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Declaration

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Dedication

This dissertation is dedicated to my mother, Gelaye Wolde Aweke.

I wish you could see how far I´ve come.

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Preliminary remarks

Parts of this thesis have been under review or are submitted for publication in peer-reviewed journals as shown below:

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Chapter 5[2]: **Forsido, S.F.**, Tsegaye, N., Belachew, T., Hensel, O. (2018). Complementary feeding practices, dietary diversity, and nutrient adequacy of diets of children 6-24 months old in Jimma Zone, Southwest Ethiopia. Maternal and Child Nutrition (Submitted)

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[1] Part of this chapter has been which focuses on child and maternal stakeholders in the study area is presented in the Agriculture, Nutrition and Health Academy Week 2017 annual conference as an oral paper and published in the book of abstracts (page 70). https://anh-academy.org/sites/default/files/ANH-NIL_2017_Abstract%20Booklet.pdf

[2] Part of this chapter which focuses on maternal diets has been presented in the Tropentag 2016 annual conference as an oral paper and published in the book of abstracts (page 516). http://www.tropentag.de/2016/proceedings/proceedings.pdf

[3] Part of this chapter has been presented in the Tropentag 2017 annual conference as a poster and published in the book of abstracts (page 416). http://www.tropentag.de/2017/proceedings/proceedings.pdf

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Nomenclature

Acronyms

AAS	Atomic Absorption Spectrophotometer
AI	Adequate Intake
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
AOR	Adjusted Odds Ratio
ARF	Amylase-Rich Flour
BDL	Below Detection Limit
BMBF	German Federal Ministry of Education and Research
BMI	Body Mass Index
CED	Chronic Energy Deficiency
CI	Confidence Interval
CRD	Completely Randomized Design
CSA	Central Statistical Agency Ethiopia
DDS	Dietary Diversity Score
DHS	Demographic and Health Survey
EHNRI	Ethiopian Health and Nutrition Research Institute
EPHI	Ethiopian Public Health Institute
FAO	Food and Agriculture Organization
HAZ	Height-for-age Z-score
HTST	High-Temperature Short Time
IYCF	Infant and Young Child Feeding
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
MAR	Mean Adequacy Ratio
NAR	Nutrient Adequacy Ratio
RDA	Recommended Daily Allowance
RELOAD	Reduction of Post-Harvest Losses and Value Addition in East African Food Value Chains Project
SD	Standard Deviation

SMEs	Small and Medium Enterprises
SNNP	Southern Nations, Nationalities and Peoples Region
SPSS	Statistical Package for Social Sciences
SSA	Sub-Saharan Africa
STROBE	Strengthening the Reporting of Observational studies in Epidemiology
UNDP	United Nations Development Program
UNICEF	United Nations Children's Emergency Fund
USDA	United States Department of Agriculture
WAC	Water Absorption Capacity
WAZ	Weight-for-Age Z-score
WHO	World Health Organization
WHZ	Weight-for-Height Z-score

Symbols

%	Percentage
a_w	Water Activity
cP	centipoise
Ea	Activation Energy
P	P value
Q_{10}	Temperature coefficient which measures the rate of change of a biological or chemical system as a consequence of increasing the temperature by 10 ^{o}C
R^2	Coefficient of Determination
T	Temperature
β	The standardised beta

1 General introduction

1.1 Context

Maternal and child undernutrition is one of the most significant health problems of our times. It accounts for 11% of the global burden of disease (Black et al., 2008). Maternal and child undernutrition is associated with well-known short-term effects and long-term impairments (Victora et al., 2008). Maternal and child nutrition has been on the global agenda as central to health, sustainable development, and progress in low- and middle-income countries (Christian, Mullany, Hurley, Katz, & Black, 2015). Malnutrition in its different forms remains to be a grand challenge to the entire world.

There are fundamental, underlying and immediate causes of maternal and child undernutrition. The fundamental causes range from economic structures to political and ideological superstructures, which affect resources and controls (Pelto, Levitt, & Thairu, 2003). The underlying causes are associated with income poverty which leads to inadequate access to food, inadequate care and insufficient health at household and community level. The immediate causes include inadequate dietary intake and disease (Black et al., 2008). The causes of malnutrition are interrelated and complex.

Inadequate dietary intake is a standard issue among communities whose diets are predominantly starchy staples and is less diversified. Nutritional status is strongly related to dietary diversity which reflects dietary quality (Brinkman, de Pee, Sanogo, Subran, & Bloem, 2010). Relying on predominantly on starchy staples may leave one vulnerable to protein and micronutrients malnutrition as these foods do not naturally contain those nutrients in a bioavailable quality and quantity (Arimond et al., 2010). As adult eating habit influences children, they are also affected by low dietary diversity and hence inadequate dietary intake (Zhou, Wang, Ye, Zeng, & Wang, 2012). The scenario in Ethiopia is not different from this.

1.2 Research need

Nowadays nutritional status of people relying on starchy staples is being compromised by the rise of several new challenges. By 2050 hunger and child malnutrition could increase by up to 20% as a result of climate-related disasters (World Food Programme, 2015). High food price inflation is also a problem associated with higher incidence of malnutrition (Arndt, Hussain, Salvucci, & Østerdal, 2016). Additionally, animal source foods are getting more and more expensive and unaffordable in low-income countries like Ethiopia (Bachewe, Minten, & Yimer, 2017). These phenomena coupled with other emerging issues like population growth and urbanisation put the future of populations relying on undiversified, starchy diets in jeopardy and there is an urgent need for identifying potential solutions.

In the past decades, several ways of upgrading starchy staples have been reported. One of these techniques is blending of high nutritive value ingredients with the starchy staples to make upgraded food products (Mouquet, Salvignol, Van Hoan, Monvois, & Trèche, 2003). Fermentation of plant raw materials is another technique used for the production of nutrient-dense foods at household levels in low-income settings (Egounlety, 2002). Incorporation of malted grain (maize, rice, millet or sorghum) flour or amylase-rich flour (ARF) which is rich in amylolytic enzymes has also been reported as an effective means of producing liquefied food from a solid base (Afoakwa, Aidoo, & Adjonu, 2010). These and many other techniques are available to improve chemical and physical properties of starchy foods.

Despite reports of possibilities of upgrading starchy staples, no affordable upgraded starchy-staple based food products have been introduced to the Southwest Ethiopian market, because of the intrinsic difficulties in product development. Development of nutritious, affordable and culturally acceptable food products for use in a local context by upgrading starchy staples is critically needed.

1.3 Research questions and objectives

The general objective of this PhD research was to see for possibilities of upgrading the nutritional value of traditional starchy staple foods mainly consumed by children less than two years old and lactating women in Southwest of Ethiopia by employing different food processing techniques.

The following is an overview of the objectives and corresponding research questions of this dissertation.

1. The first specific objective was to identify the nutritional needs, and current dietary nutrient deficiencies among children under the age of two years and their index mothers

Research question 1: What is the nutritional status of children less than two years old and their mothers in Southwest of Ethiopia and what are its determinants?

2. The second specific objective was to determine the nutritional content of currently consumed foods by these groups

   Research question 2: How is the complementary feeding practices and what is the composition of complementary foods consumed by children 6 to 24 months old and are the complementary foods nutritionally adequate?

3. The third specific objective was to develop food products which meet nutritional needs of children under the age of two years

   Research question 3: Is it possible to utilise high- and low-tech food processing technologies to develop food combinations that meet nutritional needs of children 6-24 months old?

4. The fourth specific objective was to determine the quality, stability and acceptability of newly developed food products

   Research question 4: How is the storability and acceptability of these newly developed food products?

1.4 Thesis structure

These are the hypotheses for this dissertation.

1. Complementary foods in SW Ethiopia are sub optimal and hence contribute to child undernutrition.
2. If starchy complementary foods are optimally processed, the resulting product will have desirable nutritional and sensory properties.

Table 1-1 shows the general methodology used for this dissertation. The first part of the dissertation (chapters 3, 4 and 5) is mostly a situation analysis whereby the current nutritional and dietary situations of children younger than two years old and their index mothers are assessed. Chapter 3 presents results of our study on the extent of the problem of undernutrition among children aged between zero and twenty-four months in the study area and which socio-demographic, economic or dietary factors are associated with infant and young children undernutrition. Children should be exclusively breastfed until they are six months old and breastfeeding is continued until the child is 24 months old. In line with this Chapter 4 presents research finding on how the nutritional status of the mothers (of the children studied in the previous chapter) is and what factors are associated with their nutritional status. Chapter 5 evaluates complementary feeding practices, dietary diversity and nutrient adequacy of complementary foods commonly fed to infants and young children in the study area. Information generated from these three chapters is fundamental to designing strategies and plans to tackle undernutrition.

Table 1-1 General methodology used in this dissertation

Field Work (Survey)	Chapter 3	Chapter 4	Chapter 5
	Undernutrition status and predictors among children younger than two years old in Jimma Zone, Southwest Ethiopia (Questionnaire, Anthropometry)	Nutritional status of lactating women and associated factors in Jimma Zone, Southwest Ethiopia (Questionnaire, Anthropometry)	Complementary feeding practices, dietary diversity, and nutrient adequacy of diets of children 6-24 months old in Jimma Zone, Southwest Ethiopia (Questionnaire)
Laboratory work	Chapter 6	Chapter 7	Chapter 8
	Nutritional and Sensory Quality of Composite Extruded Complementary Food (Mixture experiment)	Storage Stability and Shelf Life of Extruded Composite Baby Food Flour (Factorial experiment)	Effect of fermentation and malt addition on physicochemical and sensory properties of complementary foods prepared from selected starchy staples (Factorial experiment)

The second part of the dissertation outlines the possibilities of optimising physical and chemical properties of traditional starchy staples that are commonly used for making a child and maternal diets. Chapter 6 presents how a high-tech food processing technique (extrusion) could be utilised to develop an optimal value-added complementary food product from locally available ingredients. Chapter 7 presents a case study of storability of the newly developed extruded baby food flour by modelling quality loss kinetics. Chapter 8, on the other hand, shows how traditional food processing techniques like fermentation and malting can be effectively used to upgrade nutritional and functional properties of complementary foods.

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2 State of the art

2.1 Child and maternal undernutrition: causes, manifestations and consequences

2.1.1 Causes of undernutrition

The causes of malnutrition are conveniently categorised into three main groups. The fundamental causes include social, economic and political factors like political instability. The underlying causes are associated with income poverty such as unemployment, not having revenues and assets. The immediate causes include inadequate food intake, poor nutritional quality of diets, and frequent infections. The causes of malnutrition are multisectoral and interrelated (Black et al., 2008; Lartey, 2008).

2.1.2 Manifestations of undernutrition

The most commonly used measurable manifestation of undernutrition and nutrient inadequacy are suboptimal growth, and several growth-related indicators are available to measure malnutrition. Stunting refers to low height-for-age which occurs due to prolonged food deprival/disease and indicates chronic malnutrition. Wasting or low weight-for-height occurs due to recent food deficit/illness and indicates acute malnutrition. Underweight, low weight-for-age is a combined indicator to reflect both acute and chronic malnutrition. Chronic energy deficiency among adult women if body mass index (BMI) is less than 18.5 Kg/m^2 (WHO Expert Committee, 1995). Where there is a nutritional need that is not met and physiological process not proceeding normally, growth flattering is manifested (Butte, Lopez-Alarcon, & Garza, 2002).

2.1.3 Consequences of undernutrition

There are various short and long-term consequences of malnutrition. The short-run effects include increased risks of illness, death and disability. For instance, malnutrition contributes to twice as much to the overall burden of disease in children aged 0-4 years than they do in children aged 5-14 years in Sub-Saharan Africa (SSA) (Glewwe & Miguel, 2007) and disease often prevails among undernourished children. On the other hand, the long-term consequences of malnutrition include the reduction in adult size, cognitive performance, economic productivity, and reproductive performance and, an increase in the likelihood of chronic diseases later in life (Black et al., 2008). Malnutrition represents a massive drain on human and societal resources. Some of the consequences of malnutrition are easily visible while the others are hidden.

2.2 Child and maternal undernutrition in Ethiopia

2.2.1 Background

Ethiopia is a Sub-Saharan Africa country with development prospects and abundance of challenges. The country is the second most populous in Africa, and its economy is mainly dependent on the agricultural sector. Ethiopia has experienced strong (10.9% per year) and broad-based economic growth over the past decade. Between 2004 and 2009 only, the poverty rate was reduced from 39 to 30% (World Bank, 2017). Nonetheless, Ethiopia remains one of the world's least developed countries, 67% of the population suffers severe multi-dimensional poverty according to the 2016 UNDP Human Development Index. Lack of rain and prevalence of droughts make the situation worse for the agrarian nation. Adult mortality rate, female (per 1,000 people) is 203, and infant mortality rate (per 1,000 live births) is 41.4 (UNDP, 2016). Even if Ethiopia is among the top 10 fastest growing economies in the world, it is still with massive poverty and disease burden.

2.2.2 Nutrition profile

Child and maternal undernutrition have been a consistent public health problem in Ethiopia. Rates of stunting, underweight and wasting in children under five is 38%, 24% and 10%, respectively (Central Statistical Agency (CSA) [Ethiopia] & ICF, 2016). Sub-optimal dietary diversity, the nutrient inadequacy of diets, and questionable complementary feeding practices are mainly responsible for the high rates of child undernutrition. Only 58% of infants under age six months are exclusively breastfed. The feeding practices of only 7% of children age 6-23 months meet the minimum acceptable dietary standards (Central Statistical Agency (CSA) [Ethiopia] & ICF, 2016). Children living in rural areas are more likely to be stunted (39.9%) than their urban counterparts (25.4%). Significant regional variations also persist, with children living in Amhara (46%), Benishangul-Gumuz (43%), and Affar (41%), were more stunted than those in Somali (27%), Gambela (24%), and Addis Ababa (15%). Besides, one-fifth (22%) of women of reproductive age (15-49 years) are undernourished (with BMI less than 18.5Kg/m^2), leaving their children predisposed to undernutrition and its consequences (Central Statistical Agency (CSA) [Ethiopia] & ICF, 2016).

2.3 Interventions for improvement of child and maternal nutrition

Reduction in undernutrition has mainly focused on two approaches: nutrition specific and nutrition sensitive. Nutrition specific interventions are those that address immediate and some underlying causes of suboptimum growth and development (Bhutta et al., 2013). Nutrition-sensitive interventions are interventions of other sectors that incorporate nutrition objectives (Ruel & Alderman, 2013). In some of the highest burden countries priority must be given to scaling up a combination of nutrition specific and sensitive interventions.

Strategies for reducing and preventing undernutrition in Low-Income Countries need to involve a mix of macroeconomic policies and more targeted interventions (Belachew, Lindstrom, Hadley, et al., 2013). Interventions should also address maternal and young child nutritional status as interrelated factors as significant association exists between mother and child nutritional status (Gewa, Oguttu, & Yandell, 2012). Management strategies for childhood and maternal undernutrition need to be evidence-based (Bhutta et al., 2013) The overall recommendation is based on low-cost approaches to addressing the nutritional health of the vulnerable in Low-Income Countries (East Africa) due to resource constraints (Kasirye, 2010).

Different stakeholders have proposed several strategies for the prevention of maternal and child undernutrition. Priority interventions include breastfeeding promotion, proper hygiene and sanitation, management of severe acute malnutrition, essential vitamins and minerals supplementation, appropriate complementary feeding, literacy, livelihoods, empowerment (Ahmed, Hossain, & Sanin, 2012). The choice of intervention approaches depends on the determinants of undernutrition in the particular setting.

2.4 Maternal and child dietary information and its relevance for product development

2.4.1 0-5 months infants/breastfeeding

Exclusive breastfeeding is recommended for infants up to 6 months old. Research indicates that there are many health benefits and advantages of breastfeeding at all stages of life. Breastfeeding protects children against a broad range of immediate and long-term clinical outcomes that are a significant burden on individuals, the health system and society. While some of the benefits of breastfeeding on particular health outcomes may be small, these differences are hugely significant at the population level. All these advantages suggest that breast milk is uniquely engineered for human infants, and is the biologically ‘natural' way to feed them (Allen & Hector, 2005).

2.4.2 6-23 months/complementary feeding

From 6 months on, babies start taking complementary foods in addition to breast milk. This transition is a very vulnerable period. The infantile growth spurt which occurs between 6 and nine months is associated with rapid growth, increased levels of physical activity and physiological changes. Expansion in blood volume and haemodilution may result in physiological anaemia in otherwise healthy infants, but symptomatic, clinical anaemia in high-risk infants with low haemoglobin or iron stores. Increasing demands for energy and micronutrients also occur, and breast milk alone is insufficient to meet such growing demands, hence the need for the gradual introduction of appropriate complementary foods (Zotor, Ellahi, & Amuna, 2015).

2.4.3 Lactating women

Nutrient requirements are considerably elevated during lactation than in any other stage of a woman's reproductive life. Women of childbearing age are among those most likely to suffer from deficiencies (Arimond et al., 2011). The energy cost of milk production during exclusive breastfeeding increases mother’s daily energy needs with an additional 500 kilocalories (FAO, 1999). Women in resource-poor environments consume low-quality monotonous diets which cannot balance the extra nutrient demand them puts them at the risk of a variety of micronutrient deficiencies. Mothers in developing countries enter lactation with small bodily energy reserves, which makes them be in danger of adverse nutritional consequences (Brown et al., 1986). Lactating mothers need supplementary diets as they feed themselves and their infants.

2.5 Starchy staples

Low-income populations, whose diets are predominantly based on starchy staples, are vulnerable to nutritional problems (Steyn, Nel, Nantel, Kennedy, & Labadarios, 2006). The dominant plant-based staple foods (mainly cereals and roots and tubers) found in the Eastern and Southern African region have a low nutrient density. High unmodified starch, low micronutrient contents, and high phytate and dietary fibre (Badau, Jideani, & Nkama, 2005; Lopez, Leenhardt, Coudray, & Remesy, 2002). Complementary foods made of such plant-based ingredients are bulky and highly viscous. Young children can only take a little bit of such a thick porridge for they have small gastric capacities. Traditionally, mothers dilute the porridge with water to reduce its viscosity. By doing so, they also thin the nutrient density of the complementary food and children are unable to meet their energy requirements by consuming the diluted porridge and consequently may become malnourished (Amagloh et al., 2013). Traditional diets, especially complementary foods, made of starchy staples are of low nutritional quality and need to be upgraded.

Numerous food processing techniques have the potential to enhance the nutrient bioavailability, palatability and convenience of complementary foods including roasting, germination, milling, baking, drying, fermentation and extrusion (Melese, 2013). Some of these techniques are discussed hereunder.

2.6 Upgrading starchy staples: Application of food processing technologies

2.6.1 Extrusion

Extrusion is a high-temperature short time (HTST) cooking method which improves nutritional, functional and sensory properties of food ingredients. Food extrusion permits inactivate the undesirable enzymes that can affect the quality and eliminate several anti-nutritional factors, such as trypsin inhibitors, haemagglutinins, tannins and phytates (Singh, Gamlath, & Wakeling, 2007). During the extrusion process, the material is treated not only by heating but also by intense mechanical shearing, compression and torque, which can break the covalent bonds in biopolymers (Singh et al., 2007). Thus, the functional properties of the food ingredients are rapidly modified due to the combined influence of temperature, pressure, shear and time (Carvalho & Mitchell, 2000). High- temperature, short-time extrusion cooking can also be used to produce starchy staple -based foods in a ready-to-eat form (Pelembe, Erasmus, & Taylor, 2002). Flavour development is another effect of this technology. Extrusion cooking may decrease available L-lysine, sulphur-containing amino acids, L- arginine, L-tryptophan and vitamins. The process should, therefore, be carefully controlled (Codex Alimentarius Commission, 1991). Carefully controlled extrusion cooking process can be used for development of nutrient-rich instant food products.

2.6.2 Fermentation

Fermentation is another food processing technique known for improving nutritive and functional properties of foods. Many desirable changes occur during the fermentation process of cereal grains due to the breakdown of complex compounds into simple forms and the transformation into essential constituents (Kabeir, Shuhaimi, & Muhammad, 2004). Micronutrient bioavailability of plant-based diets is also enhanced by fermentation (Hotz & Gibson, 2007). In addition to improving nutrients of food, traditional food fermentation also creates an acidic condition which preserves the food and reduces the cooking time of the food (Fagbemi, Fagbemi, Oshodi, & Ipinmoroti, 2005). Combining fermentation with cooking improves the nutrient quality and drastically reduce the anti-nutritional factors to safe levels (Chavan, Chavan, & Kadam, 1988). Fermentation is an affordable food processing technology of nutritional importance to developing countries.

2.6.3 Addition of malt

Germination/malting is one of the most beneficial methods to upgrade nutritional and functional starchy plant-based diets. During malting of grains, α-amylase and β-amylase activity are developed. These enzymes efficiently degrade starch granules, reducing their water-binding capacity and viscosity (Afoakwa et al., 2010). Malting increases endogenous phytase activity in cereals through de novo synthesis, activation of intrinsic phytase, or both which in turn reduces the anti-nutritional factors while maintaining the maximum amount of micronutrients (Hotz & Gibson, 2007). Germination/malting also improves energy and nutrient density of plant-based complementary foods (Tizazu, Urga, Abuye, & Retta, 2010a) and the finished product is seldom free of micro-organisms (Badau et al., 2005). Malting seems to be the most efficient among the low-cost methods available to improve nutritional and functional properties of cereal-based foods.

2.6.4 Blending

Optimal mixing of starchy staple flours with various ingredients yields a composite powder with improved nutritional, functional and sensory attributes. A cereal-legume composite complementary food is a nutritionally improved product in which the beans complement the limited lysine in grains, and the cereals provide sulphur-containing amino acids that are low in legumes(Mensah & Tomkins, 2003). Incorporation of other flours with grain flours positively affects the functional properties of composite powders such as water absorption capacity and bulk density (Chandra, Singh, & Kumari, 2015). Addition of low cost and locally available ingredients like sugar and oil to the blended products can significantly improve their organoleptic quality and contribute to their high acceptance (Muhimbula, Issa-Zacharia, & Kinabo, 2011a). Blending offers families the opportunity to feed their infants on improved formulations using local, cheap and readily available ingredients.

2.6.5 Combination of techniques

A combination of food processing techniques may also be used to get an increased improvement in nutritional, functional and sensory attributes of plant-based diets. The mix of milled or ground essential ingredients (cereals, pulses, oilseed flours) may be further processed by extrusion cooking (Shadan, Waghray, & Khoushabi, 2014). Another possibility is to add malt, amylase-rich flour, and ferment the grain (Afoakwa et al., 2010). Co-fermentation of blends of cereal and pulse has also been reported (Tou et al., 2007). Such combinations of food processing technologies can, therefore, be employed to further improve the nutritive value and functionality of starchy plant-based food products.

2.7 Participation of stakeholders

Involvement of maternal and child nutrition stakeholders at different levels can increase potential impacts. Interventions, programs, policies and other actions to improve nutrition always have taken place within a social context (Pelletier, McCullum, Kraak, & Asher, 2003). Development projects that participate, relevant stakeholders, are more successful and sustainable (Zimmermann & Maennling, 2007). Neglecting or giving marginal attention to actors could make policy interventions unsuccessful (Acosta & Haddad, 2014). A vital first step to start a participatory process is to ensure to include the particular people/institutions whose input is most needed for meaningful participatory outcomes (Reed et al., 2009). Multi-stakeholder and multi-strategic approaches work better for food and nutrition security.

2.8 Knowledge gap

We identified the following general knowledge gaps. First, only a single study (Roba, 2016) has evaluated the nutritional status of lactating mothers and their children 6-23 months old in Eastern Ethiopia. No information exists on magnitude and risk factors of undernutrition among lactating mothers and their children under two years old in South-west Ethiopia. Second, most of the studies conducted in Ethiopia so far focused on studying dietary practices and dietary diversity (Haileslassie, Mulugeta, & Girma, 2013); limited information exists on the composition of maternal and child diets. Third, the different food processing techniques (mentioned under section 1.6) have worked well elsewhere. These techniques were not tested using local ingredients and literature on product development in consultation with the respective stakeholders is scant in Ethiopia, especially for complementary food applications. These gaps will be filled by my work in the following chapters.

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3 Undernutrition status and predictors among children younger than two years old in Jimma Zone, Southwest Ethiopia

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3.1 Abstract

The rate and risk factors of undernutrition among children younger than two years old are unknown in Jimma Zone, Southwest Ethiopia. In this community-based cross-sectional study, stratified multistage sampling procedure was used to identify representative samples of children. Data were collected from 558 mother-child pairs using a semi-structured questionnaire and through anthropometric measurements. Bivariate and multivariable logistic regression models were fitted using SPSS 20.0 for windows to determine predictors of undernutrition among the children. The p-value of 0.05 was used as a cut-off for determining the statistical significance of differences. Of the 558 children included in the study, 142 (25.4%) were stunted, 73 (13.1%) were underweight and 54 (9.7%) were wasted. On multivariable logistic regression, independent predictors of stunting were older age of child [AOR=1.1, 95%CI (1.1, 1.2)], being male [AOR=2.601, 95%CI (1.681, 4.025)] and residing in urban areas [AOR=0.526, 95%CI (0.323, 0.857)]. Independent predictors of wasting were younger age of child [AOR=0.894, 95%CI (0.833, 0.96)], living in lowland agroecology [AOR=3.3, 95%CI (1.4, 8.1)] and living in poor households [AOR=6.2, 95%CI (2.2, 17.7)]. Underweight was predicted by male sex [AOR=2.09, 95%CI (1.179, 3.703)], delayed initiation of breastfeeding [AOR=2.1, 95%CI (1.0, 4.2)] and lower wealth tertile [AOR=2.2, 95%CI (1.0, 4.6)]. There is a medium severity of undernutrition among children younger than two years old in Jimma zone. As the first 1000 days of life is a critical period for addressing the problem of malnutrition, strengthening interventions started using behaviour change communications targeting the independent predictors is recommended.

3.2 Introduction

Child undernutrition is a global problem with adverse economic and social consequences (Black et al., 2008). One in every two child deaths worldwide is associated with undernutrition (De Onis, Blössner, & Borghi, 2012). Undernutrition contributes to substantial physical and mental impairment in children as it increases vulnerability to infection and disease and weakens cognitive ability (Aturupane, Deolalikar, & Gunewardena, 2008; Galler et al., 2012; Prado & Dewey, 2014). On the contrary, proper nutrition and healthy growth during early childhood have lasting benefits throughout life (Smith & Haddad, 2014).

Undernutrition among children is of primary concern in Sub-Saharan Africa countries like Ethiopia (Black et al., 2008; Glewwe & Miguel, 2007). Various institutions and researchers conducted national and regional surveys in Ethiopia targeted at quantifying the prevalence and determining the risk factors associated with undernutrition of children. The 2014 mini-demographic and health survey (DHS) showed that rates of child undernutrition in Ethiopia have remained pervasively high with 40%, 9% and 25% of children under the age of five years being stunted, wasted and underweight, respectively (Central Statistical Agency [Ethiopia], 2014). Studies associated child undernutrition with various fundamental, underlying and immediate factors and there is a seasonal, spatial and agroecological variation of the risk factors.

Except for a study which characterised Jimma zone as household food insecure setting,(Belachew, Lindstrom, Gebremariam, et al., 2013) the prevalence and main predictors of undernutrition among children younger than two years old are unknown in Jimma Zone, Southwest Ethiopia. This information is indispensable for planning intervention programs aimed at improving nutrition among children younger than two years old.

Therefore, the objective of this research was to measure the prevalence and establish the predictors associated with undernutrition among children aged between zero and twenty-four months in Jimma Zone, Southwest Ethiopia.

