Physio-Chemical and Sensory Properties of a Nutrient-Fortified Extruded Product

Tajudini Lassissi Akande

University of Arkansas, Fayetteville

Follow this and additional works at: http://scholarworks.uark.edu/etd

Part of the Food Microbiology Commons, Food Security Commons, Human and Clinical Nutrition Commons, International and Community Nutrition Commons, and the Molecular, Genetic, and Biochemical Nutrition Commons

Recommended Citation
http://scholarworks.uark.edu/etd/671

This Thesis is brought to you for free and open access by ScholarWorks@UARK. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of ScholarWorks@UARK. For more information, please contact scholar@uark.edu, ccmiddle@uark.edu.
PHYSIO-CHEMICAL AND SENSORY PROPERTIES OF NUTRIENT-FORTIFIED EXTRUDED PRODUCT
PHYSIO-CHEMICAL AND SENSORY PROPERTIES OF A NUTRIENT-FORTIFIED EXTRUDED PRODUCT

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Food Science

By

Tajudini Lassissi Akande
Ahmadu Bello University
Bachelor of Science in Agriculture, 2008

May 2013
University of Arkansas
ABSTRACT

Protein malnutrition is responsible for half the deaths of children under the age of five each year in developing countries. More than 4%, 26%, and 70% of children with protein malnutrition live in Latin America/the Caribbean, Africa, and Asia, respectively. The objective of this research was to develop a novel snack made with millet, black eye bean (from Niger Republic), and rice flour fortified with soybean meal protein using extrusion technology. Proximate analysis of the four flours was carried out to determine their chemical composition. Central composite design (CCD) was used to obtain best extrusion conditions to develop a protein-enriched snack with desirable physio-chemical and sensory properties. The extrusion was conducted following the CCD at varying temperature (190-275 ⁰C) and screw speed (60-110 rpm). Sensory properties were evaluated in terms of color and overall visual acceptability of the extrudates using a nine-point hedonic scale. The results suggested that the two extrusion variables (barrel temperature and screw speed) were found to influence the extrudate physio-chemical and sensory properties both independently and interactively. The extruder barrel temperature was observed to be the most significant factor that affected the extrudate properties. The best extrusion conditions was obtained at a screw speed of 60 rpm and a barrel temperature of 190⁰C based on expansion ratio, bulk density, water holding capacity, texture, color and overall visual acceptance of the extruded products. This study demonstrated that extruded products which were acceptable to consumers could be prepared from blends of millet, beans, soy and rice flour under a range of extrusion conditions up to 30% of soy flour. This product could be supplied to the developing parts of the world which are prone to protein energy malnutrition especially in Africa. This is the first attempt to produce a soymeal-based enriched protein product with millet and beans from Niger Republic.
This thesis is approved for recommendation to the Graduate Council.

Thesis Director:

________________________
Dr. Navam S. Hettiarachchy

Thesis Committee:

________________________
Dr. Jean-François Meullenet

________________________
Dr. Steve Seideman

________________________
Dr. Pengyin Chen
THESIS DUPLICATION RELEASE
I hereby authorize the University of Arkansas Libraries to duplicate the thesis when needed for research and/or scholarship.

Agreed__________________________

Tajudini Lassissi Akande

Refused__________________________

Tajudini Lassissi Akande
DEDICATION

This work is first dedicated to ALLAH SWT (GOD) who says in the holly Quran (Chapter 6: verse 162) [Say: "Verily, my prayer, my sacrifice, my living, and my dying are for God, the Lord of the mankind, demons and all that exists)], then to the peace-makers who are looking for truth and justice in the world.
ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude to ALLAH SWT (GOD), the sustainer of the heavens and the earth and all that they contain, to spare my life and to make this work possible for me. I would like to thank my family for their infinite and unequivocal support throughout my stay in USA for which my mere expression of thanks likewise does not suffice.

This thesis would not have been possible without the help, support and patience of my principal supervisor, Dr. Navam Hettiarachchy, not to mention her motherly advice and support. Her good advice, support and help have been unquantifiable to me on both academic and personal level, for which I am extremely grateful.

I am most grateful to the rest of my thesis committee: Dr Jean-François Meullenet, Dr Steve Seideman, and Dr Pengyin for their encouragement, insightful comments, and motivating discussions. I am also indebted to all of my laboratory team mates with whom I had the pleasure to work with. They have been very supportive day in and day out during all these years. My dearest thanks to all the faculties, staffs, and students of the Food Science Department for making this department a unique place to have unforgettable experiences.

