided to the panellists for palate cleansing between tasting samples.

3.6.2 Determination of functional properties

3.6.2.1 Dispersibility

Dispersibility was measured using the method described by Kulkarni et al. (1991). Ten grams of the sample were placed in a 100ml measuring cylinder. Distilled water was added to reach a volume of 100ml and the mixture stirred vigorously. The mixture was then allowed to settle for 3 hours. The volume of settled particles was subtracted from 100 and the difference reported as percentage dispersibility.

3.6.2.2 Bulk density

Bulk density was determined by the method described by Wani et al. (2013). A tarred graduated cylinder was gently filled up to the 10ml mark with flour. The sample was then packed by gently tapping the cylinder on the benchtop from a height of five cm until there was no further diminution of the sample level and the volume noted. The weight of the filled cylinder was taken and the bulk density was calculated as the weight of sample per unit volume (g/ml).

3.6.2.3 Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI were determined using the method described by Devraj et al. (2020). A sample (1g) was suspended in 10ml of distilled water and stirred for 30 min. Subsequently, the dispersions were centrifuged at 2576 *x* g for 30 minutes. The supernatants were poured into a pre-weighed petri dish and the residue weighed after oven drying overnight at 70^{o}C. WAI and WSI were calculated using the following equations:

$$\mathrm{WAI} = \frac{\text{Weight of hydrated residue}}{\text{Sample weight}}$$

$$\mathrm{WSI} = \frac{\text{Weight of dissolved solid in supernatant}}{\text{Sample weight}}$$

3.6.3 Pasting properties

The pasting properties of the composite flours were evaluated using a Rapid Visco Analyser (Perten Instrument RVA 4500). The RVA general pasting method was selected. A sample (3.5g) of the composite flour was weighed and placed in a canister containing 25g of distilled water. A paddle was inserted and used to mix the sample and water before insertion into the RVA. The total running time was thirteen minutes and the viscosity values were recorded every four seconds by Thermocline for Windows software (version 3.0) as the temperature increased from 50℃ to 95℃ before cooling again to 50℃. The rotation speed was set at 148 *x* g for the first ten minutes and to 4 *x* g until the end. The following were recorded: peak viscosity, breakdown viscosity, final viscosity, setback viscosity and peak time. The viscosity was read directly from the RVA and reported in arbitrary Rapid Visco Units (RVU) (Choi et al., 2012).

3.6.4 Colour

The colour of the mixtures was evaluated using a Lovibond® model E Tintometer following the manufacturer's instructions. The Tintometer was set up and a sample placed in the testing cell. The light was turned on and the sample colour was matched by a combination of Red, Yellow, Blue and Neutral filters. This resulted in a set of Lovibond® RYBN units that defined the colour.

3.6.5 Determination of nutritional properties

The gross energy, proximate composition and mineral content of the developed composite flours were determined using the methods described in section 3.4.2.

3.7 Statistical data analysis

The average prices of available foods per season were calculated using Microsoft Excel Version 2016. Descriptive statistics (means and standard deviations) were derived for the nutritional, functional, colour and sensory properties using IBM® SPSS® Statistics (Version 26). One-way Analysis of Variance (ANOVA) was used to determine the significant differences among means generated for the nutritional properties of candidate foods and sensory properties of formulations generated by Design-Expert®. Tukey's test was used to separate means. Independent sample t-tests were used to determine the difference among means generated for colour, nutritional and functional properties of selected formulations. Differences in means were considered statistically significant at $p \leq 0.05$.

CHAPTER FOUR

RESULTS

4.1 Least-cost sources of energy, protein, zinc and Iron

The selected foods, their availabilities, prices and respective nutrient costs for the target nutrients are presented in Table 3. For energy, iron and zinc the five foods with the lowest nutrient cost were selected. For protein, cereals, pulses and animal sources were considered. There were two common varieties of rice namely *Kaiso* and *Super* of which *Kaiso* rice was the cheaper one. There were also two common bean varieties namely *Kanyebwa* and *Nambale* of which *Nambale* was cheaper. White fleshed sweet potatoes were found to be cheaper and more available and were the type considered in the study. The seso sorghum variety, which is commonly consumed at the household level was considered in the study.

Table 3: Price and cost of nutrients of selected foods

Season	Food	Availability	Price (shs/kg)	Energy cost (shs/1000Kcal)	Protein cost (shs/g)	Iron cost (shs/mg)	Zinc cost (shs/g)
1st dry season	Sweet potatoes	High	269	219	12	30	67
	Cassava	High	651	407	47	217	217
	Maize	Moderate	723	198	8	27	33
	Sorghum	Moderate	1,589	469	14	36	99
	Soybeans	Moderate	2,097	481	6	33	54
	Beans	High	3,875	1,117	18	76	168
	Sesame	Moderate	4,839	845	27	33	62
	Groundnuts	Moderate	5,900	1,041	23	128	179
1st rainy season	Sweet potatoes	Moderate	370	301	16	41	93
	Cooking bananas	High	543	445	42	91	543
	Cassava	Moderate	810	506	58	270	270
	Maize	Moderate	1,029	282	11	38	47
	Sorghum	Moderate	1,814	535	16	41	113

	Soybeans	Moderate	2,363	542	7	37	61
	Beans	High	3,650	1,052	17	72	159
	Sesame	Moderate	5,679	991	32	39	73
	Groundnuts	Moderate	6,153	1,085	24	134	186
2nd dry season	Sweet potatoes	Moderate	324	263	14	36	81
	Maize	High	689	189	7	26	31
	Cassava	Moderate	760	475	54	253	253
	Sorghum	Moderate	1,271	375	11	29	79
	Soybeans	Moderate	1,910	438	6	30	49
	Beans	High	4,125	1,189	19	81	179
	Sesame	Moderate	4,571	798	26	31	59
	Groundnuts	High	4,717	832	18	103	143
2nd rainy season	Sweet potatoes	High	263	214	11	29	66
	Cooking bananas	Moderate	554	454	43	92	554
	Maize	Moderate	704	193	7	26	32
	Cassava	Moderate	722	451	52	241	241
	Eggplants	High	899	3,746	90	450	450
	Sorghum	Moderate	1,211	357	11	28	76
	Soybeans	Moderate	2,083	478	6	33	53
	Beans	High	3,375	973	16	66	147
	Sesame	Moderate	4,925	860	28	34	63
	Groundnuts	Moderate	5,110	901	20	111	155

The least-cost foods in the 1st dry season were the same as the least-cost foods in the 2nd dry season. Similarly, the least cost foods in the 1st rainy season were the same as the least-cost foods selected in the 2nd rainy season. The least-cost sources of energy in the dry seasons were sweet potatoes, cassava, maize, sorghum and soybeans. In the rainy seasons, the least-cost sources of energy were sweet potatoes, cassava, maize, sorghum and cooking bananas. The five least-cost protein sources in all seasons were maize, sorghum, soybeans, beans and groundnuts. The five least-cost sources of iron and zinc in all seasons were found to be sweet potatoes, maize, sorghum, soybeans and sesame.