3.3 Methods

3.3.1 Study design and setting

A community-based cross-sectional study was conducted in Jimma zone from March to May 2014. This study was conducted in Jimma Zone, Oromia region, Southwest Ethiopia, which is located between 7°13'–8°56' North latitude and 35°49'-38°38' East longitude. The zone has 19 districts, 527 peasant associations and 31 urban centres (towns with more than 2000 inhabitants). The area has Midlands (67%), Lowlands (18%) and Highlands (15%) (Central Statistical Agency (CSA), 2007).

3.3.2 Study participants and sampling techniques

Representative samples of 558 mother-child (0-23-month-old) pairs who have been resident in the respective kebele (smallest administrative unit of Ethiopia) for at least for three years were sampled. Additionally, children who were healthy and not on medication, who gave informed oral consent to participate in the study and whose consumption was not affected by ill-health, fasting, national holidays, and festive celebrations were included.

A single population proportion formula was used to calculate the sample size assuming 44% national rate of stunting (Central Statistical Agency [Ethiopia] & ICF International, 2012) with a design effect of two for cluster sampling, a confidence level of 95% and margin of error of 5%. Power analysis was done using G-power 3.0 statistical power analyses software for Windows (Faul, Erdfelder, Lang, & Buchner, 2007).

Study subjects were identified using stratified two-stage cluster sampling procedure. On the first stage, the districts were stratified into lowland, Midland and highland agroecology. Out of the 19 districts in the zone, three (1 Lowland, 1 Midland and 1 Highland) were selected purposively. Then, out of all the kebeles in the three districts, six rural and three urban kebeles were sampled by lottery method. In these selected kebeles, households with children younger than two years old were systematically identified using the registration at the health posts. The calculated sample (558) was non-proportionally allocated to the selected districts (186 for each) then to the selected kebeles (62 for each kebele). A simple random sampling of the households was employed to recruit the study subjects.

3.3.3 Variables

Independent variables include socio-demographic variables (maternal age, religion, ethnicity, marital status, education, and household size) and socio-economic variables (maternal occupation, father's occupation, the primary source of income, ownership of land, animals, and properties). Additionally, child caring practices (breastfeeding, complementary feeding practices), maternal characteristics (number of children, feeding practice during pregnancy and lactation) and facilities (drinking water, toilet) were independent variables. A wealth index was determined using principal component analyses based on data on assets encompassing land for agriculture, production of crops, ownership of animals and properties (Garenne & Hohmann-Garenne, 2003). The index was rank divided into tertiles and used for further analyses.

3.3.4 Measurements

Anthropometric variables, weight and length, were measured using standard methods. Children, without clothing, were weighed to the nearest 0.1 Kg with a solar-powered digital scale (Seca 770, Hanover Germany) and recumbent length was measured using a wooden length-measuring board with a sliding head positioner to the nearest 0.1 cm following the procedure specified by WHO (WHO, 1995). Before converting the anthropometric measurements to Z-scores, the data were cleaned to remove outliers (Saaka, 2014). Height-for-age Z-score (HAZ), weight-for-height Z-score (WHZ) and weight-for-age Z-score (WAZ) were calculated using WHO Anthro version 3.2.2 software using WHO 2006 growth charts (WHO, 2006). A low WAZ, HAZ and WHZ below -2SD of the reference population were defined as underweight, stunting and wasting, respectively. These were the dependent variables. These anthropometric statuses were considered severe when the respective z-scores were below -3SD (De Onis et al., 2006).

Data were collected through a face to face interview using a semi-structured, interviewer-administered questionnaire and through anthropometric measurements were used to collect data. Data collection was conducted with the assistance of nine health extension workers, one from their respective kebeles. Data collectors were trained for one day. A pre-test was done on a small sample of respondents from the target population. The third author supervised data collection. Second visits were arranged to the homes of participants when it was necessary to complete incomplete questionnaires.

3.3.5 Statistical methods

The collected data were coded, entered and documented electronically using Epidata version 3.1 (Lauritsen & Bruus, 2008). SPSS 20.0 for Windows was used for data analysis. First, frequencies and proportions were computed to describe the study results. Then, categorical variables of interest associated with indicators of child undernutrition were determined by using bivariate analysis. Significant factors reported in bivariate analysis (P value less than 0.25) were further examined using multivariable logistic regression to control for potential confounding. In multivariable analysis, enter method was used to determine the presence of an association between the dependent and independent variables. Adjusted Odds Ratio (AOR) with confidence intervals (95% CI) were calculated for all predictors. The p-value of ≤ 0.05 was used as a cut-off for determining the statistical significance of differences.

3.3.6 Ethics approval and consent to participate

The study was approved by Ethical Review Board of [removed for blind peer review]. Informed oral consent was obtained from each participant. The Ethical Review Board decided to have oral consent as the study was not intervention. Besides, the data collection and consent process were randomly checked by the Ethical Review Board to ensure the noble undertaking of the research. Compliance with STROBE (Strengthening the Reporting of Observational studies in Epidemiology) has been addressed.

3.4 Results

Data were captured from 558 children younger than two years old (mean age 11.4±6.5 months) giving a response rate of 100%. From the total of 558 participants, 302 (54.1%) were male, and 256 (45.9%) were female children. Among the total respondents, a significant proportion of the mothers were Muslims (516; 92.5%), Oromo in ethnicity (486; 87.1%), married/living together (501; 89.8%) and did not receive a formal education (336, 60.2%) (Table 3-1).

Table 3-1 Demographic and socioeconomic characteristics of the children (n=558) in three agroecology of Jimma Zone from March to May 2014.

Variables	Lowland		Midland		Highland		Total	
	n	%	n	%	n	%	n	%
Age (months)								
0-5	56	30.1	33	17.7	36	19.4	125	22.4
6-11	57	30.6	53	28.5	57	30.6	167	29.9
12-23	73	39.2	100	53.8	93	50	266	47.7
Sex of child								
Male	94	50.5	108	58.1	100	53.8	302	54.1
Female	92	49.5	78	41.9	86	46.2	256	45.9
Religion								
Muslim	182	97.8	165	88.7	169	90.9	516	92.5
Orthodox	2	1.1	17	9.1	14	7.5	33	5.9
Protestant	2	1.1	4	1.1	3	1.6	9	1.6
Ethnicity								
Oromo	170	91.4	154	82.8	162	87.1	486	87.1
Other (a)	16	8.6	32	17.2	22	12.9	72	12.9
Marital status								
Married/living together	171	91.9	166	89.2	164	88.2	501	89.8
Other (b)	15	8.1	20	10.8	22	11.8	57	10.2
Educational status of the mother								
Formal education	56	130	91	48.9	75	40.3	222	39.8
No formal education	30.1	69.9	95	51.1	111	59.7	336	60.2
Occupation of the mother								
Housewife	146	78.5	147	79	143	76.9	436	78.1
Merchant	30	16.1	18	9.7	35	18.8	83	14.9
Other (c)	10	5.4	21	11.3	8	4.3	39	7
Educational status of the father								
Formal education	87	46.8	132	71	104	55.9	323	57.9
No formal education	99	53.2	54	29	82	44.1	235	42.1
Occupation of the father								
Farmer	122	65.6	108	58.1	112	60.2	342	61.3
Daily labourer	21	11.3	31	16.7	20	10.8	72	12.9
Merchant	25	13.4	16	8.6	26	14	67	12
Other (d)	18	9.7	31	16.7	28	15	77	13.8
Residence								
Urban	62	33.3	62	33.3	62	33.3	186	33.3
Rural	124	66.7	124	66.7	124	66.7	372	66.7
Wealth tertile								
Lowest	70	37.6	60	32.3	56	30.1	186	33.3
Middle	69	37.1	52	28	68	36.6	189	33.9

Highest	47	25.3	74	39.8	62	33.3	183	32.8
Feeding practices								
Early breastfeeding	149	80.1	134	72	166	89.2	449	80.5
Exclusive breastfeeding	181	97.3	181	97.3	184	98.9	546	97.8
Continued breastfeeding	163	87.6	134	72	173	93	470	84.2
Increase diet diversity	176	94.6	120	64.5	173	93	469	84.1
Complementary foods	176	94.6	140	75.3	183	98.4	499	89.4

(a) Amhara, Yem, Guraghe, Tigre, other.
(b) Single, separated, widowed, divorced.
(c) Daily labourer, government employee, farmer, other.
(d) Government employee, NGO employee, Other.

Most of the children were breastfed timely (449; 80.5%), breastfed exclusively for six months (546; 97.8%) and breastfed for up to 24 months of age (470; 84.2%). Concerning complementary feeding, 499 (89.4%) of the children were given complementary foods after the age of 6 months, and 69 (84.1%) of the mothers try to give diversified complementary foods and frequently.

Around a quarter of the children (25.4%) were stunted and 12.1% were severely stunted. The stunting rates for lowland, Midland and highland were 25.3%, 25.3% and 25.9%, respectively. Besides, 13.1% were underweight (14.0% for Lowland, 10.2% for Midland and 15.1% for Highland) and 2.9% were severely underweight. Moreover, 9.7% were wasted (15.3% for Lowland, 5.9% for Midland 8.0% for Highland) and 2.5% were severely wasted (Table 3-2). The mean z-scores for stunting, wasting and underweight were -1.01±2.43, -0.58±1.46 and -0.05±1.92, respectively.

Table 3-2 Nutritional status of children under the age of two years, Jimma Zone, 2014 (n = 558).

Variables	Lowland		Midland		Highland		Total	
	n	%	n	%	n	%	n	%
Height-for-age								
below -2 SD	47	25.3	47	25.3	48	25.8	142	25.4
below -3 SD	20	10.8	20	10.8	28	15.1	68	12.1
Normal	139	74.7	139	74.7	138	74.2	416	74.6
Total	186	100	186	100	186	100	558	100
Height-for-weight								
below -2 SD	28	15.1	11	5.9	15	8.1	54	9.7
below -3 SD	9	4.9	1	0.5	6	3.2	16	2.9
Normal	158	84.9	175	94.1	171	91.9	504	90.3
Total	186	100	186	100	186	100	558	100
Weight-for-age								
below -2 SD	26	14.0	19	10.2	28	15.1	73	13.1
below -3 SD	5	2.7	5	2.7	4	2.2	14	2.5
Normal	160	86	167	89.8	158	84.9	485	86.9
Total	186	100	186	100	186	100	558	100

Multivariable logistic regression analyses showed that age of a child, sex of a child and residence (urban/rural) were independent predictors of stunting. For a one month increase in the age of a child, the odds of stunting is increased by 10% [AOR= 1.1, 95% CI (1.1–, 1.2)]. Male children were more than 2.6 times [AOR=2.601, 95%CI (1.681, 4.025)] more prone to becoming stunted than their counterparts. Children residing in rural kebeles were 0.5 times [AOR=0.526, 95%CI (0.323, 0.857)] less likely to become stunted compared with the kids living in urban kebeles (Table 3-3).

Concerning wasting, multivariable logistic regression analyses showed that for a one-month increase in the age of a child, the odds of wasting is reduced by 11% [AOR=0.894, 95%CI (0.833, 0.96)]. Children from lowland agroecology were 3.3 times [AOR=3.3, 95%CI (1.4, 8.1)] more likely to become wasted than the midland and highland agroecology. Children from lowest wealth tertile households were 6.2 times [AOR=6.2, 95%CI (2.2, 17.7)] more likely to suffer from wasting than children from other wealth tertiles (Table 3-4).

Table 3-3 Factors associated with stunting among children below 24 months in Jimma Zone, Southwest Ethiopia, 2014 (n = 558).

Variables	Stunting		Crude OR (95% CI)	Adjusted OR (95% CI)
	Yes	No		
Age (in months)				
11.4+6.5[#]	142	416	1.1(1.1-1.2) *	1.1(1.1-1.2) *
Child sex				
Male	97	205	2.2(1.5-3.3) *	2.6(1.7-4.0) *
Female	45	211	1	1
Place of residence				
Rural	87	285	0.7(0.5-1.1) *	0.5(0.3-0.9) *
Urban	55	131	1	1

*Significant at P value ≤ 0.05.

[#]mean ± standard deviation

Table 3-4 Factors associated with wasting among children below 24 months in Jimma Zone, Southwest Ethiopia, 2014 (n = 558).

Variables	Wasting		Crude OR (95% CI)	Adjusted OR (95% CI)
	Yes	No		
Age (in months)				
11.4+6.5[#]	54	504	0.9(0.9-1.0)	0.9(0.8-1.0) *
Agroecology				
Lowland	15	171	0.5(0.3-1.0) *	3.3(1.4-8.1) *
Midland	11	175	0.4(0.2-0.7) *	0.7(0.2-2.2)
Highland (Reference)	28	158	1	1
Wealth tertile				
Lowest	25	161	2.0(1.0-4.1) *	6.2(2.2-17.7) *
Middle	16	173	1.2(0.6-2.6)	2.7(1.0-7.5) *
Highest (Reference)	13	170	1	1
Source of drinking water				
Protected well	24	206	0.5(0.3-1.1)	0.9(0.3-2.2)
Protected spring	15	202	0.3(0.2-0.7) *	0.4(0.2-1.0)
Pipe	2	37	0.2(0.1-1.1)	0.7(0.1-3.7)
Unprotected well/spring	13	59	1	1

*Significant at P value ≤ 0.05.

[#]mean ± standard deviation

Regarding underweight, multivariable logistic regression analyses showed that male children were 2.1 times [AOR=2.09, 95%CI (1.179, 3.703)] more prone to becoming underweight than girls. Children from lowest wealth tertile were 2.2 times [AOR=2.2, 95%CI (1.0, 4.6)] more likely to suffer from underweight than children from richer households. Children who were breastfed after the first one hour after birth were 2.1 times [AOR=2.1, 95%CI (1.0, 4.2)] more likely to develop underweight than their counterparts (Table 3-5).

Table 3-5 Factors associated with underweight among children below 24 months in Jimma Zone, Southwest Ethiopia, 2014 (n = 558).

Variables	Underweight		Crude OR (95% CI)	Adjusted OR (95% CI)
	Yes	No		
Sex of child				
Male	49	253	1.9(1.1-3.1) *	2.1(1.2-3.7) *
Female	24	232	1	1
Wealth tertile				
Lowest	31	155	2.1(1.1-4.0) *	2.2(1.0-4.6) *
Middle	26	163	1.7(0.9-3.2)	1.6(0.8-3.3)
Highest (Reference)	16	167	1	1
Early initiation of breastfeeding				
No	14	95	1.0(0.5-1.8)	2.1(1.0-4.2) *
Yes	59	390	1	1
Place of residence				
Rural	58	314	2.1(1.2-3.8) *	1.2(0.5-2.8)
Urban	15	171	1	1
Household own cows				
No	48	255	1.7(1.0-2.9) *	3.0(1.6-5.6)
Yes	25	230	1	1
Exclusive breastfeeding				
No	4	8	3.5(1.0-11.8) *	3.3(0.8-14.2)
Yes	69	477	1	1

*Significant at P value ≤ 0.05.

#mean ± standard deviation

3.5 Discussion

According to our results severity of undernutrition among children younger than two years old in Jimma Zone is medium. This study also found out that age of a child, sex of a child, rural/urban residence, district, wealth index and time of initiation of breastfeeding were predictors of child undernutrition.

The prevalence of stunting measured for Jimma zone in this study (25.4%) is lower than both Ethiopia's (40%) and Oromia region's (38.2%) stunting prevalence rates. Similarly, the prevalence of underweight measured for the study area (13.1%) is lower than the country's (25%) and the region's (22.7%) underweight prevalence (Central Statistical Agency [Ethiopia], 2014). This variation could be due to the inclusion of only children younger than two years old. Nevertheless, 25.4% chronic undernutrition indicates a significant proportion of the children population is failing to grow, physically and mentally.

On the contrary, the prevalence of wasting in Jimma Zone (9.7%) was higher than that of the Ethiopian (9.0%) and Oromia region (7.1%) average prevalence (Central Statistical Agency [Ethiopia], 2014). Prevalence of wasting is below 5% even in most impoverished settings, provided there be no severe food shortage or disease like diarrheal morbidity. Higher prevalence of wasting implies children are at increased risk of death.

Children's age was independently associated with childhood stunting and wasting. The rate of stunting is relatively lower in infants aged less than six months. Other studies have also reported that at six months old and onwards anthropometric failure increases gradually (Fentahun, Belachew, & Lachat, 2016). The rise in the rate of stunting with age of the children could be due to discontinuation of breastfeeding and infection with parasites and inadequate access to adequate amounts of solid food. Besides, consumption of unsafe, low quality and less diversified complementary foods with low frequency may have also aggravated stunting (Allen & Hector, 2005; Bhutta et al., 2008; Olack et al., 2011; Pei, Ren, & Yan, 2014).

Children's sex was independently associated with childhood stunting. Girls showed a lower likelihood of stunting as compared with boys. The same was true for underweight. These results are supported by a report from another study (Asfaw, Wondaferash, Taha, & Dube, 2015). Male children are known to be more affected by environmental stress than girls (Hien & Hoa, 2009; Olack et al., 2011).

Place of residence (rural/urban) was another independent predictor of stunting and children who live in urban kebeles had a higher likelihood of becoming stunted than children who live in rural kebeles. This result is in disagreement with results reported in previous studies (Fox & Heaton, 2012; Paciorek, Stevens, Finucane, Ezzati, & Group, 2013; Smith, Ruel, & Ndiaye, 2005). Nevertheless, a survey by Central Statistical Agency (CSA) of Ethiopia (Central Statistical Agency, 2012) indicated that the mean daily calorie consumption of the rural households of Ethiopia is higher (2,444) than that of the urban population (2,287). As one of the immediate causes of stunting is inadequate calorie intake, the higher prevalence of stunting observed in urban kebeles seems plausible (Yimer, 2000). Rural children have the advantage of growing in food-producing households which may positively affect their nutritional status. On the other hand, urban children grow up in food consuming families where food prices may negatively affect their nutritional status (Christiaensen & Alderman, 2004).

The study has found out that agroecology is independently associated with wasting. Children who live in lowland agroecology were more prone to be wasted than their midland and highland counterparts. A study from Eastern Ethiopia also indicated that undernutrition was more prevalent among lowland children (Yisak, Gobena, & Mesfin, 2015). A study in South Ethiopia related inferior nutritional status of children in lowlands with poor drinking water quality which cause different water-related diseases (Asfaw et al., 2015). The lowland district in the current study was also relatively distant from the zone capital, and the agriculture is less diversified and cereal dominated. There is a documented relationship ‘among 1) the agroecology and type of farming systems; 2) crops grown and food consumed; and 3) type of food consumed (intake) and micronutrient deficiencies (Maziya-Dixon et al., 2006).

This study has shown that wealth index is strongly associated with nutritional outcomes of children younger than two years old. Wealth index has an inverse relationship with wasting and underweight levels. Previous studies (Osei et al., 2010; Petrou & Kupek, 2010; Saaka, 2014) have also reported that households living in adverse conditions may not have adequate resources to benefit their children. Low-income families, predominantly consume starchy staples (Steyn et al., 2006) and these plant-based diets are low in micronutrient contents, high in phytate and dietary fibre which inhibits the absorption of micronutrients (Lopez, Leenhardt, & Remesy, 2004).

Time of initiation of breastfeeding was independently associated with underweight. Children who were timely breastfed were less likely to be underweight. The first liquid (colostrum) provides natural immunity to the infant and also helps reduce hypoglycemia and hypothermia, which could have a devastating effect on the health status of the child (Uruakpa, Ismond, & Akobundu, 2002). Considering these health advantages the national infant and young child feeding guideline encourages mothers to breastfeed their newborns within one hour after delivery (Federal Ministry of Health, 2004).

We acknowledge the following limitations of our study. First, cross-sectional studies have predictive limitations, and therefore it was not possible to examine any possible causal relationships between risk factors and outcome (Carlson & Morrison, 2009). Second, recall bias might have occurred as respondents could not give correct answers to some of the questions. Generalisability of the study results is questionable as undernutrition is very sensitive to seasonal changes.

3.6 Conclusions

This study provides clear evidence that there is a medium severity of undernutrition among children younger than two years in the study area. Age, sex, place of residence, agroecology, wealth index and time of initiation of breastfeeding were independent predictors of undernutrition among the children. As the early ages of life are the critical period for addressing malnutrition, strengthening interventions started using behaviour change communications targeting the independent predictors is recommended to tackle childhood undernutrition in Jimma zone.

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4 Nutritional status of lactating women and associated factors in Jimma Zone, Southwest Ethiopia

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4.1 Abstract

Lactating mothers are among the most vulnerable to malnutrition because they should feed themselves and their new-borns. Studies have shown that several socio-demographic, economic and diet-related factors may predispose lactating mothers to malnutrition. The objective of this study was to measure the prevalence of undernutrition and identify the predictors of nutritional status among lactating mothers in Jimma Zone, Southwest Ethiopia. A cross-sectional survey was conducted from March to May 2014. A representative sample of 558 lactating mothers from three districts of Jimma zone (Manna, Dedo and Omo Nada) were included. Data were collected on anthropometric measurements, socio-demographic, economic variables and feeding practices. Descriptive statistics were used to analyse data on feeding practices, and a linear regression model was used to isolate independent predictors of maternal nutritional status (body mass index). Half of the participants (53.6%) have low dietary diversity score, and the diet of the mothers was predominantly (68.8%) starchy cereals. Regarding their nutritional status, 15.6% of the mothers were chronically energy deficient. On multivariable linear regression model, independent predictors of nutritional status were the age of the mother ($\beta=0.72$, $P< 0.001$), husband's occupation ($\beta=0.206$, $P=0.001$), and household wealth ($\beta=0.721$, $P=0.004$). The results imply that a significant proportion of lactating mothers had low dietary diversity and chronic energy deficiency. As maternal nutrition could lead to intergeneration effects, it is recommended that locally appropriate interventions that target younger lactating mothers who live in low-income farming households be instituted to combat the problem.

4.2 Introduction

Maternal and child nutrition has been on the global agenda as central to health, sustainable development, and progress in low- and middle-income countries (Christian et al., 2015). Maternal and child undernutrition account for 11% of the global burden of disease (Black et al., 2008). Malnutrition is especially widespread among women in developing countries. The limited studies conducted regarding women's nutritional status in Ethiopia confirm that the situation is not different from many developing countries (Demissie, Mekonen, & Haider, 2004).

Lactating mothers, especially those from low-income settings, are highly exposed to malnutrition. This vulnerability is because their nutrient balance is affected due to the nursing process. For those mothers who get pregnant and breastfeed their kids, the nutritional stresses are even worse, and this contributes to the high maternal mortality in such settings (Committee to Study Female Morbidity and Mortality in Sub-Saharan Africa, 1996; Haileslassie et al., 2013). Maternal nutrient needs are higher during lactation than during pregnancy (Institute of Medicine (US) Committee on Nutritional Status During Pregnancy and Lactation, 1991). Proper nutrition during pregnancy will help a mother to accumulate adequate fat and other nutrients which can partly compensate for her additional needs. Adequate diet to mothers, with particular emphasis on protein, calcium and vitamins, is a prerequisite to optimal lactation (Haileslassie et al., 2013; Institute of Medicine (US) Committee on Nutritional Status During Pregnancy and Lactation, 1991).

Few studies have reported the nutritional status of lactating mothers in Ethiopia. More than a quarter (27.1%) of lactating women living in urban slums of Addis Ababa were malnourished (Haider, Muroki, Omwega, & Ayana, 2003). Another study in northern Ethiopia has also shown that 25% of lactating mothers were critically energy deficient (Haileslassie et al., 2013). Another recent survey in two agro-ecological zones of Ethiopia has reported, the prevalence of undernutrition of lactating mothers (BMI < 18.5 kg/m^2) ranged between 41.7% and 54.7% between pre- and postharvest seasons (Roba, O'Connor, Belachew, & O'Brien, 2015). The only published information available for Southwest Ethiopia is from nearly 20 years back (Taddese, Larson, & Hanley, 1998) which reported a chronic energy deficiency (CED) prevalence of 35%. Although the essential nutrition actions have been adopted and implemented by the Ethiopian government since 2005 as an intervention to prevent suboptimal dietary practices among mothers, no study documented the feeding practices and nutritional status of lactating mothers in Southwest Ethiopia.

The objective of this study was to measure the prevalence of undernutrition and identify the predictors of nutritional status among lactating mothers in Jimma Zone, Southwest Ethiopia.

4.3 Subjects and methods

4.3.1 Study design, setting and sampling techniques

A cross-sectional survey conducted between March and May 2014. The study was conducted in Jimma Zone, Southwest Ethiopia. Districts which represent highlands, Midlands and lowlands were included. Kebeles representing urban and rural settings were also included in this study. The source population were all mothers (aged 15-49 years) who were lactating within two years preceding the survey, while the study population were a representative sample of 558 lactating mothers who lived at least for three years in their respective kebeles (Kebele is the lowest government administrative unit in Ethiopia).

A single population proportion formula was used to calculate the sample size assuming 44% national rate of stunting (Central Statistical Agency [Ethiopia] & ICF International, 2012), with a design effect of two for cluster sampling, a confidence level of 95% and margin of error of 5%. G-power 3.0 statistical power analyses software for Windows was used for making power analysis (Faul et al., 2007).

Study subjects were identified using stratified two-stage cluster sampling procedure. On the first stage, the districts were stratified into lowland, Midland and highland agroecology. Out of the 19 districts in the zone, three districts (1 Lowland, 1 Midland and 1 Highland) were selected purposively. Then, out of all the kebeles in the three districts, six rural and three urban kebeles were sampled by lottery method. In these selected kebeles, households with children younger than two years old were systematically identified using the registration at the health posts. The calculated sample (558) was non-proportionally allocated to the selected districts (186 for each) and then to the selected kebeles (62 for each kebele). A simple random sampling of the households was employed to recruit the study subjects.

4.3.2 Measurements

The dependent variable was nutritional status. The independent variables were categorised as socio-demographic, economic, diet-related factors.

4.3.2.1 Socio-demographic and economic information

Information on the household socio-demographic and economic status was assessed using a semi-structured questionnaire administered to mothers. Trained field workers facilitated the one-on-one interviews. Socio-demographic information included marital status, religion, ethnicity of household members, and education level of the respondent and her husband. The questionnaire also accounted for employment, income, land ownership and usage, type of house, and household possessions. A wealth index was calculated by adding the dummy variables created from data on household's ownership of selected assets (Garenne & Hohmann-Garenne, 2003; Saaka, 2014). The index was used to categorise mothers into relative wealth groups.

4.3.2.2 Dietary assessment and dietary diversity score (DDS)

A single 24-hour dietary recall was used to record a complete list of all food and drink consumed by the respondents in the preceding twenty-four hours. (Steyn et al., 2006). The respondents were probed for meal and snacks not mentioned (Coulston, Boushey, & Ferruzzi, 2013).

DDS was calculated for each mother according to USDA (2005) using a set of 7 food groups (cereals and grains, dairy products, fruits, vegetables, oil and fat, protein-rich foods and discretionary calorie Foods. Consuming a single food item from a food group was given a score of "1" and not consuming any food item from a food group was given a score of "0". Then the scores were added to produce the DDS. The DDS was divided into terciles, and the highest tercile was used to define ‘‘high" DDS, while the two lower tertiles were combined and labelled as "low" DDS (Ajani, 2010; Rathnayake, Madushani, & Silva, 2012).

4.3.2.3 Anthropometric measurements

A battery powered digital scale (Seca 770, Hanover Germany) was used to measure weights of the lactating mothers to the nearest 0.1 Kg. Each subject was made to stand erect on the scale with light clothing and without shoes. The scale reading was always allowed to return to zero before the subject was asked to stand on it. Heights were measured using a portable plastic stadiometer (Seca 213, Hanover Germany) to the nearest 0.1 cm. Individual heights and weights were then used to calculate body mass index (BMI) of the study subjects. BMI was calculated by ‘dividing the weight in Kg to the height in meter squared’ (Hundera, Gemede, Wirtu, & Kenie, 2015; WHO, 1995).