Finally, my very special thanks go to Fulbright Scholarship and the University of Arkansas Sponsored Students Programs for giving me the opportunity to make my dream a reality.
TABLE OF CONTENTS

DEDICATION ........................................................................................................................................ 1

ACKNOWLEDGEMENTS ...................................................................................................................... 1

LIST OF TABLES .................................................................................................................................. 1

LIST OF FIGURES ................................................................................................................................. 1

CHAPTER I – INTRODUCTION .............................................................................................................. 2

Extruded Products ................................................................................................................................ 2

Physio-chemical properties of extruded products ................................................................................. 3

Sensory evaluation ................................................................................................................................. 5

Objectives ............................................................................................................................................. 6

CHAPTER II – LITERATURE REVIEW .................................................................................................. 7

INTRODUCTION ........................................................................................................................................ 7

Extrusion ................................................................................................................................................ 8

Extrusion of Cereal Products .............................................................................................................. 9

Proximate Analysis of Raw materials ............................................................................................... 10

Moisture ................................................................................................................................................ 10

Proteins ................................................................................................................................................. 10

Lipids ..................................................................................................................................................... 11

Starch ................................................................................................................................................... 13

Dietary Fiber (DF) ............................................................................................................................... 13

Ash ......................................................................................................................................................... 14

Physio-chemical Properties .................................................................................................................. 14

Expansion Ratio (ER) ........................................................................................................................... 15

Bulk Density (BD) ............................................................................................................................... 16

Moisture Retention (MR) ..................................................................................................................... 17

Water Holding Capacity (WHC) ........................................................................................................ 18

True Density (TeD) and Tap Density (TD) .......................................................................................... 19

Mass Flow Rate (MFR) ....................................................................................................................... 19

Fat Absorption Capacity (FAC) .......................................................................................................... 20

Milk Absorption Capacity (MAC) ...................................................................................................... 20

Protein Solubility (PS) ......................................................................................................................... 21
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Absorption Index (WAI) and Water Solubility Index (WSI)</td>
<td>21</td>
</tr>
<tr>
<td>In Vitro Starch Digestibility (IVSD)</td>
<td>23</td>
</tr>
<tr>
<td>Color</td>
<td>23</td>
</tr>
<tr>
<td>Texture</td>
<td>24</td>
</tr>
<tr>
<td>Sensory Evaluation</td>
<td>25</td>
</tr>
<tr>
<td>Sensory Evaluation of Extruded Product</td>
<td>25</td>
</tr>
<tr>
<td>Interaction between carbohydrate and protein</td>
<td>26</td>
</tr>
<tr>
<td>CHAPTER III: PHYSIO-CHEMICAL AND SENSORY PROPERTIES OF THE EXTRUDED</td>
<td>29</td>
</tr>
<tr>
<td>PRODUCTS</td>
<td></td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>29</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>29</td>
</tr>
<tr>
<td>MATERIALS AND METHODS</td>
<td>32</td>
</tr>
<tr>
<td>Experimental Design and Extrusion Conditions</td>
<td>32</td>
</tr>
<tr>
<td>Proximate Analysis of the Raw Materials</td>
<td>33</td>
</tr>
<tr>
<td>Moisture Content Determination</td>
<td>33</td>
</tr>
<tr>
<td>Protein Content Determination</td>
<td>33</td>
</tr>
<tr>
<td>Lipid Content Determination</td>
<td>34</td>
</tr>
<tr>
<td>Starch Content Determination</td>
<td>34</td>
</tr>
<tr>
<td>Dietary Fiber Content Determination</td>
<td>36</td>
</tr>
<tr>
<td>Ash Content Determination</td>
<td>37</td>
</tr>
<tr>
<td>Physio-chemical and Sensory Properties</td>
<td>38</td>
</tr>
<tr>
<td>Expansion Ratio (ER)</td>
<td>38</td>
</tr>
<tr>
<td>Bulk Density (BD)</td>
<td>38</td>
</tr>
<tr>
<td>Moisture Retention (MR)</td>
<td>39</td>
</tr>
<tr>
<td>Water Holding Capacity (WHC)</td>
<td>39</td>
</tr>
<tr>
<td>Tap Density (TD) and True Density (TeD)</td>
<td>39</td>
</tr>
<tr>
<td>Mass Flow Rate (MFR)</td>
<td>40</td>
</tr>
<tr>
<td>Fat Absorption Capacity (FAC)</td>
<td>40</td>
</tr>
<tr>
<td>Milk Absorption Capacity (MAC)</td>
<td>40</td>
</tr>
<tr>
<td>Protein Solubility (PS)</td>
<td>41</td>
</tr>
<tr>
<td>Water Absorption Index (WAI) and Water Solubility Index (WSI)</td>
<td>41</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1. Central Composite Design (CCD) of the Extrusion Experiments in their coded form and natural units................................................................................................................................. 60

Table 2. Moisture, Protein, Lipid, Total Starch, Total Dietary Fiber, Ash Content in Rice, Millet, Beans, and Soy Flours......................................................................................................................... 61

Table 3. Moisture and Protein Contents of the Nine Extruded Products...................................................... 62

Table 4. Physio-chemical Properties of the Nine extruded products................................................................. 63

Table 5. Sensory Evaluation of the Nine extruded Products ........................................................................ 64

Table 6. Protein Improvement of the extruded product using the treatment # 5 with 22% and 30% soy.................................................................................................................................................. 65
LIST OF FIGURES