4.2 Nutrient composition of least-cost sources of nutrients

The nutrient composition of the nine identified least-cost sources of nutrients is presented in Table 4. There were significant differences in the gross energy of the selected foods ($P \leq 0.05$). The gross energy ranged from 376.0 kcal/100g in cooking bananas to 797.2 kcal/100g in sesame.

There were significant differences in the proximate composition of the foods selected in this study ($P \leq 0.05$). The carbohydrate ranged from 8.1 g/100g in sesame to 98.3 g/100g in sweet potatoes. Protein content ranged from 3.4 g/100g in cassava to 40.7 g/100g in soybeans. Crude fat content ranged from 0.6 g/100g in sweet potatoes to 52.9 g/100g in sesame. Fiber content ranged from 1.4 g/100g in cooking bananas to 7.0 g/100g in soybeans. Ash content ranged from 1.4 g/100g in maize to 5.7 g/100g in soybeans.

There were significant differences in the mineral composition of the selected in this study ($P \leq 0.05$). The iron content ranged from 0.1 mg/100g in cassava, cooking bananas and sweet potatoes to 6.6 mg/100g in soybeans. The zinc content ranged from 0.1 mg/100g in cassava and sweet potatoes to 5.1 mg/100g in sesame.

Table 4: Gross energy and nutrient composition per 100g of dry matter

Food	Energy (Kcals)	Total Sugars (g)	Starch (g)	Protein (g)	Crude fat (g)	Fiber (g)	Ash (g)	Iron (mg)	Zinc (mg)
Soybeans	555.2 ± 9.62^{ab}	9.7 ± 0.34^{ab}	7.6 ± 1.54^{ab}	40.7 ± 4.58^{d}	18.0 ± 2.01^{b}	7.0 ± 0.32^{d}	5.7 ± 0.42^{d}	6.6 ± 0.40^{cd}	1.6 ± 0.24^{a}
Sorghum	431.6 ± 20.16^{a}	4.0 ± 0.39^{ab}	71.2 ± 22.34^{c}	9.7 ± 0.32^{a}	2.8 ± 0.14^{a}	2.6 ± 0.69^{ab}	2.1 ± 0.24^{ab}	4.4 ± 0.86^{b}	2.4 ± 0.47^{ab}
Maize	457.4 ± 27.06^{a}	2.2 ± 0.21^{a}	64.4 ± 8.82^{c}	9.3 ± 2.26^{a}	5.4 ± 0.73^{a}	1.8 ± 0.19^{a}	1.4 ± 0.25^{a}	1.1 ± 0.13^{a}	2.8 ± 0.40^{ab}
Sesame	797.2 ± 116.84^{c}	4.2 ± 0.57^{ab}	3.9 ± 2.60^{a}	17.2 ± 1.75^{b}	52.9 ± 3.82^{d}	3.5 ± 0.65^{bc}	6.3 ± 0.59^{d}	6.2 ± 0.57^{cd}	5.1 ± 1.37^{b}
Groundnuts	723.7 ± 31.69^{bc}	7.0 ± 0.56^{ab}	6.4 ± 3.04^{a}	29.5 ± 2.57^{c}	45.6 ± 2.37^{c}	4.3 ± 0.95^{c}	2.5 ± 0.10^{ab}	7.0 ± 0.82^{d}	4.9 ± 1.51^{b}
Cassava	534.3 ± 166.06^{ab}	3.7 ± 0.29^{ab}	67.9 ± 9.53^{c}	3.4 ± 1.59^{a}	0.7 ± 0.15^{a}	1.9 ± 0.47^{ab}	2.2 ± 0.41^{ab}	0.1 ± 0.02^{a}	0.1 ± 0.00^{a}
Cooking bananas	376.0 ± 14.07^{a}	10.4 ± 8.49^{ab}	71.0 ± 10.03^{c}	7.8 ± 0.54^{a}	0.7 ± 0.46^{a}	1.4 ± 0.27^{a}	3.9 ± 0.32^{c}	0.1 ± 0.00^{a}	1.5 ± 0.68^{a}
Sweet potatoes	442.6 ± 16.47^{a}	11.5 ± 1.22^{b}	86.8 ± 10.75^{c}	5.8 ± 1.98^{a}	0.6 ± 0.37^{a}	2.1 ± 0.46^{ab}	2.9 ± 0.19^{bc}	0.1 ± 0.01^{a}	0.1 ± 0.00^{a}
Beans	457.1 ± 10.24^{a}	7.5 ± 0.97^{ab}	35.4 ± 2.65^{b}	22.6 ± 4.10^{bc}	1.4 ± 0.43^{a}	4.6 ± 0.77^{c}	5.2 ± 0.62^{d}	4.9 ± 1.15^{bc}	2.8 ± 0.51^{ab}

Values are means ± standard deviation of triplicate determinations. Means in each column with different superscripts are significantly different ($P \leq 0.05$)

4.3 Formulation of nutritious mixtures

Table 5 shows the optimal mixtures generated by Design-Expert® software to meet the target nutrient content (Table 1) of nutrient-dense mixtures based on the recommendations of FAO & WHO (2004) and WHO (2003). The energy content of all the formulations generated met the target for this study. The protein content of the formulations except that of number 4 of the rainy season also met the target for this study. The iron and zinc contents of all formations did not meet the targets for this study.

Table 5: Optimal mixtures for the dry and wet seasons generated by Design-Expert®

Number /Season	Sweet potatoes (g)	Cassava (g)	Maize (g)	Sorghum (g)	Soybeans (g)	Beans (g)	Sesame (g)	Ground nuts (g)	Cooking bananas (g)	Energy (kcal)	Protein (g)	Iron (mg)	Zinc (mg)
	Components in the formulation per 100g									Target nutrients per 100g			
Targets										525	19.7	12.6	4.8
<u>Dry seasons</u>													
1	0.47	0.00	2.18	0.00	0.00	30.57	34.63	32.16	_	660.53	22.58	5.96	4.26
2	0.00	0.00	0.00	25.35	1.31	4.34	33.11	35.89	_	660.18	20.25	6.02	4.20
<u>Rainy seasons</u>													
1	0.00	0.00	13.48	8.66	0.00	10.51	28.72	38.63	0.00	655.57	20.81	5.55	4.23
2	0.00	0.00	16.29	9.65	0.00	6.39	29.00	38.67	0.00	656.39	20.30	5.43	4.23
3	0.00	0.00	20.46	8.10	0.00	3.94	28.93	38.57	0.00	656.29	19.94	5.27	4.23
4	0.00	0.00	18.65	13.25	0.00	0.00	29.18	38.91	0.00	656.75	19.53	5.32	4.23
5	0.00	0.00	4.95	20.98	0.00	5.49	29.39	39.19	0.00	656.16	20.35	5.85	4.21

4.4 Consumer acceptability, functional and nutritional characteristics of developed mixtures

4.4.1 Consumer acceptability

The formulations developed in this study were subjected to sensory evaluation by a panel of 43 individuals. The mean consumer acceptability scores of the mixtures are presented in Table 6. The average scores for acceptability of appearance and colour ranged between 6.3 (liked slightly) and 7.1 (liked moderately). There were significant differences in the average consumer acceptability scores for appearance and colour. There were no significant differences in the acceptability scores for taste, aroma, mouthfeel and overall acceptability amongst the seven formulations (Table 6). The acceptability scores of these attributes range from 5.6 (liked slightly) to 6.6 (liked moderately).