A BMI <18.5 kg/m^2 was classified as chronic energy deficiency (CED). CED was further categorised into mild (17.00–18.49 kg/m^2), moderate (16.00–16.99 kg/m^2) and severe (less than 16.0 kg/m^2). BMI of 18.5–24.9 kg/m^2 was considered normal. Overweight and obese were defined as a BMI of 25–29.9 kg/m^2 and ≥30 kg/m^2, respectively (James, Ferro-Luzzi, & Waterlow, 1988).

4.3.3 Quantitative variables

During the bivariate analysis, quantitative variables like BMI were converted into binary categorical variables (e.g. CED & no CED) to be able to see the relationship with other categorical variables. Whereas for the multivariable analysis, we used BMI as a continuous variable instead of CED, the cut-off for CED (BMI=18.5) may not correctly work for Ethiopian population. A meta-analysis of BMI and percent body fat among different ethnic groups indicated that populations of the same age, gender and level of fatness could have differences in BMI (Deurenberg, Yap, & Van Staveren, 1998).

4.3.4 Statistical methods

Data entry and data documentation were done electronically using Epidata version 3.1 (Lauritsen & Bruus, 2008). Data analyses were undertaken using SPSS 20.0 for Windows. First, frequencies and proportions were computed to describe the study results. Then, variables of interest associated with indicators of maternal nutritional status were determined by using bivariate analysis. Significant factors reported in bivariate analysis (P value less than 0.25) were further examined using a multivariate linear regression analysis, after adjustment for potentially confounding variables. Confidence intervals (95% CI) were calculated for all predictors. A p-value of 0.05 was used as a cut-off for determining the statistical significance of differences.

4.3.5 Ethics approval and consent to participate

The Ethical Review Board of (removed for peer review) approved the study. Informed oral consent was obtained from each study participant after being briefed about the study and given a chance to ask questions. The Ethical Review Board decided to have oral consent as the study was not intervention. Also, the Ethical Review Board checked the data collection and consent process randomly to ensure the noble undertaking of the research. Data were kept confidential.

4.4 Results

4.4.1 Participants

Five hundred fifty-eight (100%) of the lactating mothers aged 15-49 years completed interviews. Any eligible mother that was inaccessible during the data collection was replaced with the next eligible mother on the list.

4.4.2 Descriptive data

The participants were 26.6±5.1 years old on average, and the majority (89.7%) were younger than 30 years old. Sixty percent of the mothers and 42.1% of the fathers did not receive a formal education. More than three fourth (78.1%) of the participants were housewives, whereas the remaining 21.9% were involved in income-generating activities. Majority of the mothers were Muslims and Oromo in ethnicity (Table 4-1).

Table 4-1 Socio-demographic, economic and feeding characteristics of the lactating mothers (n=558) in three districts of Jimma Zone.

Socio-demographic variables	**n**	**%**
Age groups		
15-24	171	30.6
25-34	330	59.1
35-44	54	9.7
45-49	3	0.5
Mean maternal age in years	26.6 (±5.1)[1]	
Educational status of the mother		
Formal education	222	39.8
No formal education	336	60.2
Occupation of the mother		
Housewife	436	78.1
Merchant	83	14.9
Other[c]	39	7
Educational status of the father		
Formal education	323	57.9
No formal education	235	42.1
Occupation of the father		
Farmer	342	61.3
Daily labourer	72	12.9
Merchant	67	12
Other[d]	77	13.8
Religion		
Muslim	516	92.5
Christian	42	7.5
Ethnicity		
Oromo	486	87.1
Other[a]	72	12.9
Marital status		
Married/living together	501	89.8
Other[b]	57	10.2
Residence		
Urban	186	33.3
Rural	372	66.7
District of residence		
Mana	186	33.3
Omo Nada	186	33.3

Dedo	186	33.3
Wealth index		
Poor	186	33.3
Medium	189	33.9
Rich	183	32.8
Family size		
2-4 persons	201	36
≥5 persons	357	64

[1]Mean ± SD
[a]Amhara, Yem, Guraghe, Tigre, other.
[b]Single, separated, widowed, divorced.
[c]Daily labourer, government employee, farmer, other.
[d]Government employee, NGO employee, Other.

The majority of the mothers did not change their previous food intake habit during lactation, eat the same amount of meal as they were not lactating and did consume new diet during lactation. The mean (±SD) DDS of the study participants was 4.51(±1.1) with a range of 0-7. Half of the participants (53.6%) had low DDS. The majority of the participants consumed cereals and grains, vegetables, and oils and fats. In contrast, only a few of the mothers reported consumption of fruits and dairy products (Table 4-2).

4.4.3 Outcome data

The mean (±SD) weight, height, and BMI of the study participants were 50.3 kg (±6.6), 155.7 cm (±5.7), and 20.7 kg/m^2 (±2.3), respectively. Eighty per cent (80.1%) of the subjects had normal BMI. Besides, 3.9% of the mothers were overweight, and 0.4% were obese. The prevalence of CED was 15.6% of which 11.8%, 3.0% and 0.7% of the subjects had mild, moderate and severe CED (Table 4-3).

Table 4-2 Feeding practices of lactating mothers in Jimma zone, Southwest Ethiopia.

Practices	n	%
Prepare different food during lactation		
Yes	78	14
No	480	86
Eat the same amount of meal as she was not lactating		
Yes	434	77.8
No	124	22.2
Taking additional two meals		
Yes	81	14.5
No	477	85.5
Early initiation of breastfeeding (within one hour after delivery)		
Yes	449	80.5
No	109	19.5
Exclusive breastfeeding for the first six months		
Yes	546	97.8
No	12	2.2
Continued breastfeeding up to two years		
Yes	470	84.2
No	88	15.8
DDS		
0-2 food groups	11	2
3-4 food groups	288	51.6
5-7 food groups	259	46.4
Mean (±SD)	4.51(±1.1)	
Food groups		
Cereals and grains	554	99.3
Fruits	140	25.1
Vegetables	553	99.1
Protein-rich foods	442	79.2
Dairy products	72	12.9
Oil and fat	543	97.3
Discretionary calorie foods	212	38.0

Table 4-3 Nutritional status of the study participants (n=558) in three woredas of Jimma Zone.

Anthropometric variables	n	%
Maternal height		
≤ 145 cm	11	2
>145 cm	544	98
Mean	155.7 (±5.7)*	
Maternal weight		
≤ 45 kg	115	20.6
>45 kg	443	79.4
Mean	50.3 (±6.6)	
Maternal BMI		
< 16.00 kg/m^2	4	0.7
16.00-16.99 kg/m^2	17	3.0
17.00-18.49 kg/m^2	66	11.8
18.50-24.90 kg/m^2	447	80.1
25.00-29.99 kg/m^2	22	3.9
≥ 30 kg/m^2	2	0.4
Mean	20.7 (±2.3)	
Median (Range)	20.5 (14.5 – 34.1)	

*Mean ± SD (all such values).

4.4.4 Main results

On bivariate analysis, husband's occupation and household wealth status were significantly associated ($p<0.05$) with CED. A woman whose husband is a farmer was 19.4% more likely to suffer from CED than a woman whose husband is in other occupation. Prevalence of CED was highest (20.4%) among women in the middle wealth group than in the poor (16.1%) or rich (10.2%) households ($p=0.03$). All the other variables (districts, residence area, the age of the mothers, DDS, marital status, educational status, occupation, husband's education, family size and number of children) were not significantly associated with CED of the lactating mothers (Table 4-4).

Table 4-4 Association of some socio-demographic and economic variables with the nutritional status (CED) of the study participants (n=558) in three districts of Jimma Zone, South-West Ethiopia from March-May, 2014.

Variables	CED (BMI< 18.5) n (%)	No CED (BMI≥18.5) n (%)	p
Age group			
15-24	35 (20.5)	136 (79.5)	
25-34	45 (13.6)	285 (86.4)	0.33
35-44	6 (11.1)	48 (88.9)	
45-49	1 (33.3)	2 (66.7)	
District			
Mana	31(16.7)	155(83.30)	0.66
Omo Nada	31(16.7)	155(83.30)	
Dedo	25(13.4)	161(86.60)	
Residence area			
Rural	64(17.2)	308(82.80)	0.17
Urban	23(12.4)	163(87.60)	
Marital status			
Single	4(12.1)	29(87.90)	
Married/living together	79(15.8)	422(84.20)	0.7
Separated	3(18.8)	13(81.20)	
Widowed	0(0.0)	5(100.00)	
Divorced	1(33.3)	2(66.70)	
Age (Mean±SD)	25.64(5.3)	26.77(5.10)	0.06
DDS (Mean±SD)	4.38(0.9)	4.53(1.09)	0.17
Educational status			
Illiterate/informal education	51(15.1)	287(84.90)	0.72
Formal education	36(16.4)	184(83.60)	
Occupation (N=558)			
Housewife	73(16.7)	363(83.30)	0.16
Othera (Ref)	14(11.5)	108(88.50)	
Husband's educational status			
Illiterate/informal education	33(15.4)	181(84.60)	0.9
Formal education	49(16.2)	254(83.80)	
Husband's occupation			
Farmer	62(19.4)	257(80.60)	<0.0001
Other	25(10.5)	214(89.50)	
Wealth tertile			
Low	30(16.1)	156(83.90)	
Medium	38(20.4)	148(79.60)	0.03
High	19(10.2)	167(89.80)	
Family size(Mean±SD)	5.33(1.8)	5.63(1.98)	0.2

No. of children (Mean±SD)	2.89(1.8)	3.24(1.85)	0.08
Having two additional meals			
No	81(17.0)	396(83.00)	0.03
Yes	6(7.4)	75(92.60)	

[a] farmer, government employee, NGO employee, daily labourer

[b] Government employee, NGO employee, Merchant, Daily labourer

On multivariable linear regression analyses, the age of the mother, husband's occupation, and household wealth were independent predictors of CED. For a unit increase in age, the BMI also increased by 0.72 (β=0.72, P< 0.0001). Younger mothers had lower BMI than the older participants. Another factor that predicted lactating mother's BMI was husband's occupation. The result illustrates that, having a spouse who is a daily labourer increased BMI of lactating mothers by 0.206 (β=0.206, P=0.001). In this study, household wealth was another variable that was significantly associated with BMI. For a unit increase in household economy of the wealthier group, BMI also increased by 0.721 (β=0.721, P=0.004) (Table 4-5).

Table 4-5 Parameter estimates from linear regression predicting BMI among lactating mothers from three selected districts, Jimma zone Southwest Ethiopia.

Predictors (n =558)	**β**	**SE**	**P**
Having additional two meals	0.529	0.302	0.08
Household Wealth			
Poor	0.237	0.244	0.33
Rich	0.721	0.249	<0.0001
Marital status(N=558)			
Divorced	-0.412	0.587	0.48
Other [a] (Ref.)			
Age	0.72	0.2	<0.0001
Husband's occupation (N=517)			
Daily labourer	0.206	0.059	<0.0001
Other (merchant, farmer, employee) (Ref.)			

[a] single, married and living together, married but not living together, widowed

A multivariable linear regression model with BMI as a dependent variable and predictors with P<0.05 of the bivariate model. Ref= reference category. Coefficients as obtained from a multivariable linear regression model. Maximum Variance inflation factor = 1.36. SE= Standard error.

4.5 Discussion

4.5.1 Key results

The dietary assessment showed that most of the participants consumed cereals and grains, vegetables and oils and fats. Only a few of the participants consumed dairy products and fruits. Similar results have been reported from Northern Ethiopia (Haileslassie et al., 2013). Another study has also mentioned that fruits are not part of the regular daily diet in Ethiopia and people are reluctant to consume vegetables for different reasons (Amare et al., 2012).

It was also observed that more than half of participants had low DDS. Jimma zone has been denoted by household food insecurity (Belachew, Lindstrom, Gebremariam, et al., 2013). Nguyen *et al*. reported that three-quarters of mothers in Ethiopia consumed only 1–3 food groups. These authors associated the low maternal DDS in Ethiopia with limited maternal knowledge on food diversity and low maternal power to control finances (earning money and buying food) in the country (Nguyen et al., 2013).

The feeding practice of the mothers could be thought of as suboptimal as the majority of them do not take additional meal during their lactation time. A lactating mother should produce about 700 to 800ml of milk per day (Haileslassie et al., 2013; Ogechi, 2014). Accordingly, a lactating woman requires the additional energy of 500 kcal/day (equivalent to two additional meals per day) (World Health Organization, 2013) which indicates feeding practice of the lactating mothers is sub-optimal.

A 15.6% prevalence of CED among the lactating mothers in Jimma Zone is a significant proportion yet lower than that reports from other areas of the country (Bitew & Telake, 2010). Despite several success stories about Ethiopia showing progress or meeting some of the targets outlined in the Millennium Development Goals (MDG), the country as a whole is lagging behind on maternal health (United Nations Economic Commission for Africa, African Union, African Development Bank, & United Nations Development Programme, 2015).

In low-income countries like Ethiopia, farmers are usually impoverished. If a woman is highly dependent on her low-income partner (regarding educational and occupational status), she will have less access to household food security (Bitew & Telake, 2010). Concerning household wealth, women residing in households with lower economic status are more likely to be undernourished than average or higher economic status households (Bitew & Telake, 2010; Girma & Genebo, 2002; Hundera et al., 2015).

Multivariable linear regression analysis showed that maternal age is an independent predictor of CED. Adolescent (15-19 years) lactating mothers were more likely to be chronically energy deficient than older mothers. Other researchers have also reported similar findings (Bitew & Telake, 2010; Girma & Genebo, 2002). Adolescent mothers are prone to have low BMI because girls grow in height and weight until the age of 18 and do not achieve peak bone mass until about 25. So, if they were malnourished and didn't eat adequate and diversified diet before the age of 18, cannot support both her growth and that of her child (FAO, 1999).

The multivariable linear regression analysis has also shown that husband's occupation is significantly associated with CED prevalence. The probable explanation for the current result could be when the husbands are engaged in hard work, they will have money every day and mothers will have enough money at hand to buy commodities for their household expenditure. On the contrary, women engaged with agricultural or unemployed partners often have less autonomy than those whose husbands have higher occupational status or money in their pocket (Bitew & Telake, 2010).

Household wealth was significantly but negatively associated with CED prevalence. Low-income households tend to be more food insecure and consequently suffer from the inadequate dietary intake. Income of a household strongly determines its access to food which in turn is a significant determinant of wellbeing and nutritional status of mothers (Ogechi, 2014). Women in low-income countries like those from sub-Saharan Africa usually have short stature (height <145 cm) and low body mass index (<18.5 kg/m^2) (Black et al., 2013). The current finding is also consistent with the recent study (Hundera et al., 2015) that reported wealthy lactating mothers in western Ethiopia were almost 0.25 less likely to be vulnerable to undernutrition.

4.5.2 Strengths and limitations

We utilised multistage sampling technique and regression analysis to reduce bias due to selection and potential confounders, respectively. This study has the following limitations. First, a cross-sectional design was used in this study; it was not possible to seasonal variability in outcomes. Second, the responses might suffer from recall bias.

4.6 Conclusions

Generally, the mothers have suboptimal feeding practices which could predispose them to malnutrition. As most of the mothers are consuming cereal-based foods and legumes, which are characterised by high anti-nutrients and low nutritional quality, nutritional outcomes of the mother and her breastfeeding child could also be affected. Mother’s age, household’s wealth and husband’s occupation are independent predictors of undernutrition among lactating mothers in Jimma Zone, Southwest Ethiopia. Younger lactating mothers who live in low-income households and whose husbands make a living by farming were more likely to be chronically energy deficient. As maternal nutrition could lead to intergeneration effects, it is recommended that interventions that target the vulnerable using locally appropriate strategies be instituted to combat the problem.

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5 Complementary feeding practices, dietary diversity, and nutrient adequacy of diets of children 6-24 months old in Jimma Zone, Southwest Ethiopia

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5.1 Abstract

Theoretically, nutritious complementary foods should be introduced to infants when they turn six months old because breast milk alone will not meet their nutritional requirement. However, in practice, complementary foods in low-income settings are of low nutritional quality. The objective of the current study was to evaluate the quality of complementary foods and the optimality of complementary feeding practices in Southwest Ethiopia. In this community-based cross-sectional study, stratified multistage sampling procedure was used to sample 433 children, 6-24 months old, in Southwest Ethiopia. A semi-structured questionnaire was used to collect demographic, socio-economic and dietary data. The number of food groups, among seven food groups, fed to a child within 24 hours of the survey was defined as dietary diversity score (DDS). Six complementary foods predominantly fed to children were assayed for proximate composition, energy, mineral density, tannin and phytate content using standard methods. Nutrient adequacy ratio (NAR) was assessed as a ratio between actual intake and recommended intake of the nutrient. Only 16.1% of the children get the minimum dietary diversity. The children were reported to be fed with cereals & grains (68.8%), discretionary calories (53.6%), protein-rich foods (44.6%), oils and fat (40.5%), vegetables (38.5%), dairy products (17.9%) and, fruits (28.1%). The sampled foods contained 4.3-24.4%, 2.9-8.0%, 2.3-8.2%, 0.9-8.5%, 8.2-11.9%, and 58.4-79.6% and 27.9-162.6 Kcal/100g of total carbohydrate, total ash, crude fibre,

crude fat, protein, moisture, and energy content, respectively. The calcium, zinc, iron and phosphorus contents ranged between 168.4-250.4 mg/100g, 1.8-4.1 mg/100g, 22.5-42.4 mg/100g, and 225.6-317.0 mg/100g, respectively. The phytate and tannin contents ranged from below detectable level (BDL)-117.7 mg/100g and 1.2-75.2 mg/100g, respectively. All the complementary food samples predominantly fed to children were not sufficient to meet the protein, fat, carbohydrate, energy and calcium requirements, (NAR<1). However, most of the diets provided adequate iron and zinc. The nutrient density and diversity of complementary foods of 6-24 months old children in the study area were found to be sub-optimal. Upgrading the nutritional composition of the predominantly starchy complementary foods should be of highest priority to improve the nutrition of infants and young children.

5.2 Introduction

Complementary feeding refers supplementing breastfeeding with feeding children aged between 6 and 24 months with a wide range of foods (Dewey, 2013). The period between 6 and 24 months of age is a time of nutritional vulnerability because during this period nutrients especially micronutrients and energy obtained only from breast milk will not be sufficient to meet the requirements of the child (Udoh & Amodu, 2016). Ensuring adequate nutrition during the period between 6 and 24 months of age is a major global health priority (Dewey, 2013).

Among the immediate causes of undernutrition among children is consumption of too few nutrients (Black et al., 2008). In most low-income countries, including Ethiopia, beginning of growth faltering coincides with the start of complementary feeding; age-specific malnutrition rates generally increase until about 24 months of age and then level off (Shrimpton et al., 2001). The sharp rise in the occurrence of stunting in young children from the age of six months is usually associated with suboptimal complementary feeding practices (Daelmans et al., 2013). As children younger than 24 months old do not consume sufficient amount of food to cover the high nutrient needs for growth and development, food given to them should be of high nutrient density (Dewey, 2013).

Theoretically, infants should receive the most nutrient-dense diet in the family. Infants in low-income countries, however, are typically fed with nutrient-poor foods like thin porridges (Dewey, 2013). Complementary foods should contain high-biological-value protein, furthermore vitamins and minerals (WHO/UNICEF, 2003).

The National Nutrition Strategy (NNS) of Ethiopia gives considerable emphasis for nutrition of children younger than two years old in particular as nutrition received during this period influences how the children develop, grow and learn now or later. There is no documented evidence of overall complementary feeding practices and nutritional adequacy of complementary foods in Jimma Zone. This information is critically needed to be able to judge and plan the mechanisms to upgrade traditional diets. Therefore, the objective of this study was to evaluate the complementary feeding practices, dietary diversity, nutrient adequacy of complementary foods of children 6-24 months old in Jimma Zone, Southwest Ethiopia.

5.3 Subjects and methods

5.3.1 Area and subjects

This study was conducted in Jimma zone, Southwest Ethiopia. The study area is year-round green but unfortunately characterised by household food insecurity (Belachew, Lindstrom, Gebremariam, et al., 2013). Three districts were purposively selected based on their agricultural production; Omo Nada, Dedo and Mana are cereal, vegetable and cash crop producer areas, respectively.

This study is a component of a more prominent cross-sectional study which assessed the nutritional status and associated factors among children younger than two years old (See Chapter 3). The study population for the original research included all children younger than two years old in the study area. A multistage stratified sampling procedure was used to sample 558 children who were 0-24 months old (Faul et al., 2007). For the current study, only those children 6-24 months old were included.

A single population proportion formula was used to calculate the sample size assuming 44% national rate of stunting (Central Statistical Agency [Ethiopia] & ICF International, 2012) with a design effect of two for cluster sampling, a confidence level of 95% and margin of error of 5%. Power analysis was done using G-power 3.0 statistical power analyses software for Windows (Faul, Erdfelder, Lang, & Buchner, 2007).

5.3.2 Data collection

Data were collected from mothers or caregivers of the infants and children using face-to-face interviews using a semi-structured questionnaire.

5.3.3 Variables

The variables were categorised as dependent and independent variables. The dependent variable was the dietary diversity score of the 6-24 months old children. The independent variables included several socio-economic and demographic factors like family composition, household size, educational level attained by mothers and fathers, the occupation of mothers and fathers, the wealth of the household and education or training received on health and nutrition. Beyond these complementary feeding practices were also measured.

5.3.4 Measurements

5.3.4.1 Diet diversity

A single 24-hour dietary recall was used to obtain data on dietary diversity. Dietary diversity was assessed with a scale of seven food groups namely cereals and grains, vegetables, fruits, dairy products, oil and fat, protein-rich foods and discretionary calorie foods. DDS was found to be optimal when a child is fed ≥ four food groups per day (USDA, 2005).

5.3.4.2 Diet composition

First, the complementary foods fed to 6 to 24 months old children were identified from the questionnaires. Then, six predominantly fed complementary food groups were selected. Composite samples were collected, dried, ground and packaged (Pomeranz & Meloan, 2000). The samples were then analysed for proximate composition (protein, fat, carbohydrate, moisture, ash and fibre), energy content, mineral (iron, zinc, calcium and phosphorous) and anti-nutritional factors (phytate and tannin) following the respective standard methods of analysis (AOAC International, 2005).

5.3.4.3 Nutrient adequacy

Nutrient adequacy ratio (NAR) was calculated by dividing nutrient intake to estimated average nutrient requirement. The later was calculated using the Dietary Reference Intake (DRI) for age group (6-12 months, and 1-3 years) (Dietary Reference Intakes Research Synthesis Workshop (2006 : Institute of Medicine (U.S.)), 2007). Mean adequacy ratio (MAR) was calculated by dividing the sum of NARs for all evaluated nutrients to the number of assessed nutrients (Steyn et al., 2006).

5.3.5 Statistical analysis

The data were analysed using Statistical Package for Social Sciences software version 20 (SPSS Inc., Chicago, IL, USA). Descriptive statistics such as percentages were calculated. Bivariate analysis was conducted for the dietary diversity data. A p-value of 0.05 was used as a cut-off for determining the statistical significance of differences.

5.4 Results

5.4.1 Characteristics of the sample

Four hundred thirty-three out of 558 children included in the study were aged 6-24 months old. Majority 372 (66.7) of the participants were from the rural part of the survey area, Muslims in religion 516 (92.5%), Oromo in ethnicity 486 (87.1%), married and living together 501 (89.8%) and 336 (60.2%) were uneducated. A large proportion of the families belong to lower middle class or socioeconomic status because most of them were engaged in small business and many 436 (78.1%) were housewives (Table 5-1).

5.4.2 Complementary feeding practices

The majority (88.9%) of the children were exclusively breastfed, and 75.6% were breastfed up to the age of two years. Both early and late initiation of additional food was practised extensively in the study area, but most (82.9 %) of the mothers started to give complementary food to their children just at six months. However, nearly half of the mothers (53.8 %) do not prepare any particular complementary food other than the typical family dish while the rest make some other additional foods of which gruel or '*Atmit*' is the predominant one. At the same point, almost all (91.6 %) of the mothers do not prepare any particular food to their children during sickness or recovery from disease. Even though, the study signified that child feeding frequency is in an excellent condition that (96.7 %) of the mothers feed their child 3-4 times a day (Table 5-2).

Table 5-1 Description of the study participants (Jimma Zone, Southwest Ethiopia 2014).

Variable	Frequency (N=558)	Percentage (%)
Sex of index child		
Male	302	54.1
Female	256	45.9
Age of index child (months)		
0-5	125	22.4
6-11	167	29.9
12-24	266	47.7
Mean	11.41 ±6.5	
Birth order of index child		
First	128	22.9
Second	124	22.2
Third & Above	306	54.8
Number of children per mother		
1-2 children	252	45.2
3 and above children	306	54.8
Age of the mother (Years)		
15-19	26	4.7
20-29	360	64.5
30-39	161	28.9
40-49	11	2
Mean	26.6±5.1 years	

Regarding dietary intake, two-thirds (68.8%) of the study participants consumed cereal based gruel (made of barley, oat, teff, wheat, sorghum). Nearly half (44.6%) of the study participants reported that they fed their children with protein-rich food before the survey and (53.6%) of the study subjects consumed discretionary calories in the previous 24 hours. Fruits, vegetables and dairy products were consumed by 28.1%, 38.5% and 17.9% of the participants, respectively.

Table 5-2 Complementary feeding practices of children 6-24 months old in three districts of Jimma Zone, Southwest Ethiopia from March-May, 2014.

Variables	**n**	**%**
Exclusive breastfeeding [a]		
Yes	496	88.9
No	62	11.1
Continued breastfeeding ≥2 years old [a]		
Yes	422	75.6
No	136	24.4
Time of initiation of complementary feeding		
Before six month	49	11.6
Just at six-month	350	82.9
After six months	23	5.5
Preparation of special additional food		
Yes	258	46.2
No	300	53.8
Particular food during sickness or recovery		
Yes	47	8.4
No	511	91.6
Feeding frequency		
>2 times a day	39	9.2
3-4 times a day	326	76.9
3-4 times + 1-2 snack	59	13.9
Dietary diversity score		
< 4 food groups per day	303	54.3
≥ 4 food groups per day	255	45.7
Food groups fed to children [b]		
Cereals and grains	384	68.8
Fruits	157	28.1
Vegetables	215	38.5
Protein rich	249	44.6
Dairy products	100	17.9
Oil and fat	226	40.5
Discretionary calories	299	53.6

[a] Sample size =558

[b] Percentages do not add up to 100% as more than one response is possible.

5.4.3 Dietary diversity

Majority of the children (83.9%) did not get the minimum dietary diversity. Dietary diversity score was significantly ($P<0.05$) influenced by the age and birth order of the child, maternal and paternal education, socioeconomic status of the family and paternal occupation. Higher dietary diversity was scored among children aged 12-24 months old, whose birth order was first and whose parents were formally educated. Children whose fathers are not farmers and children living in homes with higher wealth status also had higher DDS (Table 5-3).

Table 5-3 Distribution of child DDS by different variables in Jimma Zone, South West Ethiopia.