Figure 1. The picture of a single-screw extruder ................................................................. 66
Figure 2. Shear Force (N) of the Nine Extruded Products....................................................... 67
Figure 3. Pictures of the Nine Extruded Products........................................................................ 68
Figure 4. Effect of barrel temperature (BT) and screw speed (SS) on bulk density (BD) of the nine extruded products........................................................................................................ 69
Figure 5. Effect of barrel temperature (BT) and screw speed (SS) on expansion ratio (ER) of the nine extruded products........................................................................................................ 69
Figure 6. Effect of barrel temperature (BT) and screw speed (SS) on moisture retention (MR) of the nine extruded products........................................................................................................ 70
Figure 7. Effect of barrel temperature (BT) and screw speed (SS) on water holding capacity (WHC) of the nine extruded products........................................................................................................ 70
Figure 8. Effect of barrel temperature (BT) and screw speed (SS) on protein solubility (PS) of the nine extruded products ........................................................................................................ 73
Figure 9. Effect of barrel temperature (BT) and screw speed (SS) on tap density (TD) of the nine extruded products........................................................................................................ 71
Figure 10. Effect of barrel temperature (BT) and screw speed (SS) on true density (TeD) of the nine extruded products........................................................................................................ 71
Figure 11. Effect of barrel temperature (BT) and screw speed (SS) on mass flow rate (MFR) of the nine extruded products........................................................................................................ 72
Figure 12. Effect of barrel temperature (BT) and screw speed (SS) on fat absorption capacity (FAC) of the nine extruded products ........................................................................................................ 72
Figure 13. Effect of barrel temperature (BT) and screw speed (SS) on milk absorption capacity (MAC) of the nine extruded products

Figure 14. Effect of barrel temperature (BT) and screw speed (SS) on water absorption index (WAI) of the nine extruded products

Figure 15. Effect of barrel temperature (BT) and screw speed (SS) on water solubility index (WSI) of the nine extruded products

Figure 16. Effect of barrel temperature (BT) and screw speed (SS) on in vitro starch digestibility (IVSD) of the nine extruded products

Figure 17. Effect of barrel temperature (BT) and screw speed (SS) on color ‘L’ of the nine extruded products

Figure 18. Effect of barrel temperature (BT) and screw speed (SS) on color ‘a’ of the nine extruded products

Figure 19. Effect of barrel temperature (BT) and screw speed (SS) on color ‘b’ of the nine extruded products

Figure 20. Effect of barrel temperature (BT) and screw speed (SS) on texture of the nine extruded products
CHAPTER I - INTRODUCTION

In Niger, one of every eight children died before the age of five (UNICEF 2011), and more than half of those deaths can be attributed to malnutrition (UNICEF 2007). Out of the 15 million people in Niger, 3.6 million are vulnerable to malnutrition including 800,000 children of less than five years of age. Of these children, 160,000 are moderately under-nourished and 32,000 are severely under-nourished (UNICEF 2005). Recent statistics show that 47% of all children under the age of five are suffering from chronic malnutrition (UNICEF 2011). International organizations, such as The United Nations Children's Fund (UNICEF), World Food Program (WFP), and United Nations Development Program (UNDP) have been helping the country by importing products rich in protein, such as peanut paste, and other essential nutrients to prevent childhood undernutrition. Unfortunately, these products are expensive because they are not made with local raw materials. Most of the extruded products in Niger are not only imported, but also too expensive for the majority of the population. It is in this perspective that we used extrusion technology to develop a product made with local cereal [HKP (millet) and DAN ILA (beans)], fortified with soybean protein flour that will not only help in reducing protein deficiency problems in Niger, but also will be more economical. Extruded products are preferable to be enriched with nutrients since they have low moisture content, are safer, and will provide extended shelf-life in comparison to non-extruded, intermediate moisture food products.

Extrusion cooking is described as a continuous process of cooking, mixing, and forming during which the raw materials can undergo chemical and structural modifications such as protein denaturation, starch gelatinization, complex formation between amylose and lipid and loss of vitamins, pigments, etc. (Ilo and Berghofer 1999). Extrusion is believed to yield safe and shelf-stable foods that can withstand spoilage for a long period of time; consequently it is helpful
against food scarcity during drought conditions (Camire 2002). Due to its versatility, low cost, productivity, product quality and eco-friendliness, extrusion has been widely used in the past two decades (Guy 2001). Wolf (2010) reported that extrusion processing plays a role in conveying, manufacturing of products, imparting of temperature and/or stress-induced morphological changes, accelerating of chemical reactions, heating, producing palatable and nutritional foods, reduction in moisture and volatile levels, generating flavor and in sterilization. The above reasons are the key factors of the extrusion process being applied to many food formulations. Extrusion cooking occupies a place of choice in the food industry as it combines high mechanical energy input and high thermal energy input in a single process thereby reducing the manufacturing cost.

As the need for gluten-free foods and beverages for people with celiac disease and other wheat intolerances is high (Taylor and others 2006), we found it useful to substitute wheat with millet flour to overcome this problem. According to Desikachar (1977), millet is more nutritious and superior to major cereals in term of protein, vitamins and minerals. Millet is a rich source of dietary fiber, phytochemicals, micronutrients, and nutraceuticals, hence it is “a nutricereal”. Due to scarcity of Ready-To-Eat (RTE) millet-based foods, millet is only consumed by traditional and low income consumers in India (Malleshi and Desikachar 1985).