Table 6: Mean scores of consumer acceptability of developed nutrient-dense mixtures

Formulation			Acceptability Scores of Different Sensory attributes					
Season	Number	Identifier	Appearance	Colour	Taste	Aroma	Mouthfeel	Overall acceptability
Dry	1	D1	6.6 ± 1.24^{ab}	6.7 ± 1.15^{ab}	5.6 ± 1.75^{a}	6.6 ± 1.22^{a}	6.0 ± 1.47^{a}	6.2 ± 1.46^{a}
Dry	2	D2	7.0 ± 1.07^{ab}	7.1 ± 1.24^{b}	5.7 ± 1.64^{a}	6.4 ± 1.57^{a}	6.1 ± 1.70^{a}	6.5 ± 1.55^{a}
Rainy	1	R1	6.8 ± 1.15^{ab}	6.9 ± 1.07^{ab}	5.7 ± 1.86^{a}	6.5 ± 1.61^{a}	6.2 ± 1.59^{a}	6.6 ± 1.44^{a}
Rainy	2	R2	6.3 ± 1.54^{a}	6.3 ± 1.43^{a}	6.1 ± 1.73^{a}	6.2 ± 1.80^{a}	6.2 ± 1.83^{a}	6.2 ± 1.48^{a}
Rainy	3	R3	7.1 ± 1.15^{b}	7.1 ± 1.00^{b}	6.0 ± 1.60^{a}	6.4 ± 1.45^{a}	6.1 ± 1.51^{a}	6.6 ± 1.03^{a}
Rainy	4	R4	6.8 ± 1.30^{ab}	7.1 ± 1.11^{b}	5.8 ± 1.78^{a}	6.3 ± 1.47^{a}	6.5 ± 1.65^{a}	6.6 ± 1.53^{a}
Rainy	5	R5	7.1 ± 1.16^{b}	7.1 ± 1.07^{b}	6.1 ± 1.89^{a}	6.4 ± 1.65^{a}	6.1 ± 1.90^{a}	6.6 ± 1.40^{a}

Values are means ± standard deviation (n=43). Means in each column with different superscripts are significantly different ($P \leq 0.05$). Scores for each sensory attribute based on a 9-point hedonic scale: 1=disliked extremely, 2=Disliked very much, 3=disliked moderately, 4=disliked slightly, 5=neither liked nor disliked, 6=Liked slightly, 7=liked moderately, 8=liked very much, 9=liked extremely

4.4.2 Functional properties

The percentage dispersibility, bulk density, WAI and WSI of the most acceptable formulation for dry and rainy seasons (D2 and R5 respectively) are presented in Table 7. The dispersibility of the formulations ranged from 76.8 to 77.2%. The bulk density of both formulations was 0.8g/ml. The WAI ranged from 1.7 to 2.0 g/g and the WSI from 0.2 to 0.3 g/g. There were significant differences in the WAI and WSI of D2 and R5.

Table 7: Functional properties of the most acceptable formulations

Formulation	Dispersibility (%)	Bulk density (g/ml)	Water absorption index (g/g)	Water solubility index (g/g)
D2	77.2 ± 0.67^{a}	0.8 ± 0.06^{a}	2.0 ± 0.06^{a}	0.2 ± 0.03^{a}
R5	76.8 ± 1.15^{a}	0.8 ± 0.05^{a}	1.7 ± 0.01^{b}	0.3 ± 0.00^{b}

Values are means ± standard deviation of triplicate determinations. Means in each column with different superscripts are significantly different ($P \leq 0.05$)

4.4.3 Pasting properties

The pasting properties of the two most acceptable formulations (D2 and R5) are presented in Table 8. The formulations had peak viscosities ranging from 55.5 to 60.3 RVU, trough 49.0 to 56.7 RVU, breakdown 3.7 to 6.3 RVU, final viscosities 86.3 to 100.7 RVU and setback 37.3 to 44.0 RVU. They also had peak times ranging from 6.6 to 6.8 minutes and pasting temperature ranging from 78.3 to 78.7^{o}C. There was no significant difference in the peak and breakdown viscosities of D2 and R5. However, D2 had significantly higher tough, final and setback viscosities.

Table 8: Pasting properties of the most acceptable formulations

Formulation	Peak viscosity (RVU)	Peak Time (Minutes)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Pasting Temperature (ºC)
D2	60.3 ± 1.15^a	6.8 ± 0.21^a	56.7 ± 0.58^a	3.7 ± 0.58^a	100.7 ± 2.31^a	44.0 ± 1.73^a	78.7 ± 0.58^a
R5	55.3 ± 4.51^a	6.6 ± 0.41^a	49.0 ± 1.73^b	6.3 ± 3.21^a	86.3 ± 0.58^b	37.3 ± 1.53^b	78.3 ± 0.58^a

Values are means ± standard deviation of triplicate determinations. Means in each column with different superscripts are significantly different ($P \leq 0.05$)

4.4.4 Colour

The colour properties of the most acceptable samples are presented in Table 9. The composite flours generally had a colour described as yellow-green based on the Lovibond® RYBN colour scale. There was no significant difference in the red, yellow, blue and sample brightness readings of D2 and R5.

Table 9: Colour properties of the most acceptable formulations

Formulation	Red (Lovibond® units)	Yellow (Lovibond® units)	Blue (Lovibond® units)	Sample brightness (Lovibond® units)	Colour (Lovibond® units)
D2	6.3 ± 0.61^{a}	8.7 ± 1.42^{a}	7.1 ± 0.58^{a}	3.0 ± 0.78^{a}	Yellow-Green 1.6
R5	6.8 ± 0.51^{a}	9.3 ± 0.76^{a}	7.5 ± 0.50^{a}	3.4 ± 0.53^{a}	Yellow-Green 1.8

Values are means ± standard deviation of triplicate determinations. Means in each column with different superscripts are significantly different ($P \leq 0.05$)

4.4.5 Nutritional properties of the developed composite flours

Table 10 shows the energy and nutrients provided by 100g of cooked D2 and R5 when prepared according to WFP (2018) instructions. There was no significant difference in the energy, moisture, protein, fibre, iron and zinc compositions of D2 and R5. However, there was a significant difference in the sugar, starch, crude fat and ash compositions.

The percentage contribution of the cooked formulations to daily RNI of energy, protein, iron and zinc for children aged 1-5 years is presented in Table 11. There were significant differences in the energy contributions of the cooked formulations to the daily energy RNI and no significant differences in the protein, iron and zinc contributions to the daily RNI of children aged 1-5 years.