Variables	MDDS No n (%)	MDDS Yes n (%)	χ2 (P-value)
Child age group			
0-5 months	124 (99.2%)	1 (0.8%)	
6-11 months	147 (88.0%)	20 (12.0%)	0.000
12-24 months	197 (74.1%)	69 (25.9%)	
Birth order of the child			
First	99 (77.3%)	29 (22.7%)	
Second	99 (79.8%)	25 (20.2%)	0.007
Third and above	270 (88.2%)	36 (11.8%)	
Districts			
Mana	159 (85.5%)	27 (14.5%)	
Omo-Nada	158 (84.9%)	28 (15.1%)	0.470
Dedo	151(81.2%)	35(18.8%)	
Maternal education			
Informal education	293 (87.2%)	43 (12.8%)	0.006
Formal education	175 (78.8%)	47 (21.2%)	
Paternal education			
Informal education	205 (87.2%)	30 (12.8%)	0.041
Formal education	263 (81.4%)	60 (18.6%)	
Maternal occupation			
Housewife	370 (84.9%)	66 (15.1%)	0.144
Other	98 (80.3%)	24 (19.7%)	
Paternal occupation			
Farming	296 (86.5%)	46 (13.5%)	0.021
Other	172 (79.6%)	44 (20.4%)	
Place of residence			
Rural	316 (84.9%)	56 (15.1%)	0.196
Urban	152 (81.7%)	34 (18.3%)	
Wealth of households			
Poor	162 (87.1%)	24 (12.7%)	
Medium	165 (87.3%)	24 (12.7%)	0.009
Rich	141 (77.0%)	42 (23.0%)	

5.4.4 Composition of diets

The moisture, total carbohydrate, protein, crude fat, total ash, crude fibre, and energy content of the sampled complementary foods ranged between 58.4%-79.6%, 4.29-24.44%, 8.21-11.87%, 0.86-8.49%, 2.94-8.03%, 2.28-8.19%, and 27.87-162.57cal, respectively (Table 5-4).

Table 5-4 The proximate composition and calorific value of sampled complementary foods (Atmits) in three districts of Jimma Zone, Southwest Ethiopia from March-May 2014.

Atmit types	**Fibre**	**Fat**	**Ash**	**Protein**	**CHO**	**Moisture**	**Calorific Value**
	(%)	(%)	(%)	(%)	(%)	(%)	(Kcal/100g)
C	**2.28**	1.33	5.34	**8.21**	**24.44**	**58.4**	142.57
CO	2.65*	**0.86**	3.78	10.49	10.02	72.2	89.78
CPO	6.99	1.27	**8.03**	8.4	**4.29**	**79.6**	**27.87**
CPS	**8.19**	2.49	4.9	10.77	5.58	67.8	87.81
CP	6.41	4.49	5.15	9.67	9.78	64.5	118.21
COPS	5.73	**8.49**	**2.94**	**11.87**	9.67	61.3	**162.57**

*Calculated from EHNRI (1997)
C=cereal; O=oilseed; P=pulse; S=spice.

The mineral content ranged between 168.41-250.4 mg/100g, 1.78-4.14 mg/100g, 22.48-42.39 mg/100g, and 225.56-317 mg/100g for calcium, zinc, iron, and phosphorus, respectively. The anti-nutritional factors contents ranged between (below detection limit) BDL-117.72 mg/100g for phytate and 1.17-75.17 mg/100g for tannin (Table 5-5).

Table 5-5 The mineral and anti-nutritional factors content of sampled complementary foods (Atmits) in three districts of Jimma Zone, Southwest Ethiopia from March-May 2014.

Atmit types	**Iron** mg/100g	**Zinc** mg/100g	**Calcium** mg/100g	**Phosphorous** mg/100g	**Phytate** mg/100g	**Tannin** mg/100g
C	30.34	**1.78**	177.57	245.32	70.68	1.17
CO	33.86	2.86	206.18	257.62	96.33	7.22
CPO	**42.39**	2.81	**168.41**	**225.56**	BDL	22.36
CPS	36.52	2.9	198.12	272.44	BDL	45.5
CP	29.2	3.03	178	**317**	**117.72**	19.67
COPS	**22.48**	**4.14**	**250.4**	259.48	-	**75.17**

C=cereal; O=oilseed; P=pulse; S=spice; BDL= below detectable level.

5.4.5 Nutrient adequacy of diets

All of the foods did not contain adequate amounts of protein, fat, energy, zinc and calcium (NAR<1). On the other hand, most of the diets provide sufficient quantities of ash and iron (NAR>1). The requirements were not met for any of the nutrients (Table 5-6).

Table 5-6 Nutrient adequacy ratio of commonly used complementary foods.

Gruel types	Protein	Fat	CHO	Fibre	Ash	Energy	Fe	Zn	Ca	MAR
C	0.55	0.13	0.38	0.46	1.78	0.36	1.9	0.56	0.36	0.72
CO	0.7	0.09	0.16	0.53	1.26	0.22	2.12	0.89	0.41	0.71
CPO	0.56	0.13	0.07	1.4	2.68	0.07	2.65	0.88	0.34	0.97
CPS	0.72	0.25	0.09	1.64	1.63	0.22	2.28	0.91	0.4	0.90
CP	0.64	0.45	0.15	1.28	1.72	0.3	1.83	0.95	0.36	0.85
COPS	0.79	0.85	0.15	1.15	0.98	0.41	1.41	1.29	0.5	0.84

C=cereal; O=oilseed; P=pulse; S=spice

5.5 Discussion

5.5.1 Complementary feeding practices

Studies in developing countries showed that both too early and a too late introduction of complementary food is familiar. Mothers in South Africa start complementary feeding within 2-3 months. In Uganda, 44.1% and 27% mothers began complementary feeding within 2-3 months in 1997 and 2005 respectively (Ajani, 2010). Our findings oppose these reports because for the majority of the children in the study area complementary feeding is initiated just at the appropriate time.

Contrary to the recommended practice of complementary feeding, the majority of the mothers do not prepare particular food during sickness or recovery. During an illness, the need for fluid often increases, so a child should be offered and encouraged to take more (Brown, 2001). However, feeding frequency in the study area was optimal for children in age group of 6-12 but not for those in the age group of 13-24 months. The recommended number of meals per day for a healthy breastfed baby should be 2-3 times at 6- 8 months, 3-4 times at 9-11 months, and 3-4 times with 1-2 additional nutritious snacks at 12 to 23 months of age (WHO/UNICEF, 2003).

The predominant complementary food fed to children in the study areas is gruel (a liquid drink made of cereals), locally named ‘Atmit', ranking first in the all of the three districts. In Ethiopia, 70% of children aged 6-23 months, predominantly consume foods made of grains (Central Statistical Agency [Ethiopia] et al., 2006). Similarly, a study conducted in Nigeria reported that the dominant food groups in the children's diet were cereal/grains (Ajani, 2010). Nutritional problems are common among populations whose diets are predominantly based on starchy staples (Steyn et al., 2006), and these plant-based foods are low in micronutrient contents, high in phytate and dietary fibre which inhibits the absorption of micronutrients (Lopez et al., 2004).

5.5.2 Dietary diversity

The results of the current study showed that nearly half of the children had sub-optimal dietary diversity. A survey of community-based production complementary foods in four regions of Ethiopia has reported that the highest mean diversity score of 3.4 was observed in Oromia region, followed by Tigray (2.9) Amhara (2.7) and SNNP (2.6) regions. In Oromia region, nearly half (49.4%), of the children had suboptimal diet diversity (Addis Ababa University, 2010).

According to our results, children from wealthier households consumed more diversified diets. The ability to produce sufficient food for one's household at home and generate enough revenue to purchase foods on the market are ways that a family could achieve food security (Hadley et al., 2011).

The results of this study also indicated that girls are fed with less diversified diet compared to their male counterparts. Male gender bias in the intra-household distribution of food and other resources has been reported from Ethiopia (Hadley, Lindstrom, Belachew, & Tessema, 2008) indicating that girls are less favoured in the resource-constrained environments.

5.5.3 Composition of diets

The complementary foods were predominantly made of starch-based cereals and hence of poor nutritional value, and do not satisfy the infant´s basic needs of protein because they have limited levels of protein both qualitatively and quantitatively. As well as macro and micronutrients may be insufficient to maintain growth and development, this results in reduced nutritional status in children (WHO/UNICEF, 2003).

5.5.4 Nutrient adequacy of diets

Complementary foods should contain the following amount of estimated macronutrients: moisture content of ≤5%, an ash content of ≤3%, the crude protein content of ≥15%, the crude fat content of 10-25%, the crude fibre content of ≤5%, and carbohydrate content of 64±4%. Additionally, the energy content of 400-425 kcal/100g, a calcium content of 500 mg/100g, the iron content of 16 mg/100g and zinc content of 3.2 mg/100g is also required (FAO/WHO, 1991). Children younger than two years old and living in developing countries should consume approximately 137-187g/day, 206-281g/day and 378-515g/day of complementary foods at the age of 6-8 months, 9-11 months and 12- 24 months, respectively to meet their energy needs (Pan American Health Organization, 2003)._The total nutrient and energy requirements of healthy breastfeeding infants have been established (Dewey & Brown, 2003). The average nutrient and energy a given complementary food should provide are estimated by subtracting average nutrient and energy content of breast milk from the total nutrient and energy requirement at each age (WHO/UNICEF, 1998). The nutrient adequacy of the food samples was below what complementary foods are supposed to contain.

Over and under-reporting of infant dietary intakes is among the reasons that made quantifying infants' diets difficult. Parents tend to over-report intakes either for they do not wish to be seen to be under-feeding babies and on the one hand not being able to distinguish between food offered to young children and the amount consumed (Conn, Davies, Walker, & Moore, 2009).

5.6 Conclusions

The feeding practices of 6-24 months old children in the study area were not satisfactory. Dietary diversity and macronutrient, energy and overall nutrient adequacy of the complementary foods were below the recommendations. The diets were found to be adequate only in iron content. Improving the nutrient adequacy of the locally available customary diets through food processing techniques and a community-based nutritional education on optimal child feeding are recommended.

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6 Nutritional and Sensory Quality of Composite Extruded Complementary Food

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6.1 Abstract

Mothers in low-income countries like Ethiopia usually make complementary foods with cereals. Blending these cereals with selected nutrient-rich plant-based ingredients coupled with appropriate processing technique can enhance the nutritional and sensory quality of cereal-based complementary foods. The objective of this study was to develop a composite extruded complementary food and assess its nutritional and sensory properties. A constrained D-optimal mixture experiment with 13 runs was designed to optimise the nutritional and sensory quality of products developed for older infants and young children between 6-23 months old with extruded composite flour (ECF) of 55-65 g/100g oats, 11-23 g/100g soybean and 6-11 g/100g linseed. A premix of sugar, salt, moringa and fenugreek was added at a fixed rate of 15 g/100g. Extruded products were obtained using a co-rotating twin screw extruder with set parameters. Overlaid contour plots and response optimiser were used to optimise the responses. The fat, protein, carbohydrate, ash, fibre and calcium content, taste, aroma, consistency and overall acceptability were significantly ($p<0.05$) affected by oats, soybean and linseed blends. Blending ratio did not seem to influence appearance and mouthfeel strongly. Higher soybean and linseed supplement levels were associated with an increase in nutrients whereas, sensory acceptability increased with

increasing proportion of oats in the blend. The optimal blending ratio was 55.0 g/100g oats, 21.0 g/100g soybean and 9.0 g/100g linseed plus 15.0 g/100g premix. Reasonable selection of locally grown raw materials, an optimal mixture of these ingredients and optimal processing can result in nutritious and acceptable complementary food product which can contribute to the fight against child undernutrition in low-income settings.

6.2 Introduction

Several diet-related factors relate to child malnutrition in Ethiopia. First, there is poor complementary feeding of children. A study has shown that only 4 percent of youngest children (6-23 months) living with their mothers in Ethiopia are fed per the national infant and young child feeding (IYCF) guidelines (Central Statistical Agency [Ethiopia] & ICF International, 2012). Second, traditional complementary foods are of low nutritional quality. A recent countrywide demographic survey showed the traditional complementary foods in Ethiopia are cereal-based (e.g., Atmit) (69%), whereas consumption of vitamin A-rich fruits and vegetables and foods made from roots and tubers are less frequent (24-25%) (Central Statistical Agency, 2012). Third, many in developing countries cannot afford quality protein-based complementary foods and nutritious trademarked complementary foods (Muhimbula, Issa-Zacharia, & Kinabo, 2011b).

Three critical factors govern the final properties of food products manufactured in a blending operation (Muteki, MacGregor, & Ueda, 2007). The first factor is an optimal selection of raw materials. Low-cost protein-rich ingredients like legumes (also called pulses) are known to upgrade starchy foods (Mensah & Tomkins, 2003). Fat rich ingredients (Muoki, de Kock, & Emmambux, 2012) and vitamin and mineral rich ingredients (Tontisirin, Nantel, & Bhattacharjee, 2002) also improve chemical properties of cereal-based diets including infant and young children food products. The second factor is the ratios in which to blend these ingredients. Studies have shown that optimal blending can optimise the nutritional and sensory quality of complementary foods (Gebretsadikan, Bultosa, Forsido, & Astatkie, 2015). The third factor is the process conditions used to manufacture the product. Extrusion is a high-temperature short time food processing technique used for the production of modified and improved products (Lobato, Anibal, Lazaretti, & Grossmann, 2011). Extrusion cooking allows gelatinisation, and partial dextrinization of starch also reduces the activity of some antinutritional factors, which makes it a useful process for the production of instant infant flours (Mouquet et al., 2003).

Despite evidence of the application of blending for the formulation of baby foods (Gebretsadikan et al., 2015), there is limited information on the use of both blending and extrusion cooking in the Ethiopian context. As to our knowledge, there is no published information on the possibility of making extrusion cooked nutrient-rich and tasty complementary food products blended from locally available, nutritious and relatively cheaper crops in Ethiopia. The objective of this study was to test the effect of mixing ratio of oats, soybean and linseed on nutritional and sensory properties of extruded complementary foods.

6.3 Materials and methods

6.3.1 Experimental materials

Ingredients were chosen primarily based on Codex Alimentarius guidelines (Codex Alimentarius Commission, 1991) and in consultation with key stakeholders such as mothers and health extension workers, and upper and lower constraint calculations were based on literature (Mouquet et al., 2003) with some modifications. Accordingly, the blend was composed of cereal which is commonly used for making complementary food in the study area (oats variety *Sinana One*), a protein-rich ingredient (soybean variety *Clark 63K*) and a fat-rich ingredient (linseed variety *Kulumsa One*). A premix *of Moringa stenopetala*, fenugreek variety *Chala*, iodised salt and sugar was also added to supplement micronutrients and improve sensory attributes of composite blends. The samples were packed in airtight polyethene bags and stored in a laboratory at room temperature until needed for processing. Table 6-1 details nutrient contents of all raw materials (US Department of Agriculture, Agricultural Research Service, & Nutrient Data Laboratory, 2015).

6.3.2 Raw material preparation

Oats were cleaned, dehusked, sorted manually, milled (2 mm screen) (Retsch mill, Retsch GmbH, 5657 Haan, West Germany) and passed through a 30-mesh sieve. The soybeans were cleaned, boiled (30 minutes) and dehulled. Afterwards, the beans were dried at 60°C for about 13 hours, milled into flour and sieved (0.5 mm sieve) (Gebretsadikan et al., 2015). The linseed was cleaned, lightly roasted (100°C for 15 minutes) until a nutty flavour was developed, milled and sieved (0.5-mm sieve) to get full-fat linseed flour (Sudha, Begum, & Ramasarma, 2010). Fenugreek seeds were cleaned, roasted (130±5°C for 7 minutes), ground and passed through standard test sieve (0.5mm). Fresh mature Moringa leaves were plucked, washed, dried under the shade at 20°C for two weeks, milled and sieved (0.5 mm) to produce fine flour (Gebretsadikan et al., 2015). All powder samples were stored at refrigeration temperature (4°C) in an air-tight container until used.

Table 6-1 Nutrient content of ingredients (U. S. Department of Agriculture and Nutrient Data Laboratory 2015).

Nutrient	Unit	Value per 100 g				
		Oats	Soybean	Linseed	Moringa leaves (raw)	Fenugreek
Proximates						
Moisture	mg	8.22	8.54	6.96	78.66	8.84
Energy	Kcal	389	446	534	64	323
Protein	g	16.89	36.49	18.29	9.4	23
Fat	g	6.9	19.94	42.16	1.4	6.41
Carbohydrates	g	66.27	30.16	28.88	8.28	58.35
Fibre, total dietary	g	10.6	9.3	27.3	2	24.6
Minerals						
Ca	mg	54	277	255	185	176
Fe	mg	4.72	15.7	5.73	4	35.53
Mg	mg	177	280	392	42	191
P	mg	523	704	642	112	296
K	mg	429	1797	813	337	770
Na	mg	2	2	30	9	67
Zn	mg	3.97	4.89	4.34	0.6	2.5
Vitamins						
Vitamin C, total ascorbic acid	mg	0	6	0.6	51.7	3
Thiamin	mg	0.763	0.874	1.644	0.257	0.322
Riboflavin	mg	0.139	0.87	0.161	0.66	0.366
Niacin	mg	0.961	1.623	3.08	2.22	1.64
Vitamin B-6	mg	0.119	0.377	0.473	1.2	0.6
Folate	µg	56	375	87	40	57
Vitamin A, RAE	µg	0	1	0	378	3

6.3.3 Experimental design

A 13-run constrained D-optimal mixture experiment (Table 6-2) was generated using Minitab® (Version 16.0, Minitab, Inc.) software. The constraints used were 55-65 g/100g for oats, 11-23 g/100g for soybean and 6-11 g/100g for linseed. Upper and lower constraints for each ingredient were determined based on data from food composition tables (Souci, Fachmann, & Kraut, 2008) and literature (Nguyen, Rivier, Eymard-Duvernay, & Trêche, 2010). The proportion of oats, soybean and linseed is converted to 85 g/100g, and the remaining 15 g/100g was reserved for the premix in all the runs.

Table 6-2 Treatment combination of oat, soybean, linseed and premix of final composite flours

Run order	Oat	Soybean	Linseed	Premix[$]	Total
1	57.92	19.92	7.17	15.0	100.0
2	57.42	17.92	9.67	15.0	100.0
3	56.00	23.00	6.00	15.0	100.0
4	65.00	11.00	9.00	15.0	100.0
5	62.42	15.42	7.17	15.0	100.0
6	55.00	19.00	11.00	15.0	100.0
7	62.42	15.42	7.17	15.0	100.0
8	57.42	19.92	7.67	15.0	100.0
9	63.00	11.00	11.00	15.0	100.0
10	59.83	16.83	8.34	15.0	100.0
11	55.00	23.00	7.00	15.0	100.0
12	61.42	13.92	9.67	15.0	100.0
13	65.00	14.00	6.00	15.0	100.0

[$]Premix = 9.9% sugar, 3% moringa, 1.5% fenugreek and 0.6% salt

6.3.4 Extrusion

The ingredients were thoroughly mixed for 5 minutes in a planetary cake mixer (H.LB20/B, Hungary). The extrusion cooking process was performed using a pilot scale co-rotating twin screw food extruder (model Clextral, BC-21 N0 194, Firminy, France). The necessary calibration and adjustment of the material feed rate, water flow rate, barrel temperature of metering section, moisture content of the raw material and screw speed were performed before the extrusion cooking process. The extrudate was allowed to cool to 20°C, and afterwards dried in a convective oven at 105° C for 15 minutes (Semasaka, Kong, & Hua, 2010), cooled to room temperature, milled, sieved (0.5mm sieve) and the flour was stored in polyethene bags at 4°C.

6.3.5 Gruel preparation

Thirteen gruel samples were prepared from the extruded composite powders. 50g of flour was added to 150ml of water, warmed at 75°C on a thermostatically controlled hot plate and stirred with a wooden ladle until it attained the desirable pasty consistency similar to the traditional gruel consumed in the study area (Gebretsadikan et al., 2015). After samples had been taken for nutritional analysis, the remaining gruel samples were allowed to cool to 45°C before sensory evaluation.

6.3.6 Nutrient analysis

Proximate compositions were determined on dry matter basis following their respective Association of Official Analytical Chemists (AOAC) methods: moisture (925.10), crude protein (979.09), crude fibre (962.09), crude fat (920.39) and Ash (923.03) (AOAC International, 2005). Total carbohydrate content was calculated by adding the proportion of other ingredients and subtracting from 100. The energy contents of the samples were obtained by multiplying crude protein, crude fat and carbohydrate by conversion factors of 4, 9 and 4, respectively (Osborne & Voogt, 1978).

Micronutrient content namely calcium (Ca), iron (Fe) and zinc (Zn) were determined using a Flame Atomic Absorption Spectrophotometer (AAS) (Shimadzu, AA-6800, Japan) following AOAC method 985.35 (AOAC International, 2005). The ß-carotene content was determined using a UV/Vis spectrophotometer T-80 (PG Instruments, China) (Biswas, Sahoo, & Chatli, 2011). The micronutrients were quantified against standard solutions of known concentrations.

6.3.7 Sensory analysis

Sensory evaluation for acceptability of gruel was performed by using 25 untrained panels selected from Jimma town, Ethiopia. After orientation, coded sample products were given in a random order to the panellists for evaluation of appearance, aroma, taste, mouthfeel and overall acceptability. A five-point hedonic scale (5 = like very much, 4 = like moderately, 3 = neither like nor dislike, 2 = dislike moderately and, 1 = dislike very much) was used (Meilgaard, Carr, & Civille, 2006).

6.3.8 Statistical analysis

The response variables measured from the 13 formulations were analysed using Minitab®, Version 16. Lack-of-fit of models was tested. Independence, normality and equality of variance of error terms assumptions were checked. Then the significance of each term was tested, contour plots were constructed for each response variable to determine the best formulation and, target goals were defined for the responses. Finally, the "sweet spot" that optimises all response variables was determined by superimposing contour plots of responses and by using the response optimiser (Montgomery, 2013).

6.4 Results

The moisture, protein, carbohydrate, fat, ash, crude fibre, and energy content of the extruded composite flours ranged between 3.2-5.6 g/100g, 18.0-20.6 g/100g, 59.8-63.7 g/100g, 6.8-9.9 g/100g, 2.3-3.1 g/100g, 3.8-4.2 g/100g and 384.5-408.2 kcal/100g respectively. The quadratic model well-described changes in protein, total carbohydrate, fibre, fat and ash contents of the flours as functions of blending ratio ($p<0.05$; $R^2>94.5\%$). Conversely, there was no significant relationship between mixing ratio and moisture and energy contents (Table 6-3).

The iron, calcium, zinc and total ß-carotene contents of the extruded composite flours varied from 6.6-7.8mg/100g, 101.3-124.4mg/100g, 2.9-3.0mg/100g and 1309 to 1900µg/100g, respectively. The linear model well-described changes in the iron content of the meals as functions of blending ratio with a high coefficient of determination ($R^2=0.99$). The linear model marginally explained changes in calcium content of the flours as functions of mixing ratio. On the contrary, zinc contents were not well described either by quadratic or by linear models. The model for ß-carotene content was significant ($p < 0.05$), presenting coefficients of determination (R^2) of 0.97 (Table 6-3).

Table 6-3 ANOVA p-values for the quadratic regression model for mixtures of proximate compositions, energy, mineral content, beta carotene and sensory attributes

Source	Proximate composition						Energy	Mineral content			β-C	Sensory attributes					
	Pro†	Fat	CHO	Fib	Ash	MC		Fe	Zn	Ca		Apr	Aro	Tas	MF	Con	OA
Linear‡	0.01	0.26	0.01	0.00	0.01	0.11	0.69	0.01	0.34	0.06	0.00	0.30	0.01	0.02	0.78	0.05	0.06
Quadratic‡	0.01	0.02	0.00	0.00	0.01	0.13	0.94	0.74	0.94	0.64	0.00	0.09	0.01	0.03	0.24	0.03	0.10
Oats*Soybean	0.06	0.27	0.01	0.67	0.01	0.86	0.85	0.64	0.75	0.95	0.10	0.63	0.01	0.02	0.71	0.04	0.08
Oats*Linseed	0.01	0.18	0.01	0.00	0.01	0.28	0.81	0.87	0.70	0.31	0.00	0.90	0.04	0.01	0.33	0.92	0.04
Soybean*Linseed	0.04	0.02	0.00	0.00	0.00	0.10	0.75	0.57	0.59	0.28	0.00	0.34	0.40	0.01	0.87	0.71	0.06
R^2 (Adjusted)	0.98	0.97	0.96	0.98	0.91	0.93	0.97	0.99	0.98	0.99	0.94	0.83	0.82	0.83	0.82	0.84	0.61

Notes:

†Pro=Protein; CHO=Carbohydrate; Fib=Fibre; MC=Moisture Content; β-C= β-carotene; Apr=Appearance; Aro=Aroma; Tas=Taste; MF=Mouthfeel; Con=Consistency; OA=Overall acceptability; R^2=Coefficient of determination.

‡Model fitting method used is mixture regression. Regression p-value less than or equal to 0.05 indicates the model explains variation in the response.

The appearance, aroma, taste, mouthfeel, consistency and overall acceptability of extruded composite flour varied between 3.0-3.7, 3.6-3.8, 3.5-3.8, 3.4-3.8, 3.6-4.0, and 3.6-4.0 respectively. The models described changes in organoleptic attributes of the gruel samples as functions of blending ratio ($p<0.05$; $R^2 > 81.9\%$) except for mouthfeel. However, there was no significant relationship between blending ratio and mouthfeel (Table 6-3).

6.5 Discussion

The crude protein content was positively influenced by oats, soybean and linseed blending ratio (Figure 6-1a). The highest protein content at the largest percentage of soy in the blend might be due to the high protein contents of soybean. An increase in protein content of foods with increased soybean supplement level has been reported by others (Gebretsadikan et al., 2015). The blending of cereal-based foods with legumes improves the protein content of flour samples (Hotz & Gibson, 2007).

The fat content increased consistently with increasing soybean and linseed proportions and decreased with an increased proportion of oats flour in the blend (Figure 6-1b). Another study has also reported that addition of soy flour increased the fat content of wheat flour (Ndife, Abdulraheem, & Zakari, 2011). The fat content of wheat-based cookies enriched with roasted linseed flour rose by 33.7% as compared with the control (only wheat cookies). This increase could be accounted by the fact that linseed is far higher in fat, compared to refined wheat flour (Ganorkar & Jain, 2014).