**Extruded Products**

Enriching extruded products is gaining popularity. Margaret and others (2008a) included dietary fiber at 5%, 10%, and 15% levels in a white flour cereal base to develop an extruded cereal product. Margaret and others (2008a) reported that supplementing dietary fiber into flour bases did not show any significant effect on the expansion ratio of the products, but there was an increase in the bulk density of the extruded products when inulin (naturally occurring
polysaccharides produced by many types of plants) was added to the products. Similarly, Margaret and others (2008b) used guar gum and wheat bran (non-starch polysaccharides) at 15% level in the production of whole meal and wheat flour extruded breakfast cereal products. In addition, extrusion cooking can be used to produce fiber-enriched foods (Maria and others 1999). In order to combat the problem of protein malnutrition (PM) among weaning infants in tropical Africa, Yvonne and others (2001) developed a snack using maize, cowpeas, peanuts, soybeans and soybean oil to generate two formulations to meet the nutrient requirements of the 6–11 month old infant. Similarly, Rinaldi and others (2000) developed an extruded cereal product using wheat flour and enhanced its protein content with wet okara (the residue left after soymilk or tofu production).

Extrusion of millet and soybean blends in the production of “fura” (a Nigerian traditional food) has been reported (Filli and others 2010). Nkama and Filli (2006) and Filli and Nkama (2007) concluded that extrusion technology adds more value to “fura” by improving its shelf-life and making it convenient for consumers.

Martinez-Flores and others (2005) developed an extruded puffed product with corn flour supplemented with soybean and safflower pastes to improve the protein content of the extrudates. They asserted that other protein sources such as defatted wheat germ, casein and soy paste could also be used to improve the quantity and quality of the protein found in corn.

However, there is a lack of knowledge in the literature on using the combination of millet, beans, and soybeans to extrude a protein-rich breakfast cereal.

**Physio-chemical properties of extruded products**

In the development of a new product based on millet, bean and soybean meal using extrusion technology, biochemical reactions can affect physio-chemical properties of the
extrudates such as bulk density, texture, color, expansion ratio, water absorption index and water solubility index, starch digestibility, sensory properties of the extrudates, and presence of microbes. Extrusion process gelatinizes starch, inactivates enzymes, denatures protein, destroys natural toxins and reduces the microbial load in the final food product (Wolf 2010). Singh and others (2007) reported that mild extrusion cooking (low temperature, low residence time and high moisture content) increases the protein and starch digestibility of foods and feeds and minimizes lipid oxidation.

Liu and others (2000) reported that depending on the operating conditions of extrusion and properties of raw material, physical properties and sensory attributes of an extruded product can change significantly. Liu and others (2000) reported that a higher screw speed can decrease the hardness of extrudate by increasing product temperature which can lead to a higher expansion and a lower density. In their research, Desrumaux and others (1999) noted that small variations in operating conditions affect product quality. Ding and others (2005) observed that increase of feed moisture leads to a sharp increase of extrudate density value at all temperature levels while increase of barrel temperature leads to a small decrease in the density of extrudate during their research. They found that feed moisture has the most significant effect on extrudate crispness. Mercier and Feillet (1975) reported that extrudate viscosity decreased with increased temperature. Protein-starch interactions are enhanced by the capability of proteins to become unfolded during extrusion which results to decrease in expansion and overall quality (Taylor and others 2006). John and Morrissey (1989) reported that heat treatment of foods rich in reducing sugars may result in Maillard or nonenzymatic browning, which occurs between sugars and amino acids, peptides, or proteins effecting changes in the color, flavor, functional properties and nutritional value of the food. Interaction between lipid content and starch content has significant
positive effects on lipid loss (Hoan and others 2010). Lipid content above 5–6% in a flour blend had been reported to limit the expansion of extruded products (Camire 2000). Evaluating the physiochemical properties of the millet, bean and soybean base extruded snack is important as it will help us develop a unique, healthy and tasty snack product.

Sensory evaluation

A sensory analysis is crucial for the market success of a newly developed product. When purchasing a product, consumers are concerned about food flavor and overall visual acceptability of the product (Luckow and Delahunty 2004). Only about 10% to 20% of new products stay more than one year in the market despite the high competition of products (Moskowitz and others 2006). Deshpande and Poshadri (2011) found that out of the three flour blends they formulated, the sample with 60%, 5%, 5%, 20%, and 10% for foxtail millet, rice, amaranth, kabuli channa (Bengal gram), and cowpea respectively had better appearance, flavor, color, taste, texture, and overall visual acceptability than the control.

Despite the fact that a significant amount of research has been performed on extrusion technology, choosing extrusion best conditions, evaluating physio-chemical properties and conducting sensory evaluation of a novel product (extruded millet in combination with bean and soybean meal) need investigation. The product was a novel formulation developed snack targeted towards malnourishment problems in Niger Republic. The evaluation of the extruder optimizing conditions, physio-chemical properties, and sensory attributes catered to a novel nutritional healthy product.

The following specific objectives have been developed in order to achieve our goal which is to formulate a healthy and nutritious snack for malnourished children in Niger.
Objectives:

a. Obtain best conditions using Central composite design (CCD) to extrude a snack using millet, beans and/or soybean meal,

b. Determine physio-chemical characteristics of the developed snack product, and

c. Evaluate sensory attributes as well as consumer visual acceptance of the extruded protein enriched millet snack.
CHAPTER II – LITERATURE REVIEW