Table 10: Energy content and nutrient composition per 100g of cooked sample

Formulation	Energy (Kcals)	Moisture (g)	Total Sugars (g)	Starch (g)	Protein (g)	Crude fat (g)	Fiber (g)	Ash (g)	Iron (mg)	Zinc (mg)
D2	87.2 ± 0.94^a	76.3 ± 1.85^a	2.3 ± 0.01^a	9.5 ± 0.11^a	5.8 ± 0.30^a	1.6 ± 0.15^a	1.7 ± 0.34^a	0.8 ± 0.01^a	7.5 ± 0.18^a	1.6 ± 0.10^a
R5	71.4 ± 0.64^a	80.1 ± 0.04^a	2.6 ± 0.04^b	7.1 ± 0.48^b	4.2 ± 0.40^a	0.9 ± 0.05^b	1.0 ± 0.00^a	0.6 ± 0.02^b	8.1 ± 0.43^a	1.4 ± 0.21^a

Values are means ± standard deviation of triplicate determinations. Means in each column with different superscripts are significantly different ($P \leq 0.05$)

Table 11: Percentage contribution of composites to the RNI[1] of target nutrients for children aged 1-5 years per serving

Formulation	% Contribution of composites to the RNI of children per serving							
	Children aged 1-3 years				Children aged 4-5 years			
	Energy	Protein	Iron	Zinc	Energy	Protein	Iron	Zinc
D2	14.2 ± 0.15^a	79.6 ± 4.14^a	129.3 ± 3.17^a	76.8 ± 4.94^a	12.7 ± 0.14^a	73.2 ± 3.81^a	173.8 ± 43.35^a	82.0 ± 5.28^a
R5	11.6 ± 0.10^b	67.7 ± 17.11^a	139.4 ± 7.34^a	68.1 ± 10.00^a	10.4 ± 0.09^b	62.2 ± 15.74^a	160.5 ± 8.45^a	72.7 ± 10.68^a

Values are means ± standard deviation of triplicate determinations. Means in each column with different superscripts are significantly different ($P \leq 0.05$). The % contributions were based per two servings; 200g for children aged 1-3 years and 250g for children aged 4-5 years based on UNICEF (2017) recommendations.

[1] For children aged 1-3 years, the RNI for protein is 14.5 g/day, iron 11.6 mg/day and zinc 4.2 mg/day. For children aged 4-5 years, the RNI for protein is 19.7 g/day, iron 12.6 mg/day and zinc 4.8 mg/day.

CHAPTER 5

DISCUSSIONS

5.1 Least-cost sources of energy, protein, zinc and Iron

In the rainy seasons, the least-cost sources of energy were sweet potatoes, cassava, maize, sorghum and cooking bananas. In the rainy seasons, the least-cost sources of energy were sweet potatoes, cassava, maize, sorghum and cooking bananas. This is consistent with the study by SNV (2020) that found that in eastern Uganda, 65% of the dietary energy was from cereals, roots and tubers. These are available throughout the year. In 2019, Pallisa District Local Government reported that maize is the highest produced crop (over 42,000 megatonnes) followed by cassava (over 33,000 megatonnes).

The five least-cost protein sources in all seasons were maize, sorghum, soybeans, beans and groundnuts, which are all plant sources. According to Vaclavik & Christian (2008), proteins can be obtained from both animal (meat, poultry, eggs and fish) and plant (beans, peas, soybeans, nuts and seeds) sources. Cereals contain a significant quantity of protein that ranges between 8-12% on dry matter basis. Cereals such as maize and sorghum are limiting in the amino acid lysine but this can be compensated for by combination with pulses such as soybeans, groundnuts and beans, which are higher in lysine (Joint FAO/WHO Codex Alimentarius Commission, 2017).

The five least-cost sources of iron and zinc in all seasons were found to be sweet potatoes, maize, sorghum, soybeans and sesame. According to FAO & WHO (2004), zinc and iron are low in cereals and tubers. Blending with legumes can slightly improve the iron content of the mixture. However, the bioavailability of non-heme iron sources is low (WHO, 2003). The availability of iron and zinc can be improved by reducing the phytate content of the mixture and including sources of animal protein (FAO & WHO, 2004).

5.2 Nutrient composition of least-cost sources of nutrients

The gross energy ranged from 376.0 kcal/100g in cooking bananas to 797.2 kcal/100g in sesame. The gross energy values in this study were higher than the values reported by Hotz et al. (2012). The joint FAO/WHO Codex Alimentarius Commission (2017) specified that the energy density of a formulated complementary food should be at least 4 kcal per gram on dry weight basis. Except cooking bananas, the foods in this study are good sources of energy for the development of complementary foods.

There were significant differences in the proximate composition of the foods selected in this study (Table 4). The carbohydrate content ranged from 8.1 g/100g in sesame to 98.3 g/100g in sweet potatoes. The carbohydrate contents of sorghum and sweet potatoes were higher than the values reported by Hotz et al. (2012). On the other hand, the values reported for soybeans, maize, beans, sesame, groundnuts, cassava and cooking bananas were lower than the values reported by Bamigboye et al. (2010), Hotz et al. (2012), Manano et al. (2018) and Nowakunda (2018). Digestible carbohydrates are major energy sources (Leong et al., 2019).

The protein content of the foods selected in this study ranged from 3.4 g/100g in cassava to 40.7 g/100g in soybeans. The protein contents of beans, sesame, groundnuts and cassava were comparable to the values reported by Bamigboye et al. (2010) and Hotz et al. (2012). However, the protein contents of soybeans and cooking bananas were higher than the values reported by Hotz et al. (2012) and Nowakunda (2018). On the other hand, the protein contents of sorghum, maize and sweet potato were lower than the values reported by Abamecha (2020) and Hotz et al. (2012). Soybeans, groundnuts, beans, sesame, maize and sorghum had a protein content greater than 8g/100g and as such are potential protein sources for the nutrient-dense mixtures (Joint FAO/WHO Codex Alimentarius Commission, 2017).

The crude fat content of the foods selected in this study ranged from 0.6 g/100g in sweet potatoes to 52.9 g/100g in sesame. The crude fat contents of maize, sesame, beans, cassava and sweet potatoes were comparable to those reported by Abamecha (2020) and Hotz et al. (2012). However, the crude fat contents of soybeans, sorghum, groundnuts and cooking bananas were lower than the values reported by Abamecha (2020) and Hotz et al. (2012). Fat can be used to increase the energy density of complementary foods (Joint FAO/WHO Codex Alimentarius Commission, 2017).

The fiber content of the foods selected in this study ranged from 1.4 g/100g in cooking bananas to 7.0 g/100g in soybeans. The fiber contents reported in this study were lower than the values reported by Bamigboye et al. (2010), Hotz et al. (2012) and Manano et al. (2018). Fiber can decrease appetite and reduce the energy density of formulated foods and also affect the efficiency of absorption of nutrients. The fiber content of a formulated complementary food should not exceed 5 g/100g (Joint FAO/WHO Codex Alimentarius Commission, 2017). As such, soybeans should be used in combination with foods that have a low fibre content. The fibre content of soybeans can also be reduced by dehulling (Riaz, 2016).