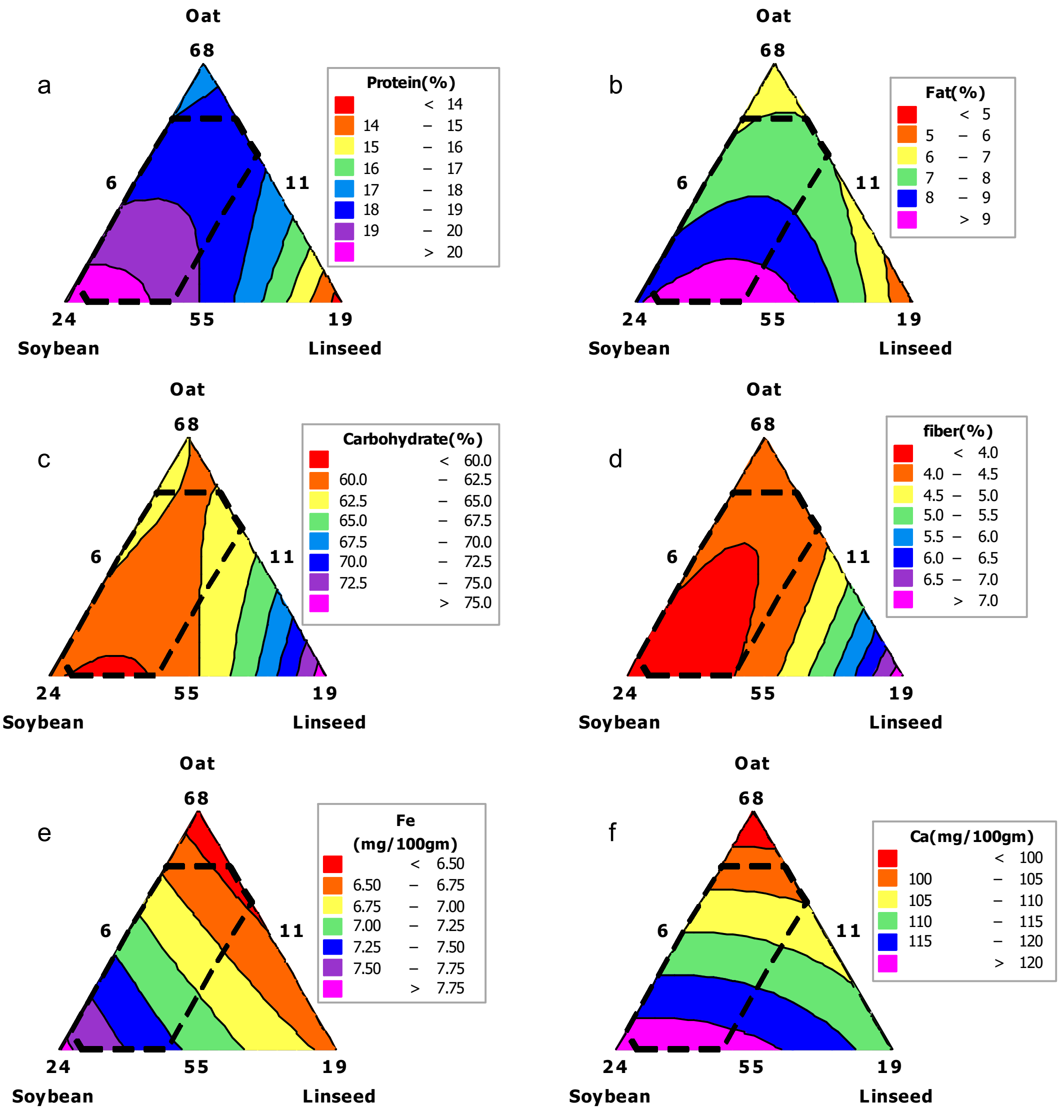

Figure 6-1 Contour plots displaying nutrient compositions of complementary foods made of composite extruded flour: A) protein (%), B) fat (%), C) carbohydrate (%), D) fibre (%), E) iron (mg/100g) and F) calcium (mg/100g) content.

The total carbohydrate content decreased significantly with a reduction in oats supplement levels (Figure 6-1c). This fall could be because cereals like oats are rich in sugar contents than pulses and oilseeds (Okoye, Nkwocha, & Ogbonnaya, 2008).

In a similar trend, contour plot for fibre content (Figure 6-1d) showed an increased fibre content of formulation as oats and linseed flour increases is related to the high fibre contents of oats and linseed. The fibre contents of soybean might be reduced due to husk removal during sample preparation. Dehulling removes the hulls, which contain much fibre (Kikafunda, Abenakyo, & Lukwago, 2006).

Ash content increased significantly with increase in soybean supplement level and decreased with increase in the ratio of oats and linseed flour in the formulation. A similar result where ash contents of blended products increased as the proportion of soybean flour increased has been reported (Okoye et al., 2008). On the contrary ash content of wheat flour was increased by the incorporation of oilseed meal (Jan, Sattar, Mehmood, & Ali, 2000).

Energy content was not significantly affected by the blending ratio. However, the contour plot shows that as the proportion of soybean and linseed increases in the blend the energy density of the extruded composite flour has also increased. This rise could be due to high-fat content in soybean and linseed which contributes to high calories, as fat provides two times more energy per unit of mass than carbohydrates and proteins (Souci et al., 2008).

Moisture content was also not significantly affected by the blending ratio. Nevertheless, moisture content tends to decrease with a decrease in oats supplement levels. The moisture content of the flour samples was small (3.2-5.6 g/100g) which is an advantage from nutrient density as well as stability points of view.

The iron content of the blend was directly associated with the soybean supplement levels (Figure 6-1e). Similarly, other researchers also reported that higher level of soy in composite flour is associated with higher level of iron (Bolarinwa, Olaniyan, Adebayo, & Ademola, 2015). Another study also indicated that iron content increased with an increase in soybean and moringa proportions in formulations (Gebretsadikan et al., 2015).

Gruel's calcium content increased significantly with increase in both soybean and linseed supplement levels (Figure 6-1f). An increase in Ca content of composites with an increase in soybean supplementation was also reported by others (Bolarinwa et al., 2015). Oilseed flours also contain an appreciable quantity of minerals and upon addition can increase in the mineral contents of blends (Jan et al., 2000). Additionally, moringa is also rich in calcium contents of the formulation (Gebretsadikan et al., 2015).

This study showed that the blending ratio did not positively influence zinc content of the formulations. On the contrary, studies reported that zinc content of composite flour could be increased by increasing the soybean supplement level (Bolarinwa et al., 2015) and incorporation of moringa into composite flour mixes can enhance their zinc contents (Gebretsadikan et al., 2015).

The high ß-carotene content of the extruded infant composite flour could be associated with the 3% moringa added in the formulation. Other researchers have also reported that ß-carotene content increased significantly with increase in moringa leaf powder which is due to the much higher level of ß-carotene in moringa leaf powder as compared to wheat flour (Sengev, Abu, & Gernah, 2013). Moringa has demonstrated the potential for improving the vitamin A content (Thurber & Fahey, 2009).

Appearance liking of the gruel increased with an increase in oats proportion in the formulation, but the increment in soybean and linseed proportion decreased the appearance score of the gruel (Figure 6-2a). Appearance is one of the organoleptic attributes that evokes the initial response of panellist. Vision plays a significant role in the sensory analysis, and the appearance of food can have a significant effect on its acceptability (Tizazu, Urga, Abuye, & Retta, 2010b). The probable reason for the low score of appearance at the high percentage of linseed could be due to pigments such as leutin/zeaxanthin in linseed which contribute to its dark brown colour and the associated further browning when cooked at high temperatures. The darker tone may also be due to Maillard reaction between reducing sugar and protein in soybean and linseed (Borrelli et al., 2003). Additionally, the presence of moringa affects the appearance of the gruel due to its green colour (chlorophyll contents of Moringa leaves) (Gebretsadikan et al., 2015).

The aroma score of the gruel increased with an increase in soybean and linseed proportion in the blend, and the lowest aroma score was recorded at the increased proportion of oats (Figure 6-2b). The high preference of the aroma attributes at high soybean and linseed ratios may be due to flavour imparted by soybean and linseed upon heating during extrusion cooking. This result is in agreement with (Ojinnaka, Ebinyasi, Ihemeje, & Okorie, 2013) who reported that the increase in aroma ratings could be attributed to flavour imparted by the oils in soybean. Dextrinization and starch breakdown take place during the extrusion process thereby enhancing the acceptability of gruel prepared from extruded flour (Mensah & Tomkins, 2003).

Taste liking was positively influenced by oats, soybean and linseed blending ratio (Figure 6-2c). Mainly, oats are a contributor towards high taste ranking. Beany taste of soy (related to lipoxygenases) and big nutty flavour imparted by linseed increase with an increase in supplement levels of these ingredients, which in turn significantly reduces the taste liking of products (Bott & Chambers, 2006).

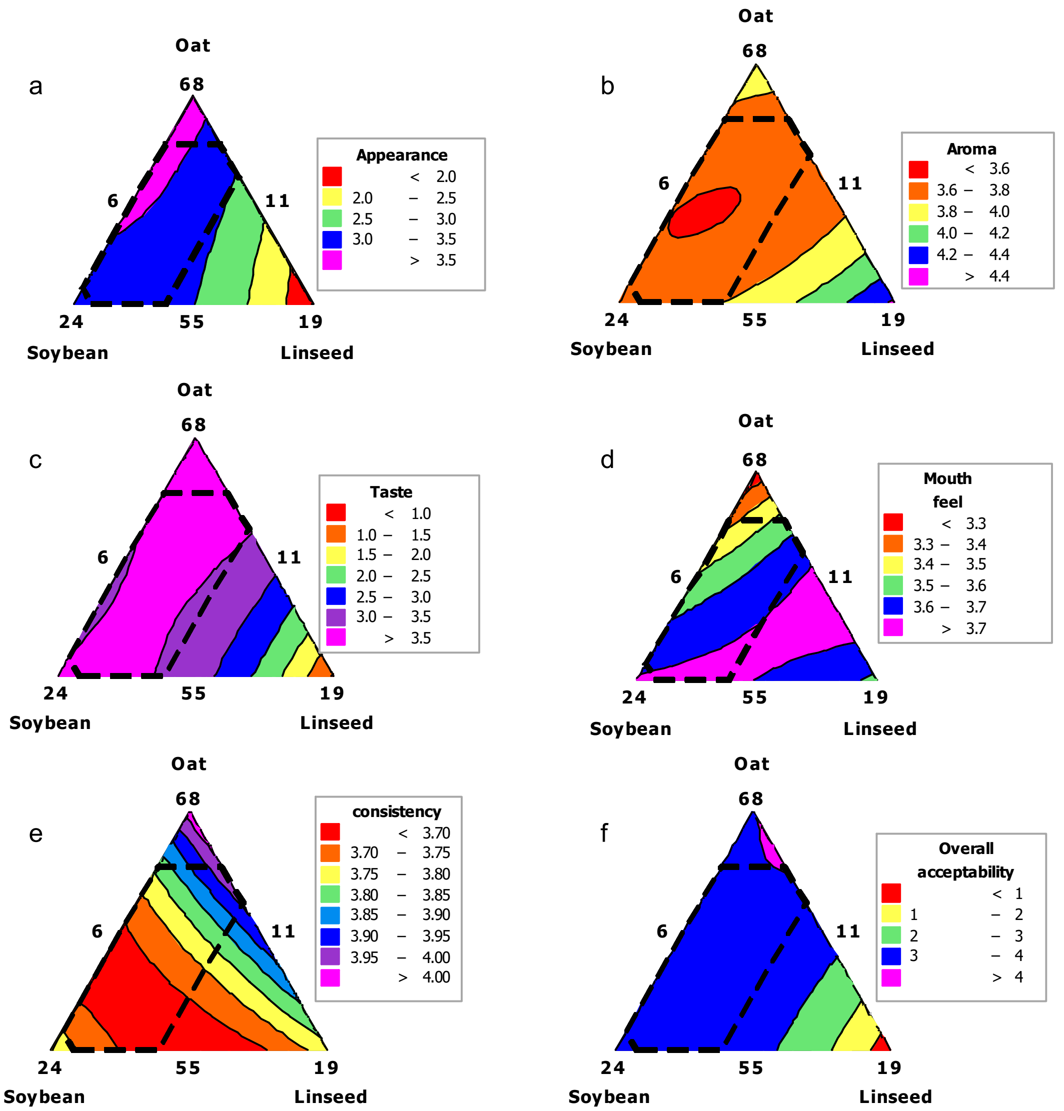

Figure 6-2 Contour plots displaying sensory attributes of complementary foods made of composite extruded flour: A) appearance, B) aroma, C) taste, D) mouth-feel, E) consistency and F) overall acceptability.

The mouthfeel score of the gruels was not significantly affected by the blending ratio. However, the contour plot shows mouthfeel score of the gruel decreased with increasing proportion of oats and linseed whereas increased with increasing percentage of soybean in the blend (Figure 6-2d).

Higher oats and linseed supplement levels resulted in more top ranking for consistency whereas increasing the proportion of soy flour decreased the sensory acceptance for consistency of the gruel (Figure 6-2e). Consistency is a major factor determining the volume and energy density of starch-based diets. Protein and protein-carbohydrate interactions were reported to influence gruel consistency, with soy protein significantly increasing viscosity. A study has shown exchanging fat for wheat flour considerably lowered the viscosity (dietary bulk), as did extrusion. As small children may have difficulty eating sufficient quantities of low nutrient density, starchy complementary foods to satisfy their nutrient needs, cereal products for preschool-age children should be formulated with desirable viscosity properties (Hellstrom et al., 1981).

The highest overall acceptability score was recorded for blends with 65 g/100g oats, 11 g/100g soybeans and nine g/100g linseeds. Gruel samples containing higher oats supplement levels were ranked higher for overall acceptability (Figure 6-2f).

Untrained panels performed the sensory analysis, and we could only get 25 volunteer panellists, which might affect the quality of the data. Having fewer testers could be considered as a limitation of the study.

The superimposed contour plots are presented in Figure 6-3, and the white area in each plot shows the "sweet spot" where blending ratio of ingredients results in an optimal response. Figure 6-3a shows the blending ratio of 56.2 g/100g oats, 21.6 g/100g soybeans and 7.3 g/100g linseeds gave an optimal compositional quality. The optimal blending ratio yielded 20.2g/100g protein, 403.6 kcal/100g energy and 3.0 mg/100g zinc. The sweet spot is close to the corner where soybean concentration was higher indicating higher soybean supplement level was associated with better nutrient composition.

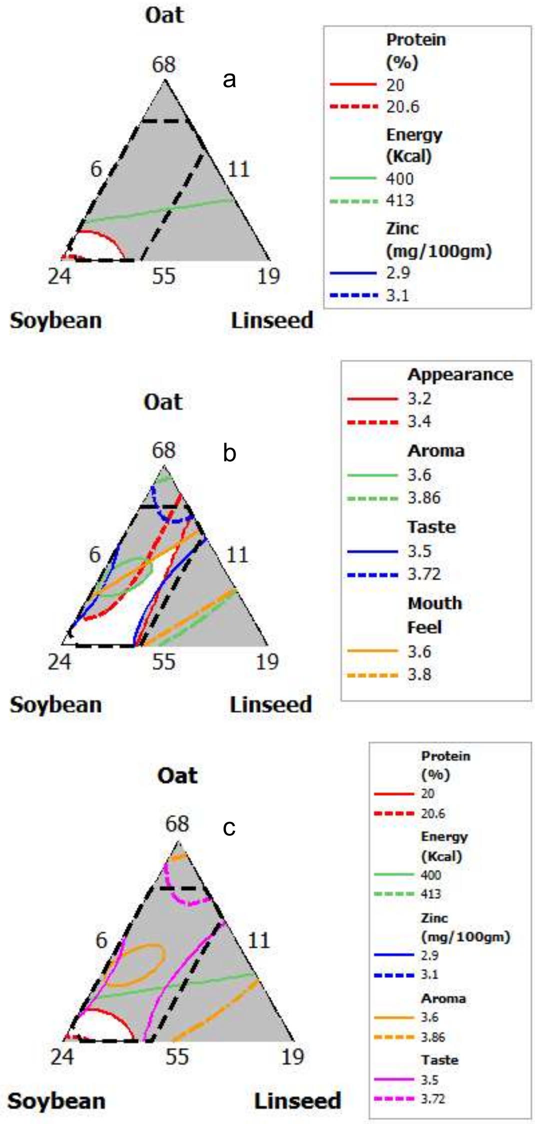

Figure 6-3 Superimposed contour plots displaying 'sweet spot' for A) nutrients, B) sensory attributes and C) nutrients and sensory attributes combined.

Based on the goal of maximising the ranking of sensory responses, the formulation with 56.0 g/100g oats, 21.7 g/100g soybeans and 7.4 g/100g linseeds gave scores of 3.4 for appearance, 3.6 for taste and 3.7 for mouthfeel (Figure 6-3b).

Overall optimisation of both nutritional and sensory qualities showed that blend ratio of 55.0 g/100g oats, 21.0 g/100g soybean and 9.0 g/100g linseed gave optimal compositions of 19.8g/100g protein, 402.5 kcal/100g energy, 1716.3 µg/100g ß-carotene, 7.4 mg/100g iron and

3.8 overall sensory acceptability (Figure 6-3c). The response optimiser also showed that the goals we defined for the responses were well achievable at the individual response level as indicated by desirability values ranging from 0.9904 to 1 and at the overall responses level as can be seen from the composite desirability value of 0.9992 (Table 6-4).

Table 6-4 Target goals for responses as defined by researchers and feasibility

Name	Goal	Lower	Target	Upper	Y	Desirability
A: Oats		55		65	55	
B: Soybean		19		23	21	
C: Linseed		7		11	9	
Moisture	Minimize		4	5	3.3021	1
Protein	Maximize	20	20.3		20.3047	1
Fat	Maximize	9.6	9.7		9.7623	1
Fibre	Minimize		3.75	3.8	3.7502	0.99604
Ash	Maximize	2.5	3.24		3.2466	1
Carbohydrate	Minimize		59.4	60	59.4058	0.9904
Energy	Maximize	400	406.5		406.5443	1
Beta Carotene	Maximize	1740	1740.2		1740.2003	1
Calcium	Maximize	123	123.1		123.1519	1
Iron	Maximize	7.5	7.51		7.5174	1
Zinc	Maximize	2.9	3		3.0026	1
Appearance	Maximize	3.2	3.3		3.3046	1
Aroma	Maximize	3.6	3.73		3.7363	1
Taste	Maximize	3.5	3.61		3.6181	1
Mouth Feel	Maximize	3.6	3.7		3.7455	1
Consistency	Maximize	3.6	3.7		3.7037	1
Overall Acceptability	Maximize	3.6	3.7		3.7322	1
Composite desirability						0.9992

6.6 Conclusions

Reasonable selection of locally grown raw materials, an optimal blending of these ingredients and optimal processing can result in nutritious and acceptable complementary food product which can contribute to the fight against child undernutrition in low-income settings. Small and medium enterprises in the food sector locally known in Ethiopia as *baltina* can make better use of these findings. We anticipate that incorporation of dried fruits and vegetables in the current product will result in products with distinct appearance and flavour.

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7 Storage Stability and Shelf Life of Extruded Composite Baby Food Flour

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7.1 Abstract

An optimum storage condition is essential for extending shelf life and maintaining the quality of flour and other processed food products. The objective of this study was to assess the storability of extruded composite flour. Extruded composite flour of oat, soybean, linseed and premix (sugar, salt, Moringa & fenugreek) were produced using a twin-screw extruder. The shelf life of the extruded composite flour packed in different packages (paper, polyethene and polypropylene) and stored under different temperatures (-18, 25, 35, 45°C) was comparatively studied. Changes in moisture content, water activity, bulk density and fat content were measured fortnightly for three months. Analysis of variance at 95% confidence limit showed significant differences between the observed samples. There was a significant ($p<0.05$) interaction between the storage temperature, packaging material and duration of storage under study in affecting moisture content, water activity, fat content and bulk density of the extruded composite flour samples. The shelf life of the samples packed in polypropylene was ten months and while those packed in polyethene was 17 months when stored at 25°C. However, the shelf life of products held under accelerated storage condition (45°C) was 6.2 months in polypropylene and 8.3 months in polyethene. From the results, it can be concluded that the flour samples were stable during the storage, with a shelf life of up to 17 months at 25°C, which can help in successful marketing and distribution of the extruded composite flour in Ethiopia.

7.2 Introduction

Fortification of cereal flours with nutrient-rich ingredients to improve nutritional, functional and sensory attributes has been well documented. Incorporation of protein-rich ingredients like legume flour improves not only protein quality but also sensory characteristics in the final product (Sharma, Punia, & Khetarpaul, 2013). Similarly, incorporation of functional ingredients like oilseed flours into cereal-based products provide an appreciable amount of bioactive compounds such as dietary fibre and linolenic acid (Moraes et al., 2010). The use of composite flour has been encouraged in some countries since it also reduces the importation of cereals (Omeire, Umeji, & Obasi, 2014). Generally, products with improved nutrient content and acceptable sensory attributes can be produced from cereal-pulse-oilseed composite flour.

Extrusion of composite flour to produce different high-value products is also reported. Extrusion is a high temperature/short time process for making food products, usually from cereals (Pérez-Navarrete, González, Chel-Guerrero, & Betancur-Ancona, 2006). Other ingredients like starches, pulses and vegetable proteins are also commonly used. These ingredients provide significant functions like structure, texture, bulk, mouthfeel and many other characteristics desired for the final products (Wani, Solanke, & Kumar, 2015). Extruded composite flour can be potentially used for making different types of food products like snacks, noodles and infant foods (Mouquet et al., 2003; Omeire et al., 2014; Wani et al., 2015).

Flour's storability and shelf life depend on several factors. Intrinsic factors like water content and composition, and extrinsic factors such as temperature, package, gases or vapours affect physical, chemical, and biochemical changes in stored flour (Li, Ma, Zhu, Guo, & Zhou, 2017). For composite extruded products, not only the level of fortification but also moisture gain, water activity and lipid oxidation can influence the quality characteristics during storage (Shaviklo, Azaribeh, Moradi, & Zangeneh, 2015). Generally, the stability of a food product is a function of the processing techniques and storage conditions (Li et al., 2017).

Temperature and type of packaging materials are important factors in controlling flour deterioration. Regulation of these parameters is crucial for extending the shelf-life of fresh flour (Li et al., 2017). To realise the full potential of flour in food processing, either alone or in combination with other raw materials, knowledge of the effects of package types and storage conditions on quality and shelf-life stability of flour is essential.

In our previous work (Forsido, Tesfaye, Belachew, Sturm, & Hensel, 2018), extruded composite flour based on a mixture of 55.0 g/100g oats, 21.0 g/100g soybean and 9.0 g/100g linseed and 15 g/100g premixes of fenugreek, moringa, sugar and salt was developed with optimal nutrient content and sensory properties. The objective of this study is to investigate the changes in physical and chemical properties of this extruded composite baby food flour that occur during storage under varying temperature and packaging conditions.

7.3 Materials and methods

7.3.1 Sample preparation

The ingredients used in this study included Oats (*Sinana One*), Soybean (*Clark 63K*), Linseed (*Kulumsa One*) and a premix *of Moringa stenopetala*, fenugreek (*Chala)*, iodised salt and sugar. The choice of ingredients and preparation methods are discussed in a previous study (Forsido et al., 2018).

7.3.2 Storage stability tests

The flour samples (250 g) were packed in paper, polyethene and polypropylene bags of 20 cm by 25.5 cm. The samples were incubated at four different temperatures: -18^{o}C (deep freezer, Ugur, UCF 600 S), 25^{o}C (room), 35^{o}C (growth cabinet, RGX 250), and 45^{o}C (incubator, MJX 150 B) for three months. Samples were removed at fifteen-day intervals and analysed for change in quality. The different rates of deterioration occurring in the sealed samples at the different temperatures were used in calculating the shelf life of the products according to the method of (Labuza, 1979). The crude fat content was used as the index for deterioration and shelf life estimation. The Arrhenius plots (log k vs 1/T) were used to obtain the activation energies, Ea, from which the Q_{10} values were calculated and used to predict the shelf life at lower temperatures (Plahar, Okezie, & Annan, 2003).

7.3.3 Experimental design and treatments

This experiment was laid out in a completely randomised design (CRD) with three factors in three replications. The three factors used in this experiment were storage temperature, packaging materials and storage time. Three levels for packaging materials (paper bag, polyethene bags and polypropylene), four levels of storage temperature (-18, 25, 35 and 45^{o}C) and seven levels of time (0, 15, 30, 45, 60, 75 and 90 days) were combined in a factorial arrangement.

7.3.4 Measurements

The flour samples were evaluated for water activity, bulk density, moisture content and fat content. Data were collected every two weeks for all samples. To measure the water activity (aW) of the stored flour, the sample cups of water activity meter (LabMaster) were half-filled with 5g flour to ensure the accuracy of the result, and to avoid flour from covering the instrument sensor. The water activity meter was positioned over the cups, and a_w level was measured within 5 min. The a_w of powder was determined at a constant temperature of 21°C (Rhim & Hong, 2011).

To measure the bulk density of the flour samples, fifty grams of flour was put into a 100 ml measuring cylinder and tapped to a constant volume, and the bulk density (gcm^{-3}) was calculated by dividing the weight of flour (g) to flour volume (cm^3) (Okaka & Potter, 1979). Whereas, moisture content was determined following the Association of Official Analytical Chemists (AOAC) method 925.10 (AOAC International, 2005). On the other hand, the crude fat content was determined on dry matter basis following the Association of Official Analytical Chemists (AOAC) method 920.39 (AOAC International, 2005).

7.3.5 Statistical analysis

The effect of packaging materials (categoric), storage temperature (numeric) and storage time (numeric) on a_w, bulk density, moisture content and fat content of extruded composite flour were determined using analysis of variance (ANOVA) at the 5% level of significance. The validity of model assumptions, namely normal distribution and constant variance of error terms were verified for each response, by examining the residuals (Montgomery, 2013). Minitab®, Version 16 software package was used for data analysis.

7.4 Results

ANOVA result showed that moisture content and a_w of the flour was significantly affected by the three-way interaction between storage temperature, packaging material and storage duration. Only a_w was affected considerably by the two-way interaction of storage temperature and packaging material. On the contrary, all response variables were significantly affected by the two-way interaction of storage temperature and storage duration (Table 7-1). The interaction effect of packaging material and storage time was also significant on moisture content, a_w and fat content of the stored flour samples. The main effects of all factors did significantly affect all measured responses of the stored samples.

Table 7-1 A factorial design with two numeric and one categorical factor: ANOVA p-values for main effects, two-way interactions and three-way interaction of storage temperature (A), packaging material (B) and storage duration (C) on chemical and physical properties of extruded composite flour.

Term	Moisture (g/100g)	a_w	Fat (g/100g)	BD (g/ml)
A	0	0	0	0
B	0	0	0	0
C	0	0	0	0
A*B	0.296	0	0.197	0.503
A*C	0.003	0	0	0
B*C	0	0	0	0.037
A*B*C	0.009	0	0.912	0.625
Predicted R-Sq	0.9667	0.9633	0.9899	0.9304
Adjusted R-Sq	0.9502	0.945	0.9877	0.896

7.4.1 Moisture content

Figure 7-1 shows that throughout the storage period, the flour contained more moisture at low temperature (-18°C) than at high temperature (45°C). Up to the 75th day of storage, no significant changes were detected in moisture content. However, on the 90th day, there was a sharp increase in moisture content of the flour samples stored at different temperatures and in all the three packaging materials. The highest moisture content was recorded on the 90th day of storage for flour stored in polypropylene bag at -18°C.

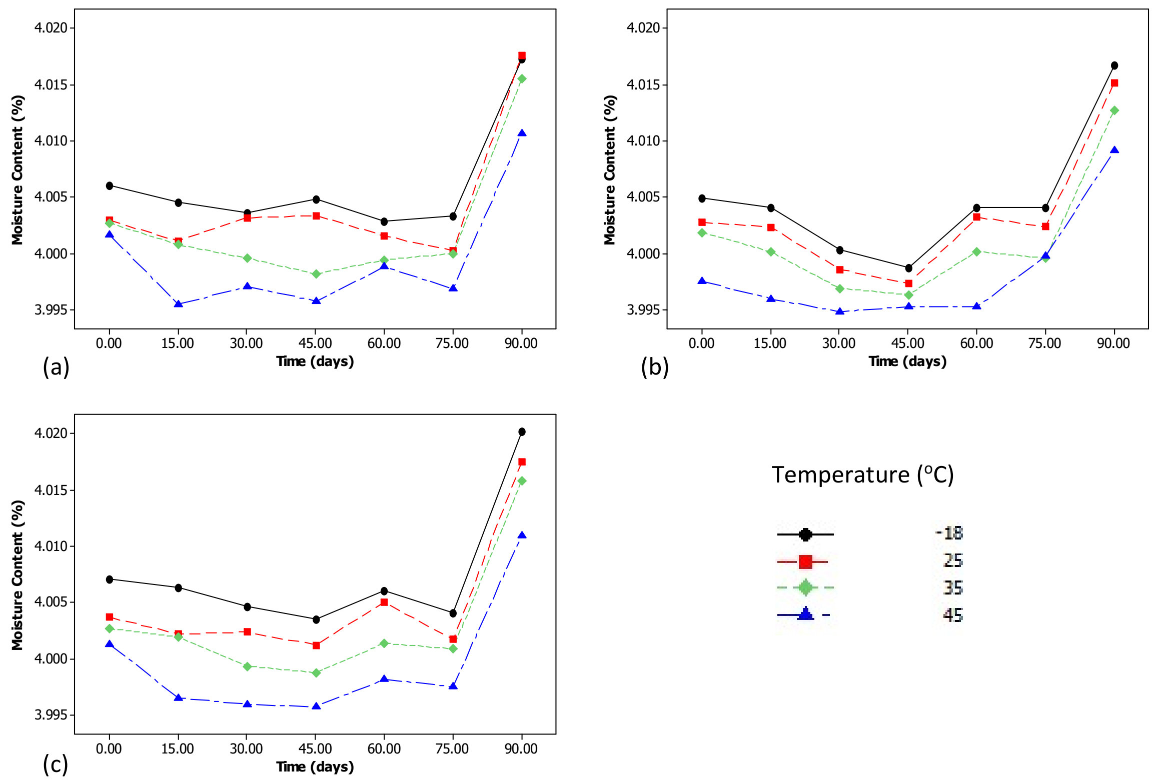

Figure 7-1 Moisture content of extruded composite flour stored at -18°C (black circle), 25°C (red square), 35°C (green lozenge) and 45°C (blue triangle) packed in (a) paper, (b) polyethylene and (c) polypropylene bags.