INTRODUCTION

According to UNICEF (2011), one of every eight children dies before the age of five in Niger. Malnutrition has been reported to be the cause of half of these deaths (UNICEF 2007). For a population of 15 million in Niger, almost 25% are vulnerable to malnutrition including 800,000 children of less than five years of age. Among these children, 160,000 are moderately under-nourished and 32,000 are severely under-nourished (UNICEF 2005). According to the research done by World Food Program, 10% of children of less than five years old were affected by acute malnutrition and 44% by chronic malnutrition (WFP.org). The recent results of the annual survey on child nutrition showed that the situation in Niger is getting worse in the last 12 months. An acute malnutrition rate of 16.7% for children aged less than five was reached in 2010 compared to an estimated 15% in 2009. Moreover, in 2010, the acute malnutrition led to an increase of mortality risks from 2.1% to 3.2% (UNICEF 2010). Because of the nutrition problems mentioned above, the United Nations Children’s Fund (UNICEF) and World Food Program (WFP) have implemented significant preventive and curative measures for children suffering from global acute malnutrition. These organisations introduced new products such as lipid-based nutritional supplements known commercially as Plumpy’ Doz and Supplementary’ Plumpy (UNICEF 2010). Unfortunately, these products are expensive because they are not made with local raw materials. Most of the extruded products are not only imported to Niger, but also they are not affordable to the majority of the population. Although other processing technologies such as steam cooker, puffing gun/chamber, hot-water boiler, steam vessel etc are
being used in the production of breakfast cereals and snack food products (Guy 1995). They are not as successful as the extrusion cooking technique.

It is in this perspective that we are proposing to use extrusion technology to develop a product made with local cereal [HkürLP (millet) and Dän ILA (beans)], fortified with soybean flour protein that will not only help in reducing protein deficiency undernutrition problems in Niger but also will be more economical. Extruded products are preferable to enrich with nutrients since they have low moisture content, are safer and will provide extended shelf-life in comparison to intermediate moisture food products.

**Extrusion**

Extrusion cooking is a rapid means to develop ready-to-eat cereals, snacks and many other products. Extrusion cooking first started in 1940s with the discovery of the single-screw cooking extruder (Mercier and others 1989). The use of twin-screw extruders for processing came in after 1970s and was believed to improve the physical properties of the extrudates, improve mixing, energy efficiency and control of the thermal changes of food constituents (Harper 1989). Hollingsworth (1996) defined extrusion as a process in which a dough-like product passes through a die plate under predetermined conditions of temperature, flow rate and pressure that is commonly used in the manufacturing of breakfast cereals, pastas, dog foods and other products with snack foods having the most rapid growth rate. Harper (1989) described extrusion cooking as a high-temperature short-time process where raw materials are exposed to transformations and chemical reactions that can lead to protein denaturation, starch gelatinization, enzymes inactivations and microbial load reduction. In the early 1950s, extrusion has been used in the production of breakfast cereals, snack foods and pet foods, though initially its use was limited to mixing and forming done by low-shear single screw extruders (Fast and
others 1990). Filli and others (2010) reported that the application of high temperature short time extrusion of producing snack cereal based foods is widely used. It is well-known in manufacturing of snacks and RTE foods and due to high temperature and short time, extrusion cooking is mostly preferred to other food processes as a result of its high productivity and significant nutrient retention (Guy 2001).

**Extrusion of Cereal Products**

In recent years, extrusion cooking has been considered to be one among the fastest growing food technology operations because of several advantages (Castells and others 2005). Extrusion is believed to yield safe and shelf-stable foods that can withstand spoilage for a long period of time; consequently it is useful during drought and food scarcity (Camire 2002). Numerous cereal based products have been developed using extrusion technology. Rice, sorghum, maize, wheat, oat, and corn are being the most commonly used products for extrusion. Ding and others (2005) developed rice-based expanded snacks through extrusion cooking. The use of cereal in combination with legumes, root crops, and fruits in product development via extrusion technology is not unusual. For example, Navneet and others (2010) combined rice flour with carrot pomace and pulse powder to develop an extruded product. Lobato and others (2011) reported extruded puffed functional ingredient with oat bran and soy flour. Deshpande and Poshadri (2011) used foxtail millet-based composite fours to extrude snacks. Ravindran and GamLath (2007) developed an acceptable snack product with fenugreek and debittered fenugreek poplysaccharide incorporated into chickpea-rice blends using extrusion cooking. Similarly, Ding and others (2005) used extrusion technology to develop rice-based expanded snacks. Serrem and others (2011) formulated and developed a fortified biscuit from sorghum, bread wheat flour and defatted soy flour.
Proximate Analysis of Raw materials

Starch, proteins, lipids, fibers, and low molecular sugars, are the main food ingredients which play a considerable role in the extrusion cooking processes. The raw materials are transformed and manipulated during extrusion cooking in the way to provide products with a unique structure and texture (Ilo and others 2000).

Moisture

Materials including water, lipids and low molecular sugars, act as plastificizers in the extrusion processes (Guy 1994). The plasticizers increase the mobility of the food polymer, and consequently decrease melt viscosity and melting of the biopolymer (Ilo and others 2000). During extrusion process, the feed moisture content gives not only the driving force for the expansion but also contributes to the rheological properties of the melt, which consequently affect expansion. Moisture is considered as the main plasticizer of flours, which enables them to undergo a glass transition and simplifies the deformation of the matrix and its expansion during the extrusion process (Moraru and others 2003). The decreased viscosity by the plastificizer decreases the shearing and the mechanical energy input in the cooking extruder which in turn affect negatively melting of the structure-forming biopolymer (Fan and others 1996), and consequently extrudate expansion. Plastificizers were reported to be used to control the mechanical energy input in extrusion processes and the functional properties of the extruded products (Ilo and others 2000).