The ash content of the foods selected in this study ranged from 1.4 g/100g in maize to 5.7 g/100g in soybeans. The ash content consists of the inorganic residue that remains after ignition of organic matter in a food sample. This inorganic residue consists mainly of the minerals present in the food sample (Ismail, 2017). Soybeans, sesame and beans were found to have significantly higher mineral content than the other foods. The ash contents of maize, sesame, cassava and cooking bananas were consistent with the values reported by Abamecha (2020), Bamigboye et al. (2010), Manano et al. (2018) and Nowakunda (2018). However, the ash contents of soybeans, sorghum, groundnuts and beans were higher than the values reported by Abamecha (2020). The ash content of sweet potatoes was higher than the value reported by Eke-Ejiofor & Mbaka (2018).

There were significant differences in the mineral composition of the foods selected in this study. The iron ranged from 0.1 mg/100g in cassava, cooking bananas and sweet potatoes to 6.6 mg/100g in soybeans. The iron contents of soybeans and sorghum were comparable to the values that were reported by Abamecha (2020) and Hotz et al. (2012). However, the iron contents of maize, beans, sesame, cassava, cooking bananas and sweet potatoes were lower than the values reported by Hotz et al. (2012). The iron content of groundnuts was higher than the values reported by Hotz et al. (2012). The iron contents of soybeans, sorghum, maize, sesame, groundnuts and beans are considered significant as they meet 5% of the daily RNI for the target group (FAO & WHO, 2001).

The zinc content of the foods selected in this study ranged from 0.1 mg/100g in cassava and sweet potatoes to 5.1 mg/100g in sesame. The zinc content of sesame was comparable to the value reported by Bamigboye et al. (2010). The zinc contents of maize and beans were comparable to the values that were reported by Hotz et al. (2012). However, the zinc contents of sorghum and groundnuts were higher than and those of soybeans, cassava, sesame, cooking bananas and sweet potatoes lower than the values reported by Hotz et al. (2012). The zinc contents of soybeans, sorghum, maize, sesame, cooking bananas, groundnuts and beans are considered significant as they meet 5% of the daily RNI for the target group (FAO & WHO, 2001).

5.3 Formulation of nutritious mixtures

The energy content of all the formulations generated met the target for this study. The protein content of the formulations except that of number 4 of the rainy season also met the target for this study. The iron content of all formations did not meet the target and were unable to meet the RNI for children aged 1-5 years (FAO & WHO, 2004). The iron content of the formulations can be improved by fortification of the flour (WFP, 2018). The zinc content of all the generated formulations did not meet the target. The zinc content however met the RNI for children aged 1-3 years but not those aged 4-5 years (FAO & WHO, 2004). The zinc content can also be improved by fortification of the flour (WFP, 2018). Animal flesh and organs are the best sources of iron and zinc. These can be included in the children’s diets (WHO, 2000).

Cereals (maize, sorghum) and legumes (soybeans, beans, groundnuts) contain anti-nutritional factors that interfere with the nutritional value of foods. These include tannins, phytate, protease inhibitors, saponins and polyphenolic compounds. They combine with nutrients resulting in reduced nutrient bioavailability (Samtiya et al., 2020). As such, the mixtures should be processed in a manner that maintains protein quality, minimizes loss of micronutrients and maintains overall nutritive value (Joint FAO/WHO Codex Alimentarius Commission, 2017). Soaking, germination, fermentation and cooking are some of the processing techniques that have been used to reduce anti-nutritional components in foods (Samtiya et al., 2020). Cooking can reduce anti-nutrients such as phytic acid, tannins, oxalic acid and protease inhibitors (Popova & Mihaylova, 2019).

5.4 Consumer acceptability, functional and nutritional characteristics of developed mixtures

5.4.1 Consumer acceptability

Children learn about their food preferences through direct experience with foods, such as tasting, touching, seeing, and smelling them, as well as through studying their food environment, such as other people's eating habits (Nekitsing et al., 2018). As such, the formulations developed in this study were subjected to sensory evaluation.

Consumers often assess the quality of a food product by its colour and appearance (Lawless & Heymann, 2010). The acceptability of appearance and colour ranged from liked slightly to liked moderately. Food colour is the most important product-intrinsic sensory in setting expectations about the taste and flavour of the food (Spence, 2015).

There were no significant differences in the acceptability scores for taste, aroma, mouthfeel and overall acceptability amongst the seven formulations (Table 6). The acceptability of these attributes ranged from liked slightly to liked moderately. Taste and aroma are crucial sensory elements in encouraging children to eat a food. A negative reaction to the taste and aroma of a food can result in rejection by the child (Nekitsing et al., 2018). The results indicated that the seven formulations were equally accepted and can be potentially adopted for use in infant feeding.

5.4.2 Functional properties

The suitability of complementary food for infant feeding is influenced by its functional properties (Tenagashaw et al., 2016). Functional properties are a function of consistency. The consistency of complementary foods supports swallowing and determines the extent to which the growing child can meet their nutrient and energy requirements (Anosike et al., 2020).

Dispersibility describes the ease with which flour samples may be distributed as single particles over the surface and throughout the bulk of the constituting water (Anosike et al., 2020). There was no significant difference in the percentage dispersibility of formulations D2 and R5. The dispersibility percentages of formulations D2 and R5 were higher than the values reported for fermented cassava paste by Adebowale et al. (2005) which ranged from 69.0 to 70.3%. The dispersibility percentages of both formulations were also higher than the values reported by Anosike et al. (2020) for complementary foods formulated from maize and African yam bean which ranged from 66.0 to 72.0%. Both formulations were easily dispersible (Table 7). As such, they can easily be reconstituted to give a paste of fine consistency (Kulkarni et al., 1991).

Formulations D2 and R5 had a bulk density of 0.8 g/ml. This was comparable to the values reported by Tenagashaw et al. (2016) for a composite flour from teff fortified with soybean and orange-fleshed sweet potato that ranged from 0.7 to 0.8 g/ml. The bulk density reported in this study was however lower than the values reported by Anosike et al. (2020) for complementary foods formulated from maize and African yam bean which ranged from 0.9 to 1.4 g/ml. A low bulk density is preferred in the formulation of complementary foods (Godswill et al., 2019). Formulations with low bulk densities can be prepared using small amounts of water while still providing the desired nutrient density and consistency. These can easily be fed to young children without choking and suffocation (Anosike et al., 2020). Infants and young children can also consume more of the lighter formulations resulting in higher nutrient intake (Ocheme et al., 2018).

Formulations D2 and R5 had significantly different WAIs. The significantly higher WAI of D2 can be attributed to the higher sorghum content of D2. Sorghum has been found to have a WAI of 4.54 g/g (Ibrahim & Ani, 2018). The values reported in this study were lower than the values reported by Tenagashaw et al. (2016) for complementary foods from teff fortified with soybean and orange-fleshed sweet potato that ranged from 2.2 to 4.9 g/g. They were also lower than the values reported by Adeola et al. (2017) for complementary foods from blends of sorghum, pigeon pea, and soybean flour that ranged from 2.0 to 3.0 g/g. Flour with a low water absorption index forms thinner gruels in which more flour can be added per unit volume. This results in nutrient-dense gruels that are desirable in the formulation of foods for infants and young children (Tenagashaw et al., 2016).