7.4.2 Water activity

Water activity profiles of the stored extruded composite flour samples are shown in Figure 7-2. Flour stored at ambient condition (25°C) showed more inconsistent a_w values as compared with other temperatures in all the three packaging materials. Powder stored at 35°C, on the other hand, remained constant in all the three packaging materials. Flour samples stored at 45°C had the lowest a_w for all the three packaging materials. At 45°C, the a_w decreased sharply during the first 15 days and then remained constant at around a_w of 0.2.

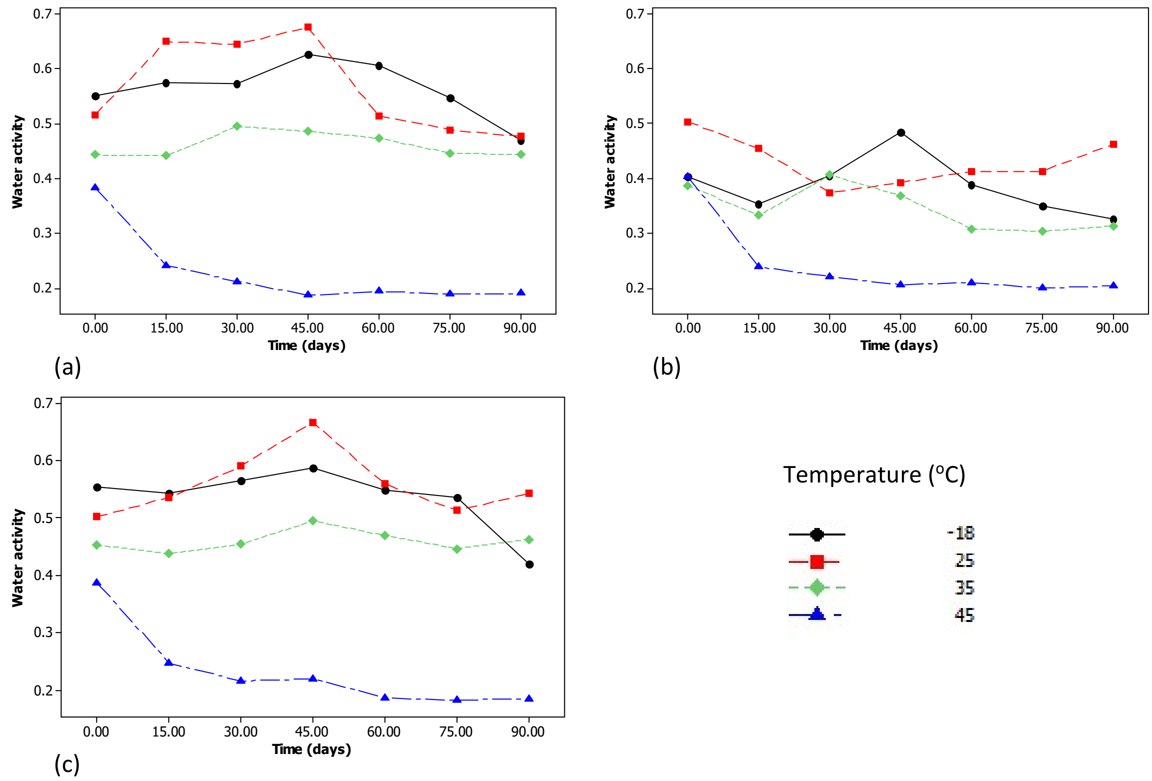

Figure 7-2 Water activity of extruded composite flour stored at -18°C (black circle), 25°C (red square), 35°C (green lozenge) and 45°C (blue triangle) packed in (a) paper, (b) polyethylene and (c) polypropylene bags.

7.4.3 Bulk density

As shown in Figure 7-3, the bulk density of the stored flour decreased significantly with storage time, and the decline was more prominent at 45°C. On the other hand, flour samples stored at -18°C showed consistently higher bulk density values throughout the storage period. Flour samples packed in polypropylene bags and for a more extended period had the lowest bulk density values.

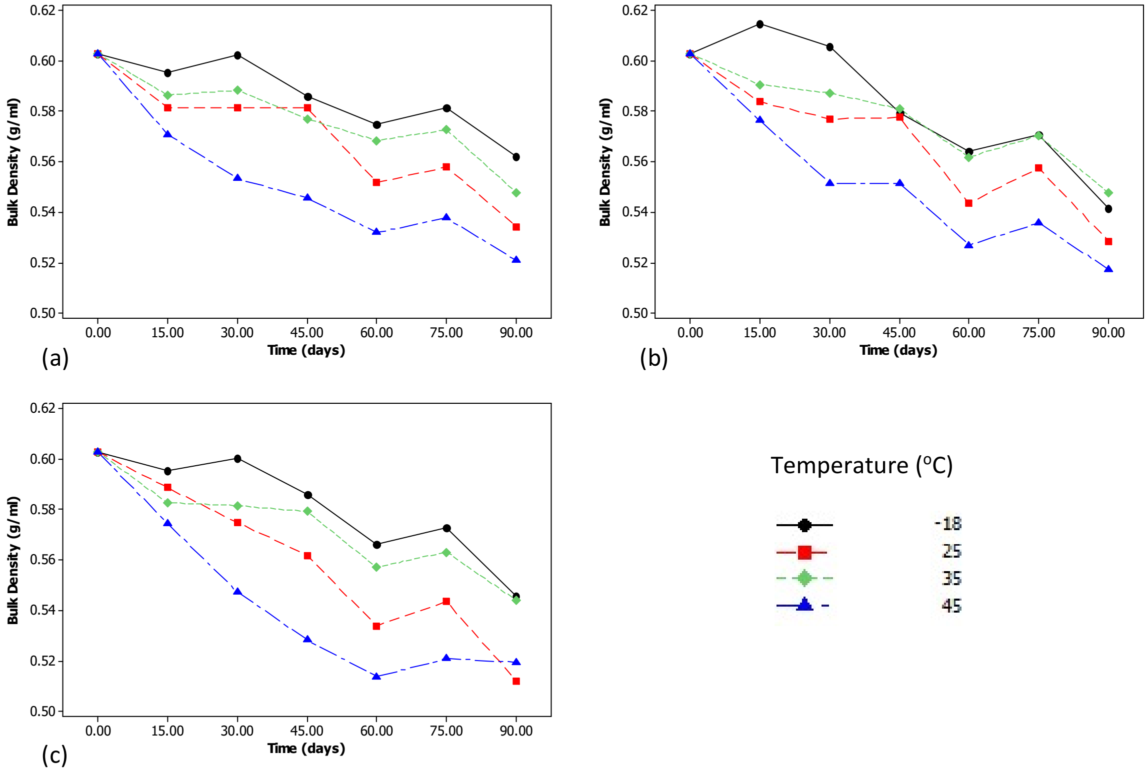

Figure 7-3 Bulk density of extruded composite flour stored at -18°C (black circle), 25°C (red square), 35°C (green lozenge) and 45°C (blue triangle) packed in (a) paper, (b) polyethylene and (c) polypropylene bags.

7.4.4 Crude fat content

A significant decrease in fat content was observed for samples stored for a longer duration (Figure 7-4). Fat content decreased by 0.8% between day 0 and day 90. Flour samples packed in polypropylene bags exhibited the highest decline in fat content with storage duration. Flour samples stored at 45°C also showed a similarly sharp drop in fat content with storage duration. The changes in the fat content of extruded composite flour samples stored at -18°C and 25°C followed a more or less similar trend.

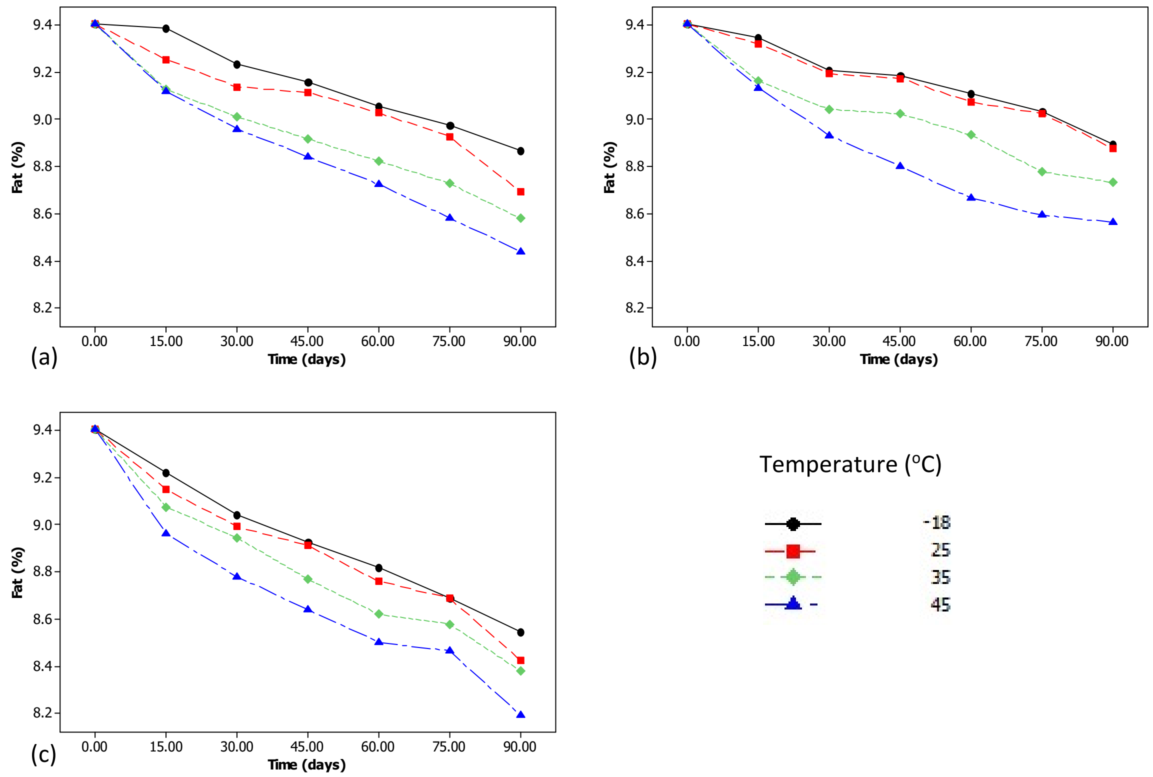

Figure 7-4 Fat content of extruded composite flour stored at -18°C (black circle), 25°C (red square), 35°C (green lozenge) and 45°C (blue triangle) packed in (a) paper, (b) polyethylene and (c) polypropylene bags.

7.4.5 Storage stability of extruded composite flour

In the accelerated storage tests, change in crude fat content was used as an index of storage stability of the extruded composite flour samples. The changes in fat content samples packed in different packaging materials during storage at different temperatures are shown in Table 7-2. The reduction rate of fat content was found to follow zero order kinetics at all temperatures used in the study. A faster rate of deterioration, regarding reduction in fat content, was observed in flour samples stored in polypropylene bags than in paper or polyethene bags.

Table 7-2 Change in the fat content of extruded composite flour samples packed in paper, polyethene and polypropylene bags during accelerated storage tests at different temperatures.

Storage period	Paper			Polyethene			Polypropylene		
(Days)	25°C	35°C	45°C	25°C	35°C	45°C	25°C	35°C	45°C
0	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4
15	9.25	9.13	9.12	9.32	9.16	9.13	9.15	9.08	8.96
30	9.14	9.01	8.96	9.19	9.04	8.93	8.99	8.94	8.78
45	9.12	8.92	8.84	9.17	9.02	8.8	8.91	8.77	8.64
60	9.03	8.82	8.72	9.07	8.93	8.67	8.76	8.62	8.5
75	8.93	8.73	8.58	9.03	8.78	8.59	8.69	8.58	8.46
90	8.69	8.58	8.44	8.88	8.73	8.56	8.42	8.38	8.19
Rate/day	0.0079	0.0091	0.0107	0.0058	0.0074	0.0093	0.0109	0.0113	0.0134
End-point value	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
Shelf life (days)	316.9	274.39	234.38	432.69	335.82	267.86	229.59	220.59	185.95
Ea. (cals/mole)		3152.48			4448.06			3317.58	
Q_{10} value		1.25			1.38			1.27	

The daily rate of fat loss for flour sample packed in paper bags was 0.0079% at 25°C, 0.0091% at 35°C, and 0.0107% at 45°C. The polyethene packed flour had 0.0058, 0.0074, and 0.0093% daily rates of fat loss at 25, 35 and 45°C, respectively. On the other hand, flour samples packed in polypropylene bags had 0.0109, 0.0113 and 0.0134% daily rate of fat loss at 25, 35 and 45°C, respectively. The end-point values for the unacceptability of fat degradation were fixed at 6.9 g/100g, which is equal to the average fat content of oats (Souci et al., 2008). The end-point data were transformed into shelf life plots on a semi-log scale from which the shelf life of the extruded composite flour at different temperatures could be obtained.

Based on the fat loss, the calculated Q_{10} values were 1.25, 1.38 and 1.27 for the paper, polyethene and polypropylene packed flour samples, respectively. The predicted shelf life of the products at the different temperatures based on the calculated Q_{10} values are given in Table 7-3. The extruded composite flour samples which were packed in polypropylene bags were found to have a significantly shorter shelf life than the samples packed in paper or polyethene bags at the average ambient temperature of about 25°C in Ethiopia. The estimated shelf life of 12.2, 17.0

and 10.0 months is expected for the paper, polyethene and polypropylene packed flour samples, respectively.

Table 7-3 The predicted shelf life of extruded composite flour samples at given temperatures based on the Q_{10}

	Predicted shelf life (months)		
Temperature (°C)	Paper (Q_{10} = 1.25)	Polyethene (Q_{10} = 1.38)	Polypropylene (Q_{10} = 1.27)
45	7.81	8.93	6.20
35	9.77	12.32	7.87
25	12.21	17.00	10.00
15	15.26	23.46	12.70
5	19.07	32.38	16.12

7.5 Discussion

7.5.1 Moisture content

Moisture content is a significant quality parameter for practically every food product, as well as for its ingredients. It plays a very important role in quality and especially on the shelf life of almost every food product and material (Li et al., 2017). Flour is a moisture-sensitive product, and it may absorb moisture during long-term storage, as the commonly used packaging materials are permeable to moisture (Sakač et al., 2016). On the other hand, low moisture content in flour is essential during storage because it favours shelf life stability of flour (Eleazu, Eleazu, Awa, & Chukwuma, 2012). Increase in moisture content can enhance the activities of microorganisms which can lead to deterioration of flour.

This result is supported by Hruškova & Machova (2002) who reported that wheat flour packaged in a hessian bag and polyethene bags increased from 9.3% to 10.73% and 9.7% respectively after three months of storage, and the moisture content of the control samples also rose to 11.2%. The increase in moisture content in the flour was probably due to the hygroscopic nature of flour and a concurrent rise in relative humidity of the air during the moisture measurement.

7.5.2 Water activity

Concerning food quality control and shelf life extension it is essential to be aware that it is much better and far more meaningful to speak of a_w and not just of water content (Li et al., 2017).

Water activity is closely related to the physical, microbial and chemical properties of flour (Maltini, Torreggiani, Venir, & Bertolo, 2003). Changes in a_w during storage could probably lead to textural changes in the stored product. Products which are characterised by lower a_w values than those that permit the growth of microorganisms ($aw > 0.6$) are known for their long shelf life (Sakač et al., 2016). Low a_w is recommended for flour storage. Care should be taken not to store flour samples in conditions that increase a_w for this could predispose flour to biochemical changes leading to irreversible organoleptic changes (Abdullah, Nawawi, & Othman, 2000).

7.5.3 Bulk density

Bulk density, which measures the density of a material, is a valuable physical property when a material is going to be produced on a large scale (Wani et al., 2015). Particle size and the density of the flour are important factors affecting the bulk density. The packaging requirement and material handling of flour are determined mainly by its bulk density (Adebowale, Adegoke, Sanni, Adegunwa, & Fetuga, 2012). The lower loose bulk density implies that less quantity of the food samples would be packaged in constant volume thereby ensuring an economical packaging. Nutritionally, loose bulk density promotes easy digestibility of food products, particularly among children with an immature digestive system (Ijarotim & Keshinro, 2012; Omeire et al., 2014).

7.5.4 Crude fat content

There was a progressive decrease in the fat contents of the samples with time more under accelerated conditions than ambient conditions. The low-fat values were observed in the more extended stored flours relative to short stored powders. Lipid oxidation occurs through the action of lipase enzymes. Lipolysis produces a rancid taste, and it generally begins when the grains are milled, although it may also start after the dehulling (Londono, Smulders, Visser, Gilissen, & Hamer, 2015). Extrusion-inactivation of lipase and lipoxidase helps protect against oxidation during storage (Cheftel, 1986).

7.5.5 Storage stability

The present study showed that packaging and storage temperature, as well as storage period, were an essential factor to be considered in establishing the shelf life stability of composite extruded flour. The more extended shelf life of the extruded product in atmospheric condition than in accelerated condition may be due to lower temperature and barrier properties of the packages. It can also be observed that shelf life of the extruded product packed in polyethene was higher than in case of paper and polypropylene which may be correlated to the more elevated oxygen transmission rate of the polypropylene bags.

7.6 Conclusions

Physicochemical changes in extruded composite flour packed in different packaging materials and stored at different temperatures were evaluated in this study. It was found that storage temperature, packaging material and storage duration induced a more significant impact on bulk density and fat content compared with moisture content and water activity of the extruded composite flour samples. The flour samples have excellent stability with predicted shelf life periods of up to 17.0 months when stored at the average ambient temperature of about 25°C. In general, packing the flour samples in polypropylene bags was found to reduce the quality characteristics of the extruded composite flour. Overall, the results of this study signify that under normal temperature circumstances (25°C), selection of appropriate packaging material has an excellent effect in maintaining physical and chemical quality and combating spoilage of extruded composite flour.

7.7 Acknowledgements

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8 Effect of fermentation and malt addition on physicochemical and sensory properties of complementary foods prepared from selected starchy staples

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8.1 Abstract

Several modification techniques can improve properties of starchy foods. The objective of this study was to assess the effects of fermentation duration and malt concentration on physicochemical and sensory properties of starchy cereals commonly used for making complementary foods in Southwest Ethiopia. Three fermentation times (0, 24 and 48 hours), three malt concentrations (0, 2 and 5%) and three cereal flour types (oats, barley and teff) were combined in a factorial arrangement. The samples were analysed for proximate and anti-nutritional factors compositions and physical and sensory properties. Treatments were compared using analysis of variance and Tukey's studentized range test, at 5% level of significance. Interaction of fermentation duration and malt concentration resulted in a significant ($p<0.01$) reduction in crude fibre, crude fat, total carbohydrate, phytate, tannin, bulk density and viscosity in the three kinds of cereals. On the contrary, crude protein and calorific value were significantly ($p<0.01$) increased by the interaction effect. Ash and mineral contents were not affected. Addition of 5% malt and fermentation for 24 hours appear to have a likely synergistic effect in improving chemical, physical and sensory qualities of starchy staples. The increase in energy density and reduction dietary bulkiness and viscosity of complementary foods will increase food intake by infants. Further research on storability of these products is recommended.

8.2 Introduction

Malnutrition during childhood is a significant public health problem in low-income countries and mostly begins after the exclusive breastfeeding period (Faruque et al., 2008). Once a baby reaches the six months old mark, his or her nutritional requirement cannot be met by breast milk alone (Adenuga, 2010). Complementary foods should be introduced to the baby to provide nutrients (Nandutu & Howell, 2009).

Complementary foods in the Eastern and Southern African region are characterised by low nutrient density (Badau, Jideani, & Nkama, 2005). The high rates of malnutrition reported in cereal-consuming areas of Africa are partly associated with the bulkiness and high viscosity of the cereal-based diets. As a result, mothers commonly dilute the porridge with water to reduce its viscosity (Bukusuba, Muranga, & Nampala, 2008). Since young children have small gastric capacities, they are unable to consume enough of the diluted porridge to meet their nutrient and energy requirements and consequently become malnourished (Ramakrishna, Rani, & Rao, 2006).

Several techniques are available to reduce dietary bulk and increase nutrient density. One of such techniques is fermentation. Natural fermentation which is applied in traditional African food preparations is an effective method of improving the protein and complex carbohydrate digestibility of cooked cereals (Chavan, Chavan, & Kadam, 1988). The acidic pH of fermented foods make them microbiologically safe and storable (Khetarpaul & Chauhan, 2007). Another technique is the addition of malt to starchy flours used for making complementary foods. Malt is rich in the enzyme alpha-amylase which hydrolyses large polysaccharides like starch to glucose and maltose improving digestibility. The addition of amylase-rich flour also dramatically reduces the viscosity and bulk density of complementary foods, changing it to nutrient dense liquefied food that is convenient for a young child to consume (Afoakwa, Aidoo, & Adjonu, 2010).

In a search for a simple technique to reduce dietary bulk and viscosity and increase the nutrient density of cereal-based complementary foods, we assessed different fermentation durations and malt concentrations on three kinds of cereal grains commonly used for making complementary foods in Ethiopia. The objective of this study was to assess the effects of fermentation duration and malt concentration on physicochemical and sensory properties of starchy cereals commonly used for making complementary foods in Southwest Ethiopia.

8.3 Materials and Methods

8.3.1 Experimental materials and sample preparation

The experimental materials used for the study were Oats, barley, teff and malt. Oats (*Sinana 01*) was collected from Sinana Agricultural Research Center, barley (*BH-1307*) was collected from Holeta Agricultural Research Centre, Teff (*Kuncho*) was collected from Debre Zeit Agricultural Research Centre, and malted barley (*Holker*) for ARF preparation was collected from Assela malt factory.

The grains and malted barley were cleaned manually to remove husks, damaged grains and extraneous materials. The seeds were then dried in a drying oven at 55°C (Model 400, Memmert, Germany) for 2 hours. The dried grains were milled into flour using a grain mill (KARLKOLB D-6072, Dreich, West Germany) to pass through a sieve of 0.5 mm aperture size. The milled samples were packed in airtight polyethene bags until next processing step.

8.3.2 Experimental design and treatments

The experiment had three factors namely cereal type (Oats, Barley and Teff), fermentation time (0 h, 24 h and 48 h) and malt concentration (0%, 2% and 5%). The treatments were arranged in a 3x3x3 factorial design in three blocks.

Measured quantities of malt flour were added to each of the flour samples according to the levels indicated in the experimental design. Then the grain-malt blends were homogenised using a homogeniser. The flour samples were then added to deionised water in plastic containers at a concentration of 1:3 (w/v). The flour slurry was allowed to ferment naturally with only the microorganisms carried on or inside the seeds. The fermentation took place at room temperature and lasted for 0, 24, and 48 h depending on the treatment. When the fermentation time is over, the water was decanted. The fermented samples were transferred to aluminium trays and dried in convective oven-drier (LEICESTER LE67 5FT, England) at 70 °C for 3-4 h. Dried samples were ground with a mill (KARLKOLB D-6072, Dreich, Germany) to pass through a 0.5 mm sieve. The milled samples were packed in airtight polyethene plastic bags until next processing step.

8.3.3 Measurements

8.3.3.1 Chemical composition

Proximate compositions were determined on dry matter basis following the Association of Official Analytical Chemists (AOAC) methods: moisture (925.10), crude protein (979.09), crude fibre (962.09), crude fat (920.39) and ash (923.03) (AOAC International, 2005). The proportion of these constituents were summed and subtracted from 100 to get the total carbohydrate content. The energy contents of the samples were obtained by multiplying crude protein, crude fat and carbohydrate by conversion factors of 4, 9 and 4, respectively (Osborne & Voogt, 1978).

8.3.3.2 Antinutritional factors

The antinutritional factors studied in this study were phytate and tannin contents of the flour samples. The Phytate determination was done as per the colorimetric method described by Vaintraub and Lapteva (1988). The amount of phytic acid was calculated using phytic acid standard curve. Condensed tannin content of flour samples was determined by the method of Maxson and Rooney (1972).

8.3.3.3 Physical properties

Three physical properties namely bulk density, water absorption capacity (WAC) and viscosity were considered in this study. The bulk density of flour samples was determined by dividing the weight of the sample by its volume after tapping (Adeleke & Odedeji, 2010). The WAC of flour samples was determined as the percent water bound by 1 g dry flour (Sosulski, 1962). The viscosity of gruel samples was determined by using a HAAKE Falling sphere viscometer (D-76227 Karlsruhe, Germany). A glass cylinder was filled with gruel. A sphere of known diameter and density was dropped into the liquid and the time taken for the ball to travel a calibrated distance of 100 mm was measured. Viscosity was calculated by rearranging Stoke's law (Flude and Daborn 1982).

8.3.3.4 Sensory properties

To avoid panellist fatigue from evaluating 27 different products only nine treatments were selected for sensory analysis. The selection was made by clustering each cereal based on the combination of fermentation period and malt level. Then three treatments were selected from each cereal at which high energy (kcal) was recorded. A total of 50 untrained mothers were selected as panellists in this study. The panellists were asked to rank the gruels by appearance, aroma, taste, mouth-feel, consistency and overall acceptability using a five-point hedonic scale (Muhimbula, Issa-Zacharia, & Kinabo, 2011).

8.3.4 Statistical analysis

The effect of type of starchy staple, fermentation time and malt concentration on physicochemical properties of flour and gruel were determined using a three-way analysis of variance. The validity of model assumptions, namely normal distribution and constant variance of error terms were verified for each response, by examining the residuals (Montgomery, 2013). Data were assessed by analysis of variance (ANOVA) and by Tukey's method for multiple comparisons at the 5% level of significance. Minitab®, Version 16 software was used for data analysis.

8.4 Results

Descriptive data (means ± standard deviations) for proximate composition, antinutritional factors, and physical properties for oats, barley and teff, are presented in Table 8-1, Table 8-2 and Table 8-3, respectively.

Table 8-1 Changes on proximate composition, anti-nutritional factors and physical properties of oats flour during fermentation and malt addition. Data are shown as the mean ± standard deviation.