Proteins

It has been reported that legumes are one of the most important sources of protein in developing countries (Molina and others 1977). The amount of protein and its digestibility are important to a feed material in extrusion process. Some proteins play a foremost role on structure
formation of the extrusion-cooked products (Ilo and others 2000). Moreover, complex such as maitland reactions can occur between protein and reducing sugars which can consequently lead to a reduced availability of dietary protein (Mauron 1981). Previous studies reported that, during extrusion cooking, high temperature can unfold and redistribute protein molecules within the plasticized mass in the extruder barrel and can expose them to thermal denaturation, in which amino acids can be altered or destroyed and can consequently lead to a final extruded product with decreased protein quality (Cumming and others 1973; Nielsen 1976; Dahl and Villota 1991). The digestibility of proteins can however be improved with heat treatment within certain limits (Rosentrater and others 2005).

**Lipids**

The extrusion cooking behavior of cereals and other starch-based materials is known to be highly dependent on fat content. In most cases, defatting improves the extrusion cooking behavior and increase overall expansion of the extruded products (Janes 1993). Oils and fats provide a powerful lubricant effect in the compressed polymer mix during extrusion cooking. All lipids become oils under extrusion cooking conditions the extruder barrel temperature rise to their melting points (Ilo and others 2000). Fats and oils were reported to affect the textural properties of the extruded product (Harper 1979). According to Acquistucci (2000), excessive heating destabilizes fat which results in evaporation of fine flavor volatiles and leads to a sticky mass of the product. Lipid oxidation is the major chemical challenge for extruded products preservation. A products’ nutritive quality such as essential fatty acids like C18:3 and C18:2, long-chain, unsaturated fatty acids can be reduced by lipid oxidation (Tran and others 2011). Moreover, due to metal wear on extruder part, high extrusion temperatures may increase the pro-oxidant transition metal concentration; especially iron (Lin and others 1998). O’Keefe and
Steward (1999) have reported that neutral, inorganic form of minerals, such as iron promote oxidation. A small significant interaction effect of lipid content and moisture content on the expansion ratio has been observed. Interaction between lipid content and starch content has significant positive effects on lipid loss (Hoan and others 2010). A decrease in expansion as a result of increase of the lipid content of wheat starch and flour blends have been reported by Faubion and Hoseney (1982b). Similarly, Bhatnagar and Hanna (1994) noted a decrease in expansion ratio due to the addition of 4% stearic acid in cornstarch before extrusion. According to Camire (2000), the expansion of extrudate with lipid content above 5–6% is limited. Conversely, addition of 3% oil to rice before extrusion has been found to improve expansion (Su and Kong 2007). Addition of emulsifiers such as sucrose esters could reduce oil loss during extrusion processing (De Pilli and others 2007).

The secondary decomposition of products such as ketones and aldehydes is as a result of lipid rancidity which consequently produces unpleasant odors and flavors (Milo and Grosch 1996). Autoxidation can be inhibited or retarded by the use of an appropriate or ideal antioxidant. Mujahid and others (2005) reported a significant decrease of free fatty acids and peroxide value of rice bran by extrusion cooking. They explained it to be as a result of inactivation of lipases and lipoxygenases which consequently stabilize the rice bran. Kong and others (2011) determined malonaldehyde and peroxide values in Extruded Salmon Jerky Snacks using SafTest Aldesafe test kit and Peroxysafe kit respectively. The use of an antioxidant to the extruded product will help in reducing rancidity. Methods used to monitor rancidity are: thermogravimetric analysis, chemiluminescence, infrared spectroscopy, high performance liquid chromatography (HPLC), differential scanning calorimetry (DSC), head space volatiles, and ultraviolet absorption.
Starch

Conditions of extrusion cooking conditions such as high temperatures, pressures and shear forces favored the disruption of starch granules, melting or swelling of starch granules at low moisture contents, and gelatinizing of starch granules at high moistures (Harper 1992). It was reported that the amount of polymer in continuous phase determines the extensibility of bubble cell walls in the foam and therefore the overall expansion of extrudate at the die (Guy 1994). The conditions of extrusion cooking such as temperature, moisture, pressure, shear and residence time were reported to affect the amount of the melted biopolymer, which forms the continuous phase (Ilo and others 2000).

Dietary Fiber (DF)

Beans are a major source of dietary protein, dietary fiber (DF), vitamins, starch, and certain minerals. Extrusion cooking is a good technique of producing fiber-enriched foods (Maria and others 1999). Camire and others (1997) reported that extrusion cooking is another means of modifying the functionality of DF. Maria and others (1999) concluded that extrusion caused a significant solubilization of DF components especially pectic polymers. Jin and others (1995) and Walsh and Woo (2010) reported a decrease in WSI with an increase in fiber. Walsh and Woo (2010) observed that extrudate properties showed significant statistical differences based on the amount of fiber in the extrudate (18, 36, 48%) and the type of fiber (cellulose, wheat, and oat) used. They noticed negative effects on physical properties as the amount of fiber in the extrudate increased. They also found out that expansion ratio was significantly influenced by fiber concentration and the interaction between fiber concentration and type. It was concluded that the addition of dietary fiber at approximately 18% in whey protein-extruded products can lead to limited undesirable effects on the physiochemical properties of the extrudates.
Ash