There was a significant difference in the WSI of formulations D2 and R5 that can be attributed to the higher sorghum content of D2. Sorghum has been found to have a WSI of 5.5 g/g (Ibrahim & Ani, 2018). These values were higher than the values reported by Tenagashaw et al. (2016) for complementary foods from teff fortified with soybean and orange-fleshed sweet potato that ranged from 0.08 to 0.16 g/g. They were also higher than the values reported by Adeola et al. (2017) for complementary foods from blends of sorghum, pigeon pea, and soybean flour that ranged from 0.04 to 0.05 g/g. The water solubility index of D2 was comparable to 0.2 g/g reported by Mahgoub et al. (2020) for instant porridge supplemented with mung bean but the WSI of R5 was higher. WSI is indicative of the quantity of water-soluble molecules in a flour. The higher water solubility of the formulations suggests that they are easier to digest and are desirable for feeding infants and young children (Hyacinthe et al., 2021).

5.4.3 Pasting properties

There was no significant difference in the peak and breakdown viscosities of D2 and R5. However, D2 had significantly higher tough, final and setback viscosities. The significant differences in the trough, final and breakdown viscosities can be attributed to the difference in components of D2 and R5. D2 contains more sorghum and sesame than R5. In addition, D2 contains soybeans whereas R5 does not and R5 contains maize whereas D2 does not.

The peak, trough, breakdown, final and setback viscosities reported in this study were lower than 235, 127, 108, 183 and 74 RVU respectively reported by Anosike et al. (2020) for complementary foods formulated from maize and African yam bean flours. These were The viscosity values in this study were also lower than 268, 247, 21, 406 and 159 RVU respectively reported by Onwurafor et al. (2017) for complementary foods formulated from sorghum, maize and mung bean. Flours with low peak viscosity and low final viscosity are desirable for feeding infants and young children as they form less viscous nutrient-dense pastes (Anosike et al., 2020). Tough viscosity and breakdown viscosity are a measure of paste stability. A low tough viscosity and breakdown viscosity indicate higher paste stability during high temperature and shear during cooking (Ocheme et al., 2018). Setback viscosity is a measure of the retrogradation tendency of the paste on cooling (Wani et al., 2013). The low setback viscosities of D2 and R5 imply the formulations have a high resistance to retrogradation on cooling (Ofori et al., 2020). Retrogradation causes an increase in viscosity (Choi et al., 2012). This is undesirable in foods for infants and young children. The significantly lower trough viscosity, final viscosity and setback viscosity however imply that

R5 will form a less viscous and more stable paste that is more resistant to retrogradation. This makes R5 more suitable for feeding infants and young children

Peak time is the time taken to reach peak viscosity (Choi et al., 2012). It is a measure of cooking time. A higher peak time implies a longer cooking time (Adebowale et al., 2005). The peak times in this study were higher than the peak times reported by Anosike et al. (2020) that ranged from 6.09 to 6.35 minutes. They were also higher than 5.13 minutes reported by Onwurafor et al. (2017) for complementary food formulated from sorghum, maize and mung beans. D2 and R5 will thus take longer to cook.

Pasting temperature is the temperature at which viscosity starts to increase during heating (Kumar & Khatkar, 2017). It's a measure of the minimum temperature required to cook a sample. A lower pasting temperature indicates that less energy is required to cook a sample (Iwe et al., 2016). The pasting temperatures of D2 and R5 were lower than the values reported by Anosike et al. (2020) for complementary foods formulated from maize and African yam bean flours and Onwurafor et al. (2017) for complementary foods formulated from sorghum, maize and mung bean.

5.4.4 Colour

Colour is the first parameter used to judge the quality of food making it one of the most important attributes influencing consumer food choices (Pathare et al., 2013). Young children are drawn to brightly covered foods (Spence, 2015). Both D2 and R5 were bright samples suggesting that they could be desirable to children in the target age group. The colour of D2 and R5 were acceptable to the sensory panellists (Table 6).

There were no significant differences in the colour properties implying that the differences in formulations did not impact the overall colour of the composite flours developed. This could be attributed to the fact that although D2 and R5 were different formulations, the main components of both were sesame, groundnuts and sorghum. They both contained beans as well.

5.4.5 Nutritional properties of the developed composite flours

The energy, moisture, protein, fibre, iron and zinc compositions of D2 and R5 were not significantly different. However, there was a significant difference in the sugar, starch, crude fat and ash compositions. The differences can be attributed to the difference in foods used in the formulations (Table 5). The higher sugar content of R5 can be attributed to the higher quantity of beans and groundnuts in R5 (Table 4) which were found to have significantly higher sugar contents. R5 also had a higher starch content than D2 and this can be attributed to the inclusion of maize in formulation R5 as well as the higher quantity of beans. The higher crude fat and ash content of D2 can be attributed to the higher quantity of sesame in D2 as sesame was found to have significantly higher crude fat and ash content than all the other foods that were used in the formulations.

WHO (2003) recommends that the energy density of a complementary food should be at least 0.67 kcal/g and closer to 1 kcal/g. The energy density of D2 was 0.872 kcal/g and that of R5 was 0.714 kcal/g (Table 10). Therefore, both D2 and R5 met the minimum energy density. The energy content of the formulations can however be brought closer to 1 kcal/g by addition of energy containing ingredients such as fats and oils or digestible carbohydrates (Joint FAO/WHO Codex Alimentarius Commission, 2017). R5 contributed a significantly lower percentage to the energy RNI than D2 per serving (Table 11). This can be attributed to the significantly lower sugar, starch and crude fat contents of R5 as these are the major sources of energy (Leong et al., 2019).

The minimum requirement of a complementary food is to meet at least 50% of the RNI for most nutrients except energy per serving (WFP, 2018; WHO, 2003). The protein, iron and zinc contents of both D2 and R5 provided more than 50% of the RNI for children aged 1-5 years (Table 11).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study found that in selected Eastern Ugandan districts, the least-cost foods in the 1st dry season were the same as the least-cost foods in the 2nd dry season. Similarly, the least-cost foods in the 1st rainy season were the same as the least-cost foods selected in the 2nd rainy season. The study also found that the least-cost foods can be blended to make low-cost acceptable nutrient-dense mixtures for children aged 1-5 years. For the dry seasons, mixtures containing sweet potatoes, maize, sorghum, soybeans, beans, sesame and groundnuts were developed. The formulations developed for the rainy season contained maize, sorghum, beans, sesame and groundnuts.

The formulations developed met the minimum recommended energy density and more than 50% of the recommended RNI for protein, iron and zinc for children aged 1-5 years when prepared according to the WFP (2018) instructions. The most acceptable formulations for the dry and rainy seasons had functional properties that are desirable in foods for infants and young children such as high dispersibility, low WAI and high WSI. The pasting properties indicate that the most acceptable formulations also form stable low viscosity pastes that can withstand breakdown during cooking and have high resistance to retrogradation on cooling. The adoption of the formulations developed in this study could reduce undernutrition in the target age group by providing low-cost nutritious options.