Cer	Fer (h)	Mal (%)	MC (%)	Ash (%)	Pro (%)	Fat (%)	Fib (%)	Car (%)	Cal (Kcal/100g)	Phy (mg/100g)	Tan (mg/100g)	BD (g/ml)	WAC (%)	Vis (cP)
Oats	0	0	5.00±0.00	1.81±0.00	11.07±0.16	4.55±0.07	4.56±0.08	73.01±0.19	377.26±0.58	88.59±3.64	42.89±0.70	0.92±0.01	136.27±0.47	650.00±52.20
	0	2	5.00±0.00	1.75±0.01	11.35±0.08	4.43±0.02	4.16±0.04	73.32±0.13	378.49±0.21	75.92±3.42	33.31±1.76	0.86±0.01	129.00±0.00	653.70±44.30
	0	5	5.00±0.00	1.78±0.00	11.83±0.11	4.14±0.02	4.38±0.14	72.88±0.04	376.06±0.65	64.92±2.51	29.97±1.27	0.84±0.00	120.67±0.58	621.00±46.50
	24	0	5.50±0.00	1.80±0.02	12.63±0.16	3.64±0.03	3.91±0.03	72.53±0.23	373.34±0.03	52.37±2.85	26.99±0.55	0.78±0.01	116.15±0.25	577.00±34.60
	24	2	6.17±0.29	1.77±0.01	12.95±0.05	3.27±0.07	3.56±0.05	72.28±0.40	370.38±0.83	45.04±3.28	23.46±2.99	0.76±0.01	109.11±0.20	538.30±57.70
	24	5	5.17±0.29	1.82±0.01	13.66±0.07	3.07±0.06	3.33±0.03	72.95±0.33	374.10±1.01	40.30±2.84	20.43±2.13	0.75±0.01	101.15±0.26	506.70±72.00
	48	0	4.67±0.29	1.89±0.01	14.38±0.18	2.97±0.03	3.15±0.07	72.94±0.31	376.03±1.43	34.66±2.80	18.06±2.29	0.74±0.01	94.86±0.75	465.30±87.00
	48	2	4.50±0.00	1.89±0.01	15.61±0.31	2.91±0.02	3.08±0.07	72.01±0.28	376.68±0.32	27.64±3.46	14.63±2.02	0.72±0.01	85.67±1.15	433.70±79.70
	48	5	4.50±0.00	1.79±0.02	16.82±0.11	2.70±0.02	2.98±0.04	71.20±0.10	376.42±0.08	18.63±2.47	13.50±3.10	0.70±0.01	74.41±0.53	436.30±81.90

Cer: cereal type; Fer: fermentation time; Mal: malt concentration; MC: moisture content; Pro: protein; Fib: fibre; Car: carbohydrate; Cal: calorie; Phy: phytate; Tan: tannin; BD: Bulk density; WAC: water absorption capacity; Vis: viscosity

Table 8-2 Changes on proximate composition, anti-nutritional factors and physical properties of barley flour during fermentation and malt addition. Data are shown as the mean ± standard deviation.

Cer	Fer (h)	Mal (%)	MC (%)	Ash (%)	Pro (%)	Fat (%)	Fib (%)	Car (%)	Cal (Kcal/100g)	Phy (mg/100g)	Tan (mg/100g)	BD (g/ml)	WAC (%)	Vis (cP)
Barley	0	0	5.83±0.29	2.20±0.00	8.78±0.07	3.31±0.11	5.96±0.13	73.92±0.30	360.61±1.77	108.90±3.06	18.55±2.67	0.89±0.01	143.12±0.13	1016.30±29.50
	0	2	6.00±0.00	2.31±0.01	8.97±0.12	3.13±0.04	5.78±0.03	73.81±0.12	359.33±0.36	105.15±2.09	15.15±1.03	0.87±0.01	136.00±0.00	785.00±65.00
	0	5	5.50±0.00	2.10±0.00	9.22±0.13	2.94±0.05	5.61±0.06	74.63±0.21	361.89±0.28	93.00±5.86	14.02±1.82	0.85±0.01	132.05±0.09	825.30±39.70
	24	0	5.00±0.00	2.20±0.00	10.33±0.16	2.25±0.06	4.82±0.03	75.41±0.20	363.17±0.42	86.75±4.47	12.92±2.06	0.82±0.00	128.00±0.00	740.00±75.40
	24	2	5.17±0.29	2.30±0.00	11.03±0.15	2.02±0.07	4.75±0.06	74.72±0.18	361.24±1.07	80.14±5.94	11.98±2.48	0.76±0.01	121.00±0.00	791.70±29.50
	24	5	5.50±0.00	2.30±0.00	11.77±0.38	1.95±0.03	4.59±0.03	73.89±0.43	360.20±0.12	72.64±5.04	10.66±1.28	0.75±0.00	115.15±0.25	758.70±70.50
	48	0	4.17±0.29	2.40±0.00	12.42±0.25	1.85±0.02	4.35±0.06	74.82±0.50	365.55±1.46	68.76±3.53	9.15±0.96	0.73±0.00	102.14±0.25	749.70±52.40
	48	2	5.17±0.29	2.21±0.01	12.34±0.09	1.73±0.03	4.21±0.02	74.33±0.34	362.28±1.29	62.66±5.82	7.90±0.42	0.71±0.01	94.48±0.46	729.00±49.50
	48	5	4.00±0.00	2.30±0.00	12.99±0.21	1.63±0.04	3.96±0.02	75.12±0.19	367.11±0.26	41.55±4.54	5.33±0.82	0.66±0.01	85.51±0.78	493.70±70.70

Cer: cereal type; Fer: fermentation time; Mal: malt concentration; MC: moisture content; Pro: protein; Fib: fibre; Car: carbohydrate; Cal: calorie; Phy: phytate; Tan: tannin; BD: Bulk density; WAC: water absorption capacity; Vis: viscosity

Table 8-3 Changes on proximate composition, anti-nutritional factors and physical properties of teff flour during fermentation and malt addition. Data are shown as the mean ± standard deviation.

Cer	Fer (h)	Mal (%)	MC (%)	Ash (%)	Pro (%)	Fat (%)	Fib (%)	Car (%)	Cal (Kcal/100g)	Phy (mg/100g)	Tan (mg/100g)	BD (g/ml)	WAC (%)	Vis (cP)
Teff	0	0	5.50±0.00	2.67±0.01	8.12±0.11	3.53±0.04	3.20±0.00	76.98±0.15	372.18±0.21	175.07±2.08	8.49±0.70	1.00±0.00	121.00±0.00	523.70±45.60
	0	2	4.50±0.00	2.60±0.00	8.34±0.10	3.46±0.02	2.92±0.05	78.18±0.11	377.24±0.23	153.81±2.45	7.26±0.85	0.96±0.00	117.00±0.00	497.30±54.70
	0	5	5.17±0.29	2.60±0.00	9.53±0.08	3.42±0.03	2.74±0.04	76.55±0.43	375.06±1.15	150.12±1.99	6.31±0.64	0.92±0.00	113.04±0.07	484.30±63.50
	24	0	4.00±0.00	2.60±0.00	9.93±0.06	2.83±0.04	2.53±0.08	78.11±0.14	377.60±0.27	145.43±2.52	5.39±1.15	0.89±0.00	105.34±1.21	426.70±53.70
	24	2	5.33±0.29	2.67±0.01	10.57±0.08	2.74±0.02	2.26±0.09	76.43±0.24	372.66±1.30	133.49±4.65	4.69±1.02	0.84±0.00	94.78±0.38	402.00±37.00
	24	5	4.50±0.00	2.70±0.00	11.66±0.02	2.68±0.03	1.99±0.08	76.47±0.07	376.61±0.45	122.48±4.20	4.16±0.95	0.82±0.00	88.67±0.58	360.30±44.30
	48	0	3.83±0.29	2.70±0.00	11.80±0.09	2.60±0.01	1.85±0.07	77.22±0.28	379.50±1.42	102.86±6.97	3.51±0.70	0.75±0.00	81.00±0.00	337.70±44.50
	48	2	3.67±0.29	2.71±0.01	12.09±0.20	2.53±0.04	1.72±0.05	77.28±0.22	380.26±0.93	88.27±3.50	2.52±0.79	0.71±0.00	73.00±0.00	307.30±33.60
	48	5	5.67±0.29	2.67±0.01	12.61±0.16	2.19±0.03	1.58±0.02	75.28±0.40	371.31±1.06	76.35±4.51	0.84±0.10	0.69±0.00	61.33±1.01	235.00±33.20

Cer: cereal type; Fer: fermentation time; Mal: malt concentration; MC: moisture content; Pro: protein; Fib: fibre; Car: carbohydrate; Cal: calorie; Phy: phytate; Tan: tannin; BD: Bulk density; WAC: water absorption capacity; Vis: viscosity

Table 8-4 provides ANOVA p-values for main effects and two-and three-way interactions of cereal type (X1), fermentation time (X2) and malt concentration (X3) on chemical and physical properties. Significant three-way interaction effects were observed between cereal type, fermentation time and malt concentration for the proximate composition and physical variables: moisture, ash, protein, fat, fibre, carbohydrate, calorie, bulk density, water absorption capacity and viscosity. Significant two-way interaction effects were observed between cereal type, fermentation time and malt concentration for anti-nutritional factors: phytate and tannin. Significant two-way interaction effects were found between fermentation time and malt concentration for all variables. The main effects of the three factors were significant for all the variables under consideration.

Table 8-4 General full factorial 3 × 3 × 3 design: ANOVA p-values for main effects and Two- and three-way interactions of cereal type (X1), fermentation time (X2) and malt concentration (X3) on chemical and physical properties.

Model	MC (%)	Ash (%)	Pro (%)	Fat (%)	Fib (%)	Carb (%)	Cal (Kcal/ 100g)	Phy (mg/ 100g)	Tan (mg/ 100g)	BD (g/ml)	WAC (%)	Vis (cP)
X1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
X2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
X3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
X1*X2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99
X1*X3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
X2*X3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.03
X1*X2*X3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00	0.00

MC: Moisture content; Pro: Protein; Fib: Fibre; Carb: carbohydrate; Cal: calorie; Phy: Phytate; Tan: Tannin; BD: Bulk density; WAC: water absorption capacity; Vis: Viscosity

8.4.1 Chemical composition

Figure 8-1 presents the two-way interaction of fermentation time and malt addition on proximate composition of flour samples. The highest moisture content was recorded from 24 h fermented flour with 2% added malt and the lowest was registered from 48 h fermented flour with no added malt (Figure 8-1a). For ash content, the highest value was recorded 48 h fermented flour with no added malt whereas the lowest was obtained from unfermented flour with 5% malt (Figure 8-1b). In the case of crude protein content, the highest value was recorded for 48 h fermented flour with

5% added malt and the lowest was obtained from unfermented flour with no added malt concentration (8.12%). Protein content increased with an increase in fermentation time and malt concentration (Figure 8-1c).

The highest crude fat content was recorded from unfermented flour with no added malt, and the lowest value was obtained from 48 h fermented flour with 5% added malt. Ash content decreased with an increase in fermentation time and malt concentration (Figure 8-1d). Crude fibre content tends to decrease with an increase in fermentation time and malt concentration (Figure 8-1e). Fermentation and addition of malt decrease carbohydrate content of the cereal flours. The total carbohydrate content of unfermented flour does not increase or decrease consistently with the added malt (Figure 8-1f).

Highest energy content was calculated for 48 h fermented flour with no added malt. There was an inconsistent increase or decrease in energy content of the unfermented and 24 hour fermented flour samples with changes in the concentration of added malt (Figure 8-2a).

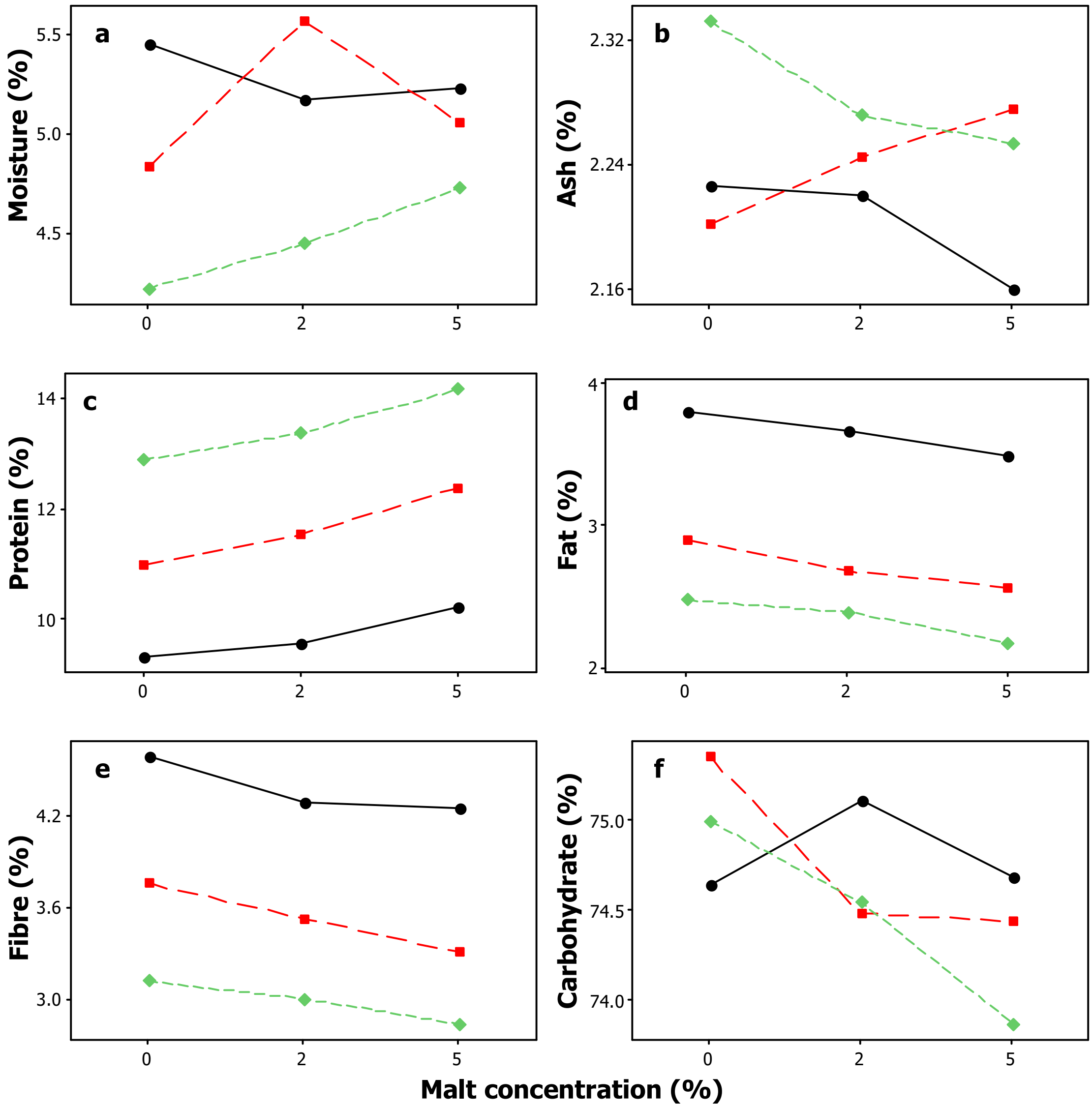

Figure 8-1 Two-way Interaction plots from the ANOVA procedures for (a) moisture, (b) ash, (c) protein, (d) fat, (e) fibre and (f) carbohydrate content. Fermentation*Malt Interaction. (0h fermentation (black circle), 24h fermentation (red square), 48h fermentation (green lozenge)).

8.4.2 Antinutritional factors

Phytate (Figure 8-2b) and condensed tannin (Figure 8-2c) contents decreased consistently with the increase in fermentation time and malt concentration where the lowest values were obtained for 48 h fermented flours with 5% added malt.

8.4.3 Physical properties

Figure 8-2d through Figure 8-2f shows the two-way interaction of fermentation time and malt concentration on the physical properties of the sample flour and viscosity of gruel samples. The results showed that bulk density (Figure 8-2d) and water absorption capacity (Figure 8-2e) of cereal flours and viscosity (Figure 8-2f) of the cereal flours decreased consistently with an increase in fermentation time and malt concentration.

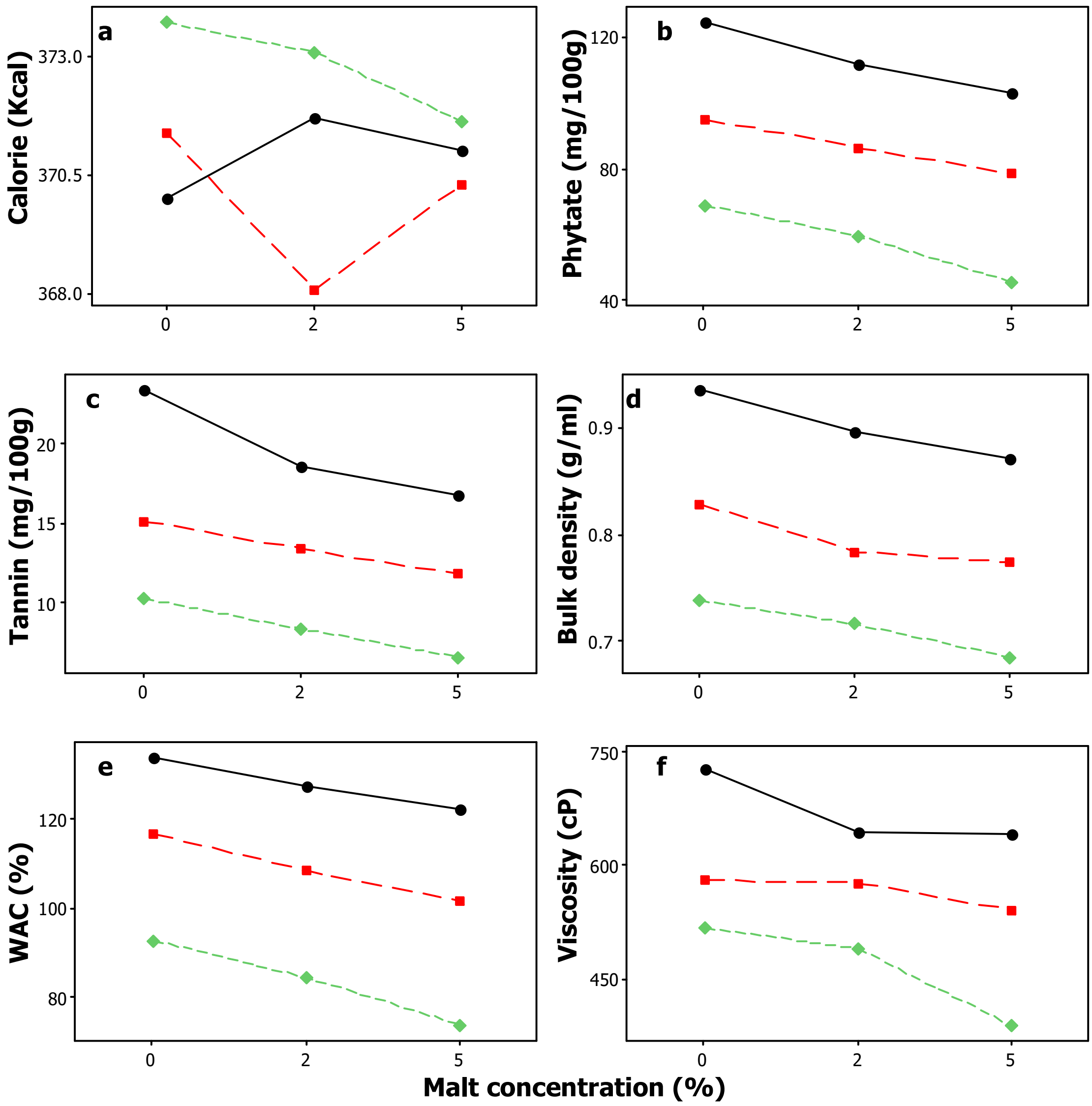

Figure 8-2 Two way interaction plots from the ANOVA procedures for (a) calorie, (b) phytate, (c) tannin, (d) bulk density, (e) water absorption capacity and (f) viscosity. Fermentation*Malt Interaction. (0h fermentation (black circle), 24h fermentation (red square), 48h fermentation (green lozenge))

8.4.4 Sensory properties

Analysis of variance shows that there was a significant difference (P<0.01) among the samples prepared from selected grain flours regarding appearance, aroma, taste, outh feel, consistency and overall acceptability.

The highest preference ranking for appearance, aroma, taste, and overall acceptability was recorded for gruel made of 24h fermented oat flour with 5% added malt. Whereas gruel prepared from 48h fermented barley flour with 5% added malt was the least preferred regarding appearance, aroma, taste, and overall acceptability. The consistency of gruel prepared from both 24h and 48h fermented cereals were mostly preferred while gruel prepared from all unfermented cereal flours was least accepted. For all the three cereal types, 24h fermentation tended to give the gruel sample a preferred sensory attribute (Table 8-5).

Table 8-5 Sensory ranking of gruel samples made from fermented cereals with added malt as evaluated by untrained panels

Flour	Ferm (h)	Malt (%)	Appearance	Aroma	Taste	Consistency	Overall acceptability
	0	2	4.38a	4.16ab	4.02ab	2.10b	4.00ab
Oats	24	5	4.44a	4.52a	4.42a	3.90a	4.42a
	48	2	2.14c	2.28e	2.38cd	4.38a	2.64d
Barley	0	5	3.60b	3.34cd	3.48b	1.64b	3.28cd
	24	0	4.06ab	4.00ab	3.72b	3.76a	3.80abc
	48	5	1.88c	2.20e	1.94d	4.02a	2.66d
Teff	0	2	3.90ab	3.68bc	3.58b	2.26b	3.40bc
	24	0	3.90ab	4.18ab	4.06ab	3.92a	3.98ab
	48	2	2.26c	2.80de	2.64c	4.16a	3.34bc
CV (%)			29.43	29.25	32.86	34.05	31.08
LSD(5%			0.62	0.63	0.69	0.71	0.68

Means sharing the same letter(s) are not significantly different at P=0.05 according to LSD Test. Ferm= fermentation time.

8.5 Discussion

8.5.1 Chemical composition

Variation in moisture content may not be explained as a function of fermentation or malt addition. The variation might have occurred due to differences in the water holding capacities of the flour components like carbohydrate and protein which were affected by the processes. The maximum moisture content recorded in this study was 6.17%. Very close moisture content was reported for complementary food flour made from fermented maize, rice, soybean and fish meal (Amankwah et al., 2009). Fermented cereal flours should have a moisture content of less than 10% (Olorunfemi, Akinyosoye, & Adetuyi, 2006).

Variations in fermentation time and malt levels did not uniformly increase or decrease the total ash contents of the cereals. The observed variation in total ash content could be due to inherent variation in mineral contents of the cereals as well as leaching of some minerals into the fermentation medium during the process. A study on cowpea fortified nixtamalized maize showed that fermentation medium and amylase-rich flour (ARF) level did not dramatically increase or decrease total ash content (Afoakwa et al., 2010). The total ash contents of all samples in the present study were less than 5% which was in agreement with the recommendation by WHO which advice that total ash contents of complementary foods should be less than 5g/100g (WHO & FAO, 2004).

As both fermentation time and malt concentration increased, the crude protein contents also increased for the three-grain types. This increment could be because of the proteolytic enzymes produced by microorganisms during fermentation which increased the bioavailability of amino acids. Another study reported that increment in protein content after fermentation could be associated with a microbial synthesis of proteins from metabolic intermediaries during fermentation (Zamora & Fields, 1979).

The crude fat content gradually decreased with an increase in fermentation time and malt concentration. Other researchers have also reported that longer fermentation time decreased the crude fat content of fermented complementary foods. The reduction in fat content at the end of fermentation time may have resulted from oxidation during fermentation. It could also be attributed to the use of lipid by the microorganisms to obtain energy for their metabolic activities during fermentation (Fasasi, Fasasi, Adeyemi, & Fagbenro, 2007; Mbata, Ikenebomeh, & Ahonkhai, 2006).

The crude fibre content decreased significantly as fermentation time, and malt concentration increased. Complementary foods preferably have low fibre content to reduce the dietary bulk and hence indigestion in babies (Olorunfemi et al., 2006). Bulky nature of cereal-based complementary foods is one of the factors discouraging many infants from consuming them (Gernah, Ariahu, & Ingbian, 2011). Therefore, the reduction in fibre content is desirable.

Total carbohydrate content decreased with an increase in fermentation time and malt concentration, except for Teff flour. This change may be due to the increasing or decreasing values of other chemical components like moisture, ash, protein, fat and fibre by the effect of malt and fermentation process. All the fermented flours in the current study contain the recommended amount of carbohydrate in complementary foods of ≥65g/100g (WHO & FAO, 2004).

As the fermentation time and malt concentration increased, the calorific value increased for barley and Teff flours but decreased for oats flour. This variation may be due to the increasing or decreasing values of the three sources of calories namely protein, fat and carbohydrate by the effect of added malt and fermentation. The energy content obtained in the current study is less than the recommended energy content of 400-420kcal/100g for complementary infant foods (WHO & FAO, 2004). The calorific contents were calculated for uncooked flour samples we expect cooking may further enhance the calorific content by changes in starch, fat and protein.

8.5.2 Antinutritional factors

The phytate content of the cereals decreased with increase in the concentration of malt flour and fermentation period. This result of the current study agrees with another report which showed that fermentation reduced phytic acid the most in the cereal flours among compared to other processing techniques (Fagbemi, Fagbemi, Oshodi, & Ipinmoroti, 2005). Fermentation can induce phytate hydrolysis to lower inositol phosphates via the action of microbial phytase enzymes. Different researchers have suggested that the loss of phytate during fermentation could be a result of the activity of native phytase and the fermentative microflora (Elyas, El Tinay, Yousif, & Elsheikh, 2002; Shimelis & Rakshit, 2005).

The condensed tannin content of the cereals also decreased with an increase in malt concentration and fermentation period. The activity of polyphenol oxidase produced by fermenting microflora might have caused the reduction in tannin contents as fermentation progress (Fagbemi et al., 2005).

8.5.3 Physical properties

In this study, the bulk density of flour samples decreased gradually with an increase in fermentation period and concentration of malt. Other studies have also indicated that bulk density of fermented cereals or cereal blends decreased as fermentation period increased (Alka, Neelam, and Shruti 2012).

Water absorption capacity (WAC) decreased with an increase in fermentation length and malt concentration. This result is consistent with a report which stated that WAC of selected fermented cereal flours (sorghum, pearl millet and maize) decreased by half as fermentation period increased from 0 to 36 h (Alka et al., 2012).

The viscosity of gruel samples decreased significantly with an increase in the length of fermentation and concentration of malt. A study on the addition of maize and millet malts to fermented maize showed that malt effectively lowered the viscosity of corn-based porridges (Amankwah et al., 2009). The decrease in viscosity during fermentation may be due to increased α-Amylase activity from the amylase-rich malt flour. This enzyme can hydrolyse amylose and amylopectin to dextrins and maltose, thereby reducing the viscosity of thick cereal porridges (Gibson, Perlas, & Hotz, 2006). The viscosity of infant food must be less than 3000 cP (Mosha & Vicent, 2004). The viscosity values recorded in this study are far lower than 3000 cP which indicates the product is already liquified. There is no need to dilute these products with water to make them suitable for infant feeding as African mothers practice it.

8.5.4 Sensory properties

For all the three cereal types, the appearance of gruels prepared from 24hr fermented and unfermented flour samples were the most preferred than 48hr fermented flour. This preference is because gruels made from unfermented and 24hr fermented flour were whitish while those made from 48h fermented flour were dark brown. The results obtained in this investigation was consistent with findings reported by Kikafunda, Abenakyo, & Lukwago (2006), who reported that the most preferred porridge concerning appearance was the most white, while the least preferred was the creamiest in colour. The gruels prepared from 48hr fermented flour was brownish. This browning is probably due to the formation of (melanoidins through a Maillard reaction when sugars from starch hydrolysis reacted with proteins probably during oven drying following fermentation (Kikafunda et al., 2006).