High extruder barrel temperature seemed to produce extruded products with higher ash contents than the low extruder barrel temperature (Rosentrater and others 2005). Based on the research of Rosentrater and others (2005), the screw speed did not have an effect on ash content of the extruded corn masa by-product. The results of the studies of Catootjie and others (2011) showed that extrusion cooking of peas had no effect (P<0.05) on the ash content of the extruded products. Similar result was reported by Alonso and others (1998), who also did not observe any extrusion conditions effect on ash content. In contrast, Diaz and others (2006) reported that the ash content of peas was increased by 4% following extrusion conditions. The discrepancy between earlier reports was probably due to the differences in the extruder type they used (single-screw and twin-screw extruders). As reported by Björk and Asp (1983), the extruder type is an important critical factor, which affects the degree of modification in nutritional properties of extruded products.

Physio-chemical Properties

Ding and others (2005) reported that that screw speed, screw configuration, feed rate, feed moisture and temperature profile in the barrel session, including the type of extruder affect significantly the quality of extrudates. They reported that the increase of barrel temperature decreases the extrudate density slightly and that feed rate and feed moisture significantly affect the expansion of the extrudates. They also observed that extrudate crispness are affected by barrel temperature and feed moisture. Badrie and Mellowes (1991) and Liu and others (2000) reported that an increase in feed moisture leads to an increase in the hardness of extrudate. Liu and others (2000) concluded that the increase in moisture content reduces expansion. Extrusion cooking sterilizes the finished product, gelatinizes starch, denatures undesirable enzymes,
denatures protein, preserves natural colors and flavors of foods, inactivates some antinutritional factors such as trypsin inhibitors, haemagglutinins, tannins and phytates, and reduces the microbial load in the final food product (Fellows 2000; Wolf 2010). Gelatinization occurs in extrusion at much lower moisture (12-22%) compared to other food processing techniques (Qu and Wang 1994). Singh and others (2007) concluded that mild extrusion cooking increases the protein, starch digestibility of foods and feeds and minimizes lipid oxidation. Filli and others (2010) reported that stretching and repeated fracture of protein-protein matrix are caused by increase in input energy as a result of the increase in screw speed. In their research, they reported that viscosity of the extruded millet-soybean blends is influenced by the screw speed. Gomez and Aguilera (1983) reported that high temperature and low moisture favor starch dextrinization during extrusion cooking of corn flour. The optimal Water solubility index (WSI) of 6.15% was obtained in an extruded product with 14.8% soybean of feed composition, 15.2% feed moisture and 220 rpm of screw speed (Filli and others 2010).

**Expansion Ratio (ER)**

Expansion describes the degree of puffing undergone by the extrudate as it exits the die of the extruder (Chanlat and others 2011). Ding and others (2005) reported that feed rate and feed moisture significantly affected the expansion of extrudates. Fletcher and others (1985) reported that increase in feed rate and screw speed results in greater elastic effects and an increase in the barrel temperature reduced the melt viscosity that lead to easier expansion of the extrudate. Results by Mercier and Feillet (1975) showed the expansion increases with increase of the extrusion temperature. More elastic dough that improves expansion is enhanced by a decrease in extrusion moisture. Chinnaswamy and Hanna (1988) reported that crispness, a major attribute of all snack foods, is related to the expansion of the extrudate.
Deshpande and Poshadri (2011) showed that the expansion ratio of extrudates decreased with increased level of cereals starch (millet) and decreased amount of proteins (chick pea and cow pea) which they attributed to a high level of dietary fiber contained in foxtail millet flour. Moraru and Kokini (2003) reported that protein affects expansion during extrusion via water distribution in the matrix as a result of their macromolecular structure, covalent and non-bonding interactions. Ravindran and GamLath (2007) reported a decrease in the radial expansion ratio of 70:30 chichpea-rice blend on which fenugreek and fenugreek polysaccharide were added. They concluded this result to be due to the high protein and dietary fiber contents in chichpea and fenugreek. Moreover, they asserted that the longitudinal expansion of extrudates increased as fenugreek and fenugreek polysaccharide were included in the blend. Expansion ratio, density, and hardness of snacks were observed to be significantly affected by soybean flour (Suksomboon and others 2011). The fragility, unit density, hardness of the extrudates were influenced by the level of the expansion of the extrudate while extruding out from the die (Rosentrater and others 2009a). The degree of expansion influences the texture and structure of the extrudate. High expansion of the extrudate will yield flour with a desirable texture (Hoan and others 2010).

Expansion ratio is important because it indicates the degree of starch gelatinization of the extrudate products. The greater the expansion ratio the greater the degree of gelatinization (Ding and others 2006).