6.2 Recommendations

Since results from this study have revealed the significant contribution of the developed mixtures to the nutrient requirements of children aged 1-5 years, it is recommended that the nutritional benefits of the formulations developed in this study are provided to caregivers. It is also recommended that the energy density of the formulations be improved by addition of energy containing ingredients such as fats and oils or digestible carbohydrates. In addition, i*n vitro* digestibility and mineral bioavailability of the formulations should be carried out in order to predict the fraction of nutrients that would be absorbed by a child`s gastrointestinal tract. This will establish whether the formulations require readjustment of the ingredients ratios and/or processing before consumption by infants and young children.

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APPENDICES

Appendix 1: Questionnaire for determining the least cost sources of different foods

Table 1: Geographic Information of Clients:

District:	
Sub county:	
Parish:	
Village:	
GPS:	

Table 2: Price range of common foods

	Food	Unit of measurement	Season	Availability	Price range per unit
Carbohydrate sources	Cassava		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Sweet potatoes		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Maize		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium	

				☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Rice		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Orange fleshed sweet potatoes		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Grain amaranth		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Millet		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High	

				☐ Medium ☐ Low	
	Sorghum		1^{st} rainy season	☐ High ☐ Medium ☐ Low	
			1^{st} dry season	☐ High ☐ Medium ☐ Low	
			2^{nd} rainy season	☐ High ☐ Medium ☐ Low	
			2^{nd} dry season	☐ High ☐ Medium ☐ Low	
Protein sources	Red kidney beans		1^{st} rainy season	☐ High ☐ Medium ☐ Low	
			1^{st} dry season	☐ High ☐ Medium ☐ Low	
			2^{nd} rainy season	☐ High ☐ Medium ☐ Low	
			2^{nd} dry season	☐ High ☐ Medium ☐ Low	
	Soybeans		1^{st} rainy season	☐ High ☐ Medium ☐ Low	
			1^{st} dry season	☐ High ☐ Medium ☐ Low	
			2^{nd} rainy season	☐ High ☐ Medium ☐ Low	
			2^{nd} dry season	☐ High ☐ Medium ☐ Low	
	Sesame		1^{st} rainy season	☐ High ☐ Medium ☐ Low	
			1^{st} dry season	☐ High ☐ Medium ☐ Low	
			2^{nd} rainy season	☐ High ☐ Medium ☐ Low	
			2^{nd} dry season	☐ High ☐ Medium ☐ Low	
	Silver fish		1^{st} rainy season	☐ High ☐ Medium ☐ Low	

			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Haplochromines		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Groundnuts		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
Micronutrient sources	Eggplants		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Pumpkin		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	

			2nd dry season	☐ High ☐ Medium ☐ Low	
	Mushrooms		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Carrot		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
	Garden eggs		1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
Any other food (1)			1st rainy season	☐ High ☐ Medium ☐ Low	
			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	
Any other food (2)			1st rainy season	☐ High ☐ Medium ☐ Low	

			1st dry season	☐ High ☐ Medium ☐ Low	
			2nd rainy season	☐ High ☐ Medium ☐ Low	
			2nd dry season	☐ High ☐ Medium ☐ Low	

Appendix 2: Price and cost of nutrients of available foods in the different seasons

Table 12: Price and cost of nutrients of available foods in the 1st dry season

Food	Availability	Price (shs/kg)	Energy cost (shs/1000Kcal)	Protein cost (shs/g)	Iron cost (shs/mg)	Zinc cost (shs/g)
Sweet potatoes	High	269	219	12	30	67
Cooking bananas	Moderate	621	509	48	104	621
Cassava	High	651	407	47	217	217
Maize	Moderate	723	198	8	27	33
Yam	Moderate	1,375	1,165	92	275	688
Sorghum	Moderate	1,589	469	14	36	99
Soybeans	Moderate	2,097	481	6	33	54
Rice	Moderate	2,210	614	33	276	184
Millet	Moderate	2,743	726	25	91	161
Beans	High	3,875	1,117	18	76	168
Sesame	Moderate	4,839	845	27	33	62
Groundnuts	Moderate	5,900	1,041	23	128	179
Silverfish	High	15,274	4,162	37	587	664
Haplochromines	High	24,241	6,605	58	932	1054

Table 13: Price and cost of nutrients of available foods in the 1st rainy season

Foods	Availability	Price (Shs/kg)	Energy cost (shs/1000Kcal)	Protein cost (shs/g)	Iron cost (shs/mg)	Zinc cost (shs/mg)
Sweet potatoes	Moderate	370	301	16	41	93
Pumpkin	High	520	2,000	52	65	173
Cooking bananas	High	543	445	42	91	543
Cassava	Moderate	810	506	58	270	270
Eggplants	Moderate	867	3,613	87	434	434
Maize	Moderate	1,029	282	11	38	47
Garden eggs	High	1,409	5,871	141	705	705
Sorghum	Moderate	1,814	535	16	41	113
Yam	Moderate	1,875	1,589	125	375	938
Soybeans	Moderate	2,363	542	7	37	61
Rice	Moderate	2,590	719	39	324	216

Millet	Moderate	2,837	751	26	95	167
Beans	High	3,650	1,052	17	72	159
Sesame	Moderate	5,679	991	32	39	73
Groundnuts	Moderate	6,153	1,085	24	134	186
Silverfish	High	15,274	4,162	37	587	664
Haplochromines	High	24,241	6,605	58	932	1054

Table 14: Price and cost of nutrients of available foods in the 2nd dry season

Foods	Availability	Price (Shs/kg)	Energy cost (shs/1000Kcal)	Protein cost (shs/kg)	Iron cost (shs/g)	Zinc cost (shs/g)
Sweet potatoes	Moderate	324	263	14	36	81
Cooking bananas	Moderate	643	527	49	107	643
Maize	High	689	189	7	26	31
Cassava	Moderate	760	475	54	253	253
Sorghum	Moderate	1,271	375	11	29	79
Soybeans	Moderate	1,910	438	6	30	49
Garden eggs	Moderate	1,924	8,017	192	962	962
Millet	High	2,110	558	19	70	124
Rice	Moderate	2,330	647	35	291	194
Beans	High	4,125	1,189	19	81	179
Sesame	Moderate	4,571	798	26	31	59
Groundnuts	High	4,717	832	18	103	143
Silverfish	High	15,274	4,162	37	587	664
Haplochromines	High	24,241	6,605	58	932	1054

Table 15: Price and cost of nutrients of available foods in the 2nd wet season

Foods	Availability	Price (Shs/kg)	Energy cost (shs/1000Kcal)	Protein cost (shs/kg)	Iron cost (shs/g)	Zinc cost (shs/g)
Sweet potatoes	High	263	214	11	29	66
Pumpkin	High	457	1,758	46	57	152
Cooking bananas	Moderate	554	454	43	92	554
Maize	Moderate	704	193	7	26	32
Cassava	Moderate	722	451	52	241	241
Eggplants	High	899	3,746	90	450	450
Sorghum	Moderate	1,211	357	11	28	76