The production of volatile compounds such as lactic acid, butyric acid and alcohol by microbial activities which increased as the fermentation progressed may account for the perceived changes in the aroma of the gruels fermented for a different length of time (Oyewole & Ogundele, 2001). On the other hand, longer fermentation time led to lower taste preference score of gruel samples. This dislike could be due to higher acidity which resulted from the prolonged fermentation time. This study is in agreement with Mihiret (2009) who reported that sensory panelists least accepted gruel prepared from 48h fermented sorghum flour.

Gruels prepared from 24h, and 48h fermented flour was less thick (less viscosity) than unfermented cereals flours this might be due to the activity of fermentation microbes and amylase that convert starch to sugar and makes the gruels or porridge less thick. Starch degradation reduces the viscosity of thick cereal porridges without dilution with water while simultaneously enhancing their energy and nutrient densities (Michaelsen et al., 2009).

The overall acceptability of the gruel prepared from the starchy staples that were subjected to 24h fermentation was also ranked first. Short fermentation may lead to improvement in palatability and acceptability by developing improved flavours and textures (Parveen & Hafiz, 2003).

8.6 Conclusions

Fermentation and addition of malt resulted in significant reduction in crude fat, crude fibre, total carbohydrate, phytic acid, tannin, bulk density and water absorption capacity. Fermentation and addition of malt have also caused a significant increment in crude protein and calorific value. Additionally, the gruel prepared from fermented cereals was less viscous and liquefied. The increase in energy density and reduction in dietary bulkiness and viscosity is desirable as it will increase food intake by infants. Fermentation and the addition of malt can play a significant role in improving the chemical, physical and sensory properties of cereal-based complementary foods especially in countries like Ethiopia where these techniques are not commonly practised for baby food applications.

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9 General discussion

This thesis describes possibilities of upgrading starchy staples by application of food processing technologies with emphasis on improving childhood and maternal nutrition. In this section overall impression of past research, the methodology followed for the current study and significant findings are highlighted. Additionally, weaknesses and limitations of the study are explained. The implications of the findings, why they are significant, how they affect our understanding of the research problem are also described. Finally, recommendations are given on where future work should focus.

9.1 Discussion

Studies on the burden of child malnutrition in developing countries indicated that there is a decreasing trend in childhood stunting between the years 1970-2010 with an average stunting rate of 40.0% in 2010 for Sub-Saharan Africa (Smith & Haddad, 2014). Past research into the nutritional status of children is concentrated into two groups: those dealing with nutritional status in under-five children and those dealing with school children. Meanwhile, the current study identifies determinants of nutritional status of children younger than two years old in Southwest Ethiopia and highlights which factors are essential during interventions which address malnutrition among children in this age group. Accordingly, there is a medium severity of undernutrition among children in the study area, and the determinants of undernutrition were found to be multidisciplinary and interrelated. The prevalence of child malnutrition reported in the current study is lower than reports from the other parts of the country. Naturally, undernutrition will slow down the pace of development of a society. Therefore, inclusive interventions are needed, and these findings will serve as evidence base required for prioritising intervention.

Mothers should exclusively breastfeed their children until the infants are six months old and should also continue breastfeeding until their children are two years old. Maternal nutritional status is therefore closely associated with nutritional status of their children. Past research on the nutrition of mothers indicated that various fundamental, underlying and immediate factors play a determinant role in the nutritional status of mothers (Black et al., 2008). Previous studies have reported that nutritional status of the lactating women in different regions of Ethiopia was short of the national and international recommendations (Haileslassie et al., 2013). The current study also reported the magnitude of undernutrition and its predictors among lactating women living in Jimma Zone, Southwest Ethiopia. The results showed that a significant proportion of the lactating mothers had chronic energy deficiency. Past studies have indicated that the nutritional adequacy of milk of mothers from less privileged countries has been of particular concern because sizable proportions of these women are marginally nourished or, at times, frankly undernourished (Brown et al., 1986). Maternal nutrition could lead to intergeneration effects. These findings will serve as evidence base needed for prioritising intervention.

Previous research regarding infant and young child feeding has indicated that children should be exclusively breastfed during their first six months of life as it provides adequate nutrition (Butte et al., 2002). Earlier studies have also found out that dietary diversity score can be meaningfully related to the micronutrient adequacy of diet (Ruel, 2003; Steyn et al., 2006). There have only been few studies describing the nutrient adequacy of diets Ethiopian infants and young children (6-24 months old). Nutrient inadequacy can be explained by limited dietary diversity (Arsenault et al., 2013). In this study, complementary feeding practices were assessed, diversity and composition of child diets were evaluated, and the nutrient adequacy of the diets was determined. The diversity of diets of the infants and young children (6-24 months old) was sub-optimal. The dietary pattern is monotonous and predominantly starchy. Nutrient adequacy of the complementary foods was sub-optimal. Inadequate nutrient intakes are primarily responsible for nutrient deficiencies and are linked to a wide range of consequences, such as congenital disabilities, growth restriction, impaired cognition, and increased morbidity and mortality (Black et al., 2008). The results also showed that there was no significant difference between districts regarding dietary diversity scores which indicate production diversity may not necessarily mean dietary diversity. During the focus group discussions, we have learnt that some households sell animal source foods like eggs and buy discretionary calorie foods like biscuits and soft drinks to their children. Similarly, even if it not included in this dissertation, diversity and nutrient adequacy of the maternal diets was suboptimal, and the dietary pattern was also monotonous and dominated by starchy staples. More research is needed on strategies for optimising nutrient intake to meet the needs of both the mother and her infant (Dewey, 2004). Nutrition education may help families make informed dietary choices and purchase decisions.

Current and past research on the upgrading of starchy staples dealt with a variety of approaches and strategies to blend or process complementary food products by using both hi- and low-tech food processing techniques. Only a few studies have reported combined use of optimal mixing of selected ingredients and extrusion cooking for development of instant products (Pelembe et al., 2002). This study aimed to apply extrusion to develop instant complementary food flour with oat, soybean, linseed and premix to attain excellent nutritional and sensory properties. It was possible to develop optimal products whose nutritional quality fulfils the requirements of older infants and young children. The new product scored 3.65 out of five in sensory performance ratings. The use of locally available ingredients in such products can make a significant contribution to food security in the region. Small and medium scale industrialists can be involved in the production of inexpensive, value-added complementary foods using extrusion cooking. A minor hedonic adjustment can be made to make the sensory properties appealing to different food cultures. To tap the potentials of the newly developed product future work should focus on working with small and medium enterprises (SMEs) for mass production and distribution of the product.

Estimation of the shelf life of a product is part and parcel of the product development task. Previous studies reported that storage stability of extruded composite flour is affected by the type of packaging material used (Wani et al., 2015) and extruded products also have a longer predicted shelf life (Plahar et al., 2003). Sensory attributes of the extruded composite product were also reported to be stable during storage (Shaviklo et al., 2015). Our study on storage stability and shelf life of extruded composite baby food flour showed that the extruded composite flour samples were shelf stable, with a predicted shelf life of up to 17 months at 25^{o}C. This shelf stability is a decisive point for distribution and marketing of the extruded composite flour in Ethiopia.

Previous researchers unanimously praise household food processing techniques like fermentation and malting/germination as inexpensive and straightforward candidates for improving nutritional and functional quality of starchy diets. In this study, we assessed the combined effects of natural fermentation and malt addition on the quality characteristics of oats, barley and teff flour samples. Fermentation and malting led to increment in protein content and energy density, and reduction in dietary bulkiness and viscosity of the complementary foods. Improvements in textural properties of gruel imply ease of mastication and swallowing by infants and hence improved intake of nutrients. Gruels made of cereals that are fermented briefly were ranked favourably for all sensory acceptability variables. In some parts of Africa, one can find gruel made of grains that have undergone fermentation or malting process, but such products are not very common in Ethiopia. These simple traditional food-processing practices offer an alternative, cheap technological options for preparation of low-cost, nutritious complementary foods. Future research should focus on adoption of these technologies among populations like those living in Southwest Ethiopia, who are not yet using these household food processing techniques for complementary food applications.

Improving nutritional quality of diets has an immediate impact on child nutrition. Food products developed using locally available ingredients and that have an upgraded nutritional, functional and sensory attributes will contribute to the fight against childhood undernutrition in low-income settings. Food processing technologies whether modern or traditional have an enormous potential for improving child nutrition in the study setting and beyond. Simple traditional food-processing practices like fermentation and malting offer alternative cheap technological options for preparation of low-cost complementary foods. Small and medium scale industrialists can be involved in the production of inexpensive value-added complementary foods using extrusion cooking. Although undernutrition is a ‘wicked problem', this study shed a light that food processing technologies have an untapped pivotal role to play in the fight against childhood undernutrition in Ethiopia.

9.2 Reflections and further research

The trends of child malnutrition in Ethiopia show that substantial reduction in child undernutrition has been achieved in recent years. National stunting, wasting and underweight prevalence rates have dropped from 58 to 38%, 12 to 10% and 41 to 24%, respectively in the past two decades (2000 - 2016) (Central Statistical Agency (CSA) [Ethiopia] & ICF, 2016). The launching of the national nutrition program (NNP) is one of the country's responses to tackling undernutrition in the country. The strategic objectives of the revised NNP include improving the nutritional status of infants, young children and children under 5, improving the nutritional status of women (15 - 49 years), and strengthening implementation of nutrition-sensitive interventions across sectors. Additionally, the Government of Ethiopia showed its bold national commitment by launching the Seqota Declaration in 2015 which aspires to end child undernutrition in the country by 2030 (Ministry of Health of Ethiopia, 2015).

Despite all the positive and encouraging news, undernutrition remains a critical issue in Ethiopia which is mainly attributed to inadequate diet (Central Statistical Agency (CSA) [Ethiopia] & ICF, 2016). The high rates of child undernutrition are attributed to lack of dietary diversity and consumption of low nutrient food and questionable child feeding practices. Moreover, not breastfeeding exclusively, and not introducing complementary foods at the appropriate time, and not receiving a minimally acceptable diet is also customary. Children of undernourished women are predisposed to low birth weight, short stature, lower resistance to infections, and a higher risk of disease and death.

Incorporation of food processing technologies in nutrition programs can be one of the potential areas to work on to alleviate the child undernutrition challenge in Ethiopia. In line with this nutrition sensitive interventions at agriculture sector have been proposed on the NNP. One of these interventions is the promotion of value addition to ensuring availability and consumption of diverse, nutritious foods. The other area of response is supporting local complementary food production and creating economic opportunities for women through development groups and cooperatives.

The following are research and strategic recommendations that can be obtained from this dissertation work.

a. Recently, the Government of Ethiopia is developing integrated agro-industrial parks (IAIPs) which are a geographic cluster of independent firms grouped together to gain economies of scale. Each IAIP is served by a network of rural transformation centres (RTC) which provide linkages to producers. There is a need for research for aligning the IIAPs development strategy with the strategic objectives of the revised NNP.
b. Small and medium enterprises in Ethiopia involved in food processing (locally known as *Baltena*) often overlook production of value-added baby foods. Development partners may help in organising mothers into development groups and providing them with seed money to start up investment in high and low-tech food processing technologies so that local value-added baby food products are made available to the market.

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10 Summary

Child undernutrition is a critical public health challenge in Ethiopia which is caused by several complex and interrelated factors. One of the immediate causes of child undernutrition is inadequate dietary intake. In countries like Ethiopia, relying on one or few starchy staples contributes to insufficient nutrient intake amongst children and thereby to undernutrition. Malnutrition during the first 1000 days of human life is critical as it causes irreversible damage to the health and quality of life of the affected individual. Therefore, utmost attention should be given to improving diets of infants and young children if significant and fast changes are to be seen in the reduction of undernutrition.

The present work took place in a framework of a research project investigating the possibility of enhancing the nutritional quality of starchy staples. The primary focus of this PhD study is to examine the potentials of utilising appropriate food processing technologies for developing value-added food products for infants and young children in Ethiopia.

To achieve the objective mentioned above, first and foremost, a situation analysis was conducted in Jimma Zone, Southwest Ethiopia which is a cross-sectional nutritional survey on 558 representative samples of mother-child pairs to measure the prevalence and establish the predictors associated with undernutrition among children aged between zero and twenty-three months. Semi-structured interviews and anthropometric measurements were employed for data collection. The prevalence of stunting, wasting and underweight in the study area was 25.4%, 9.7% and 13.1%, respectively. Older male children residing in urban areas were more likely to be stunted. Meanwhile, younger children living in poor lowland households were more likely to be wasted. Additionally, male children whose breastfeeding was delayed and living in low-income families were more likely to be underweight. Generally, there is a medium severity of child undernutrition in the study area.

Nutritional status of infants and young children is significantly associated with nutritional status of their mothers. Keeping this in mind an assessment of nutritional status of lactating mothers and the factors related to their nutritional status was evaluated. Regarding their nutritional status, 15.6% of the mothers were chronically energy deficient or in other words undernourished. The independent predictors of nutritional status were the age of the mother, husband's occupation and

household wealth. Adolescent (15-19 years) lactating mothers were more likely to be chronically energy deficient than older mothers. On the other hand, women whose partners were engaged in agricultural activities or whose husbands were unemployed were more likely to be undernourished. Lactating women living in low-income households also tended to be more undernourished.

After understanding the child and maternal undernutrition situation in the study area, complementary feeding practices of 6 to 24 months old children were assessed to measure the nutrient adequacy of diets of the children. Complementary feeding practices, diversity, composition and nutrient adequacy of predominantly consumed complementary foods were analysed. Only16.1% of the children get the minimum dietary diversity. The complementary foods were mainly based on starchy staples. All the complementary foods predominantly fed to children were not sufficient to meet the protein, fat, carbohydrate, energy and calcium requirements (NAR<1). Additionally, the sampled foods provided inadequate nutrients as compared with the recommendations by WHO. Overall, the complementary feeding practice in the study area was found to be suboptimal.

As a potential means of tackling undernutrition in the study area through improving the quality, extruded composite infant flour was developed. This study examined the effect of blending ratio and extrusion on nutritional and sensory quality of complementary food. A preferred starchy cereal (oats), a protein-rich ingredient (soybean), a fat-rich ingredient (linseed) and a premix *of Moringa stenopetala*, fenugreek, iodised salt and sugar were blended in a calculated and meaningful fashion, and the blends were extruded under calibrated and optimised conditions. Results indicated that optimal selection of raw materials, mixing and extrusion yielded a nutritionally improved product with superior sensory properties. Small and medium enterprises can adapt modern food processing techniques like extrusion cooking as part of the fight against child undernutrition.

An accelerated shelf life test was conducted on the newly developed extruded composite complementary food flour to estimate its shelf life. The flour samples were packed in different packaging materials (paper, polyethene and polypropylene) and stored under different temperature conditions (-18, 25, 35, 45^{o}C) for different durations. Extruded composite flours packed in polyethene bags can be successfully stored for more than a year at room temperature

without significant physical and chemical changes. Shelf stability of the extruded composite flour is a decisive point for its commercialisation and distribution in Ethiopia.

After establishing the possibility of developing a value-added product using a high-tech option, i.e. extrusion cooking, another study was conducted employing a simple household food processing technique namely fermentation and malt addition. The study assessed how the processes mentioned above affect the quality of complementary foods made from different cereals in the study area. Different concentrations of malt (0, 2 and 5%) was added to oats, barley and teff flour samples and these flour samples were fermented for varying duration of time (0, 1 and two days). Fermentation and addition of malt have also resulted in significant improvement in nutritional and sensory properties of complementary foods made from the traditional starchy grain flours. Nutritional quality of complementary foods can be improved at the household level by employing conventional food processing techniques like minimal fermentation. Addition of malt to complementary foods is another potential area of investment.

Zusammenfassung

Die Unterernährung bei Kindern ist eine der besonderen Herausforderungen im öffentlichen Gesundheitswesen Äthiopiens. Eine der unmittelbaren Ursachen für die Mangelernährung bei Kindern ist ein nicht angepasster Ernährungsplan, der vorwiegend auf wenigen stärkehaltigen Bestandteilen beruht. Um einen bedeutenden und schnellen Schritt bei der Verbesserung der Ernährungssituation von Säuglingen und Kleinkindern zu erzielen, ist es notwendig, die Ernährungsvielfalt zu verbessern. Die vorliegende Arbeit untersucht die Möglichkeiten des Einsatzes geeigneter Verarbeitungstechnologien, um verbesserte Lebensmittelprodukte für Säuglinge und Kleinkinder zu entwickeln.

Die Kapitel 3 und 4 geben einen Überblick über den Ernährungszustand von Kindern und deren Mütter im Süd-Westen Äthiopiens. Die Häufigkeit der verschiedenen Indikatoren belaufen sich dort auf: Unterernährung 25%, chronische Unterernährung13%, akute Unterernährung 9%. Diese Werte liegen zwar unter dem landesweiten Durchschnitt, deuten aber dennoch auf schwerwiegende Mangelernährung hin. Die Unterernährung von Kindern zeigt sich hauptsächlich in Form von Wachstumsstörungen, die wiederum abhängig sind vom Alter, Geschlecht und Wohnort. Im Untersuchungsgebiet besteht bei 16 % der untersuchten Mütter eine Chronische Energiemangelversorgung (Chronic Energy Deficiency - CED), dieser Wert ist niedriger als in anderen Regionen in Äthiopien. Die wichtigsten Einflussfaktoren für eine vorliegende CED sind der finanzielle Hintergrund, das Alter und das Beschäftigungsverhältnis des Ehemannes.

In Kapitel 5 werden die Ernährungsgewohnheiten der Kinder sowie die Nährstoffzusammensetzung der genutzten Ergänzungsnahrungsmittel untersucht. Die Stillgewohnheiten und die ergänzend verabreichte Zusatznahrung entsprechen grundsätzlich zwar den Empfehlungen der WHO, jedoch erhält nur die Hälfte der Kinder die notwendige Nährstoffvielfalt. Die ergänzend verabreichten Nahrungsmittel bestehen hauptsächlich aus Getreide und enthalten kaum Obst oder Molkereiprodukte. Die Berechnung der Nährstoffgehalte zeigt einen Mangel an Protein, Zn und Ca in den Stichproben auf, während Ballaststoffe und Asche ausreichend vorhanden sind.

In den Kapiteln 6, 7 und 8 werden eigene Versuche zur Entwicklung verbesserter Ergänzungsnahrungsmittel vorgestellt. Getestet wurden Hoch- und Einfachtechnologien zur Weiterverarbeitung von Lebensmitteln in Bezug auf Qualität, Stabilität und Akzeptanz. Entsprechende Versuche zeigten, dass es möglich ist, nahrhafte, schmackhafte und lagerstabile Komplementärnahrung aus pflanzlichen Rohstoffen mit stärkehaltigen Inhaltsstoffen durch eine optimale Rezeptur und die Verwendung eines Extruders zu erzeugen. Die so verbesserte Babynahrung kann als Ausgangsprodukt für eine Vermarktung durch kleine und mittlere Lebensmittelunternehmen dienen. Weiterhin zeigten die Versuche, dass der Zusatz von 2,5% Malz und eine 24 stündige Fermentierung die chemischen, physikalischen und sensorischen Eigenschaften der Ergänzungsnahrung verbessern können. Innovative Verarbeitungstechnologien von Lebensmitteln sollten in Ländern wie Äthiopien gefördert werden, da sie dort bislang nicht zur Veredelung von Babynahrung verwendet werden.

Appendix

Questionnaire used for data collection

Name of the Interviewer ________________________Date: (DD____/MM_____/YYYY)
____

District ____

Kebele/Gott____

Indicate time in 24-hour system

Start of Interview (HRS/MIN) ____

End of Interview (HRS/MIN) ____

Individual ID________________________________

Appendix Table 1 Demographic and socio-economic part

Background characteristics of woman and their husbands		Response
1.	What is your age? Age in Completed Years	_____Years
2.	What is your religion? 1. Muslim 2. Orthodox 3. Protestants 4. Catholic 5. Other (specify)_____________	___________
3.	What is your Ethnicity? 1.Oromo 2.Amhara 3.Guraghe 4.Tigray 5.Wolayta	_____________

	6. Yem 7. Other(specify)----------------------	
4.	What is your Marital status? 1. Single 2. Married and living together 3. Married but not living together 4. Widowed 5. Divorced	______________
5.	What is your educational status? 0. Illiterate/ informal education 1. Formal education, Grade____	______________
6.	Are you currently attending education? 0. No 1. Yes	______________
7.	What is the level of educational you are attending? 0. informal education 1. Formal education, Grade____________	______________
8.	What is the educational status of your husband? 0. Illiterate/ informal education 1. Formal education, Grade_________	______________
9.	What is your occupation? 1. Housewife 2. Farmer 3. Government Employee 4. NGO Employee 5. Merchant 6. Daily laborer	

	7. Other (specify)______________________________	___________
10.	What is the occupation of your husband? 1. Farmer 2. Government Employee 3. NGO Employee 8. Merchant 9. Daily laborer 10. Other (specify)______________________________	___________
11	What is the household size (number of people living in the HH)?	_________
12	Does this change throughout the year? NO 1. YES	___________
13	If yes, what is the reason? 1.With labor migration, 2.Agricultural season, 3. School semester? 4. Other (specify)______	
14	How many of these are children? _____________________	_________
15	Are all your children? 0. NO 1. YES *if NO, go to special questions	
16	What is their age and sex?	Sex | Age

	1st child 2nd child 3rd child 4th child 5th child 6th child 7th child Other		
17	Where is the place of residence of the respondent? Rural Urban	________	
B. Household income			
1.	What is the main source of income for the household? 1.Farming 2.Cattle production 3.Business 4. salary 5.wedge 6.Other (specify) _______________	___________	
2	Does the household have new or alternative income-generating activities? 1. Yes 0. No	__________	
3	What is the new income generating activity? _________________		

4	Who is making the money in the new income generating activity? 0. Husband 1. Wife	_________	
House hold Wealth			
1.	Does any member of this household have a land that can be used for agriculture? * That can be rent, borrow or community land 0. No 1. Yes	___________	
Does the house hold have any of the following animals?		0.NO 1.YES	How many
12	Cows		
13	Oxen		
14	Goats		
15	Sheep		
16	Chicken		
17	Bees		
18	Donkeys		
19	Horses		
20	Donkeys		
21	Mules		
Does the household have any of the following properties?		0.NO	1.YES
22	Functioning radio/Tape recorder/CD player		
23	Functioning Television		
24	Watch (Hand/Wall)		
25	Sofa		

26	Chair/Stool		
27	Mattress		
28	Sponge/Foam mattress		
29	Cotton mattress		
30	Grass Mattress		
31	Refrigerator		
32	Gas Stove		
33	Electric stove		
34	Phone (Mobile or fixed)		
35	Bicycle		
36	Motor Cycle		
37	Cart/Gari		
38	Plough		
Facilities			
1.	How does your household obtain drinking water? from 1.Under-ground water 2. Spring water 3.pipe 4. Unprotected well/spring/ river….	________________	
2.	Does your household have toilet facilities? NO 1. YES	______________	
3	If YES, what type is it? Pit latrine Ventilated improved pit	______________	

	Flash type Other (specify)	
4	Is there any health post or health center in your area? NO 1.YES	________________
5	If YES, how much is it far from here/your home/kebele?	________________
6	Is there any market place in your kebele? 0. NO 1. YES	________________
7	If NO, where do you exchange goods?	_______________
8	Are there any shops near to your home? NO 1. YES	________________

Appendix Table 2 Breast feeding practice (0-6 month)No	Questions	Responses
1	**Childs Sex**	**Male** **Female**
2	**Child's age**	**____________months**
3	**Child's Length**	**_____: ____Cm**
4	**Child's Weight**	**_____: ____ Kg**
5	**Are you breastfeeding (NAME)?** **0. NO** **1. YES**	_____________

6. How long after birth did you first put (NAME)to the breast? In hour or minute		______________	
7	Did you squeeze out and throw away the first milk? 0. NO 1. YES	______________	
8	After delivery, was (NAME) given anything to drink other than breast milk? 0. NO 1. YES	_______________	
If yes, what was given to drink		NO	YES
9	Milk (other than breast milk)		
10	Water		
11	Butter		
12	Syrup		
13	Sugar-salt-water		
14	Tea		
15	Coffee		
16	Other _____________		
17	Are you still breastfeeding?		
18. If not, for how many months did you breastfeed?		________________months	
19. How many times did you breastfeed last night between sunset and sunrise?		________________Times	
20	Does (NAME) drink anything yesterday during the day or at night?	0. No	1. Yes
If yes what are they			
21	Fresh or powdered Milk		
22	Infant formula		
23	Water		
25	Tea		
26	Coffee		
27	Fruit juice		
28	Other (specify)….		
29	Does (NAME) eat anything yesterday		

	during the day or at night?		
If yes what are they			
30	**Porridge**		
31	**Comercialy fortified baby food**		
32	**Bread**		
33	**Biscut**		
34	**Other specify….**		
35	**Does your child started to have complementary food?**		
36	**Which food do you feed your child during sickness and after recovery from sick**	______________________	

Appendix Table 3 Health Facilities and Educations

Trainings from governmental or non -governmental bodies			
Did the health extension officer (some other body) train you the following trainings?		**0.NO** **1. YES**	**Adoption (Mark)**
1	Family planning		
2	Children's care		
3	Early initiation of breast feeding		
4	Exclusive breast feeding		
5	Continued breast feeding to 2 years		
6	Complementary food		
7	Dietary diversity and frequency		
8	Consumption of supplementary foods		
9	If they adopt Q#15, what are the supplementary foods you give to your child? _____________		

		________________
10	From where do you get supplementary foods? Health center/post Shops Aid from other agents	____________

Food consumption/ feeding habit of children				
		0. NO 1. YES	Ingredients **(list)**	method of processing **(circle)**
1	Is there any special food you prepare and feed your child? ________________________			Raw boiled roasted baked fried whole de-hull fermented germinated other (specify) ____________
2	Is there any special food you prepare and feed your child during sickness? ________________________________			Raw boiled roasted

				baked fried whole de-hull fermented germinated other (specify) ___________
3	Is there any type of foods forbidden to feed to child due to your religion/ ethnicity?	0. NO	1. YES	List
Which starchy staple do you use dominantly		**Circle**		
4	Cereal Crops	Corn/maize Sorghum Wheat Teff Barley Millet Oat Rice,/Rye		
5	Root and Tuber Crops	Cassava Potato Sweet potato, Taro		

		Tania Yam
6	Fruit Crops	Banana
7	Pulses	Chickpea Common bean Lentil Pea Soybean

24-HOUR DIETARY RECALL PART

Please describe the foods (meals and snacks) that your child ate or drank yesterday during the day and night, whether at home or outside the home. Start with the first food or drink of the morning.

Appendix Table 4 Dietary diversity score (DDS) within 24-hour (under-two children)

Food group	Break fast	Snack	lunch	snack	dinner	snack	score
1. Cereals and grains Corn/Maize, Rice, Wheat, Sorghum, Millet Oats Teff							
2.Fruits Mango, Avocado, Orange, Papaya, Banana, Apple,							

Jack Fruit, Grape, Pineapple, Passion Fruits Peaches, Watermelon, Strawberry, Guava, Others							
3.Vegetables Tomato, Broccoli, Carrots, Squash, Sweet Potato, Potato, Beet Root, Eggplant, Green Pepper, Onion, Dark green Lettuce, Lettuce, Cabbage, Cucumber Mushrooms, Ginger Leeks Pumpkin Shallot Zuchinni Other___________							
4.protien rich foods Meat Beans Egg Fish Chicken Nuts and Seeds Lentils							
5. dairy products Milk Yogurt Cheese							

6.Oil and fat Butter, Animal Fat, Vegetable Oil, Commercial Oil							
7.Discretionary calorie foods Sugar, Honey, Soft drink, Juice Drinks, Chocolates, Candies, Cookies, Cakes, Other________							

***When the respondent has finished, investigation for meals and snacks not mentioned was done.**