Yam	High	1,375	1,165	92	275	688
Garden eggs	Moderate	1,394	5,808	139	697	697
Soybeans	Moderate	2,083	478	6	33	53
Rice	Moderate	2,323	645	35	290	194
Millet	Moderate	2,460	651	22	82	145
Beans	High	3,375	973	16	66	147
Sesame	Moderate	4,925	860	28	34	63
Groundnuts	Moderate	5,110	901	20	111	155
Silverfish	High	15,274	4,162	37	587	664
Haplochromines	High	24,241	6,605	58	932	1054

Appendix 3: Pasting curves of the two most acceptable formulations

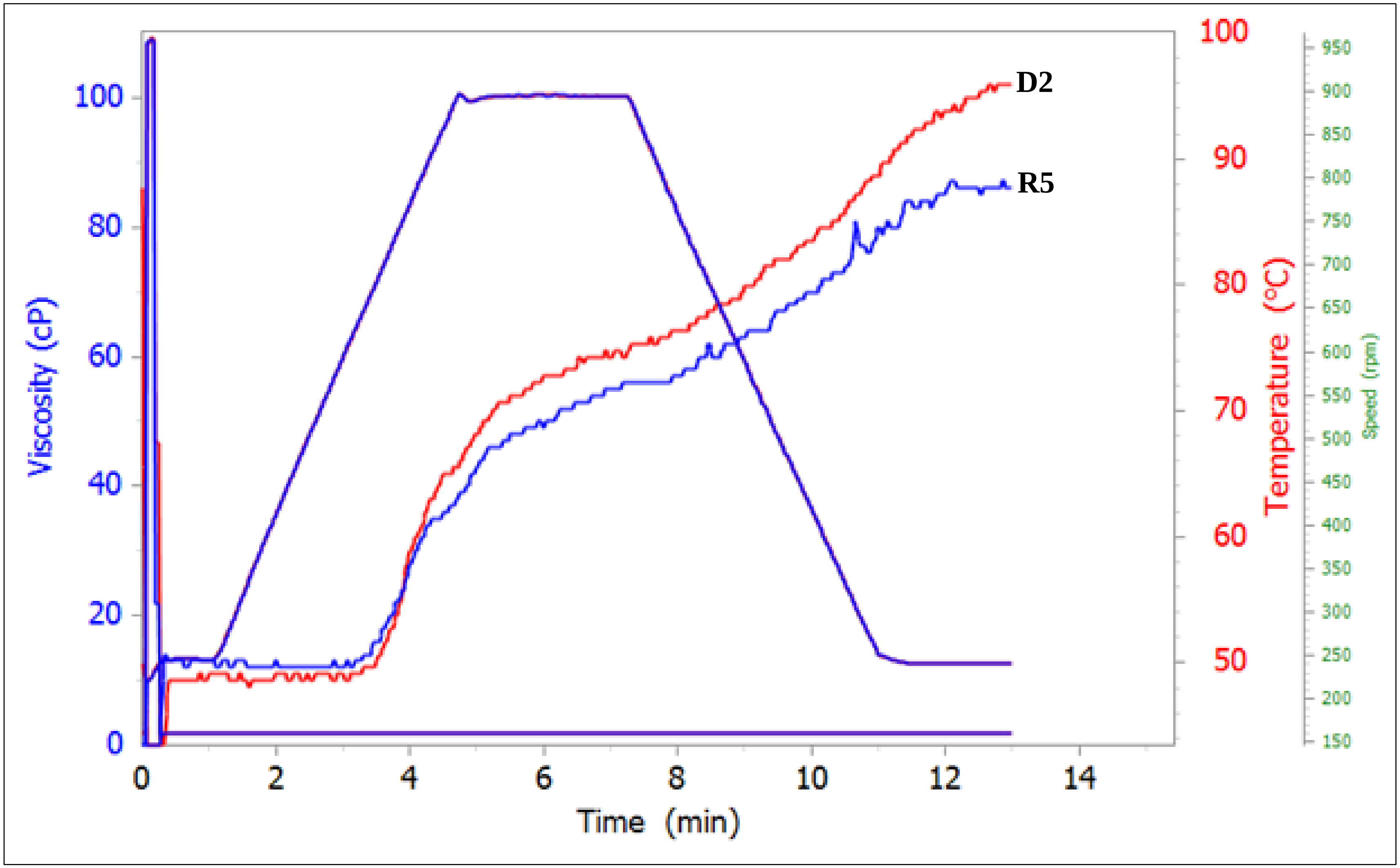

Figure 2: Pasting curves of the two most acceptable formulations

Appendix 4: Constraints used to generate optimal nutrient-dense mixtures

Dry seasons

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Sweet potatoes	is in range	0	50	1	1	3
B:Cassava	is in range	0	50	1	1	3
C:Maize	is in range	0	50	1	1	3
D:Sorghum	is in range	0	50	1	1	3
E:Soybeans	is in range	0	50	1	1	3
F:Beans	is in range	0	50	1	1	3
G:Sesame	minimize	0	50	1	1	3
H:Groundnuts	minimize	0	50	1	1	3
Energy	maximize	563	700	1	1	3
Protein	maximize	14.5	19.7	1	1	3
Iron	maximize	5	40	1	1	3
Zinc	is in range	4.2	14	1	1	3

Rainy seasons

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Sweet potatoes	is in range	0	50	1	1	3
B:Cassava	is in range	0	50	1	1	3
C:Maize	maximize	0	50	1	1	3
D:Sorghum	maximize	0	50	1	1	3
E:Soybeans	is in range	0	50	1	1	3
F:Beans	minimize	0	50	1	1	3
G:Sesame	minimize	0	30	1	1	3

H:Groundnuts	minimize	0	40	1	1	3
J:Cooking bananas	is in range	0	50	1	1	3
Energy	maximize	563	700	1	1	3
Protein	maximize	14.5	19.7	1	1	3
Iron	maximize	5	40	1	1	3
Zinc	maximize	4.2	8.3	1	1	3

Appendix 5: Sensory evaluation ballot

ACCEPTABILITY TEST FOR NUTRIENT-DENSE MIXTURES

Date………………….……… Sex……………… Gender………………………

Instructions

You are provided with four coded samples of porridge. Please assess these samples for appearance, taste, aroma, mouth feel and overall acceptability basing on the scale given below. Write down the figure that corresponds to your response in the table below. Please rinse your mouth with water provided before and after tasting each sample. Feel free to give any comments about these samples.

Dislike extremely	1
Dislike very much	2
Dislike moderately	3
Dislike slightly	4
Neither like nor dislike	5
Like slightly	6
Like moderately	7
Like very much	8
Like extremely	9

Sample code	Appearance	Colour	Taste	Aroma	Mouthfeel	Overall acceptability
524						
269						
458						
374						

Any other comments (please note the sample code)

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Thank you for your participation