**Bulk Density (BD)**

Bulk density (BD) is a measure of how much expansion has occurred as a result of extrusion (Boison and others 1983). It has been reported that the nature of protein in flour blends modifies the expansion of extrudates which consequently can affect the bulk density (Conway and Anderson 1973). Taranto and others (1978) reported that high bulk density indicates a more
uniform and continuous protein matrix of the extrudate. Deshpande and Poshadri (2011) reported that out of the three flour blends composed of foxtail millet, rice, amaranth, kabuli channa (Bengal gram), and cowpea at different proportions, the sample that had the highest amount of foxtail millet and rice had the highest bulk density which they concluded to be the result of the availability of more crude fiber in the flour blend. Ding and others (2005) reported that the extrudate density, feed moisture and temperature are dependent. They observed a sharp increase of extrudate density value as feed moisture increases. Limón-Valenzuela and others (2010) reported that the interaction between milk protein concentrate (MPC) and feed moisture in the expansion index in the extruded corn starch and quality protein maize blend showed that MPC increased bulk density when the feed moisture is low. However, the bulk density decreased at high moisture content. Bulk density has been shown to have an effect on the texture of the extrudates. High density will yield hard extrudate and vice-versa (Ding and others 2006). Density also indicates product floatability (Chevanan and others 2008).

**Moisture Retention (MR)**

Ravindran and GamLath (2007) reported a decrease in moisture retention of 70:30 chickpea-rice blend on which fenugreek and fenugreek polysaccharide were added. They concluded this result to be due to the high protein and dietary fiber contents in chickpea and fenugreek. Deshpande and Poshadri (2011) reported that out of the three samples (A, B, and C) they formulated using different proportions of foxtail millet flour, rice flour, amaranth flour, kabuli channa (Bengal gram) and cowpea flour, sample C which had the highest amount of kabuli channa flour and the least amount of foxtail millet flour to have the highest moisture retention. They explained this result to be due to high protein content of sample C as a result of its high amount of kabuli channa flour (a pulse). The protein content of the extrudates increased
the moisture retention. Moisture retention is important because it determines how much moisture content the flour blend can hold as it passes through the extruder barrel heat.

**Water Holding Capacity (WHC)**

Water holding capacity is believed to have an important functional property because of the role it plays in the formation of hydrogen bonds between water and polar residues of protein molecules (Filli and others 2010). Deshpande and Poshadri (2011) found that water holding capacity was at maximum for the sample with 70% millet flour which they concluded to be as a result of a high level of starch and crude fiber. The same observation was made by Shirani and Ganeshranee (2009) in chick pea and rice blend. The moisture retention of extrudates decreased as the proportion of chickpeas in the blend increased from 50% to 80%. Chang and others (2011) did not find any significant effect of WHC during extrusion cooking on fenugreek gum. Hwang and others (1998) and Ralet and others (1993) who worked on extrusion of apple pomace and pea hull noted that the WHC of their extrudates remained almost constant at milder extrusion process conditions, but noticeably decreased at more severe extrusion process conditions. Wu and others (2010) reported that the WHC of extruded flaxseed and maize samples were greater than those of unextruded blends. They noted that increase of feed moisture content significantly increased the WHC. The same result was reported by Njoki and Faller (2001). Wu and others (2010) explained this result to be as a result of protein denaturation, starch gelatinization and gel forming of the extruded sample which was induced by the increase of feed moisture. Porter and Skarra (1999) reported that WHC is important for various food systems consisting of protein or gel starch and water because it indicates the ability of a protein or starch matrix to absorb, bound hydrodynamically to capillary, and physically entrapped water against gravity.
**True Density (TeD) and Tap Density (TD)**

TeD and TD are an indication of the overall expansion and the changes in cell structure, pores and voids developed in the extrudates as effect of processing as well as raw material parameters (Deshpande and Poshadri 2011). TeD can also be used to quantify the structure of a food material by accounting for internal pores (Stroshine and Hamann 1995). Preetam and others (2011) reported a decrease in true density with increase in fruit solid level in the utilization of prickly pear fruit solids in extruded food products where feed rate, feed moisture content, screw speed, and barrel temperature were the variable factors. Previous studies reported that the true density increased with cereals starch in extrudates (Qing and others 2005; Deshpande and Poshadri 2011). Rosentrater and others (2005) reported higher true density values on an extruded corn masa by-product than the corresponding unit density values which they explained to be due to the fact that many of the entrained pores were open to the surface.

**Mass Flow Rate (MFR)**

Mercier and others (1989) reported that mass flow rate (MFR) relies on the pressure flow as a result of the die and the drag flow due to screw rotation in a single-screw extruder. Deshpande and Poshadri (2011) showed that mass flow rate variation was minimal for the three flour blends composed of foxtail millet, rice, amaranth, kabuli channa (Bengal gram), and cowpea at different proportions. They concluded that the little variation of mass flow rate of the three blends was due to constant maintenance of barrel temperature and the moisture content of the feed mixtures. Factors such as the diameter of the die, the screw speed (Kannadhason and others 2009b), viscosity, moisture content, shear rate, blend composition (Chevanan and others 2008) can influence MFR. The mass flow rate is a way of knowing the execution or performance of the extruder during processing.
Fat Absorption Capacity (FAC)

Fat Absorption Capacity (FAC) denotes the amount of oil which can be bound to matrices in a particular food system and used as the index of hydrophobicity of the food. It is expressed as the grams of oil bound per gram of the extrudates (Deshpande and Poshadri 2011). Oil absorption capacity is important because oil plays a role in retaining flavor; therefore changing the mouth feel of foods (Aremu and others 2007). Abdel-Aal and others (1992) reported that extrusion conditions had little effect on Fat Absorption Index (FAI) when rice flour and faba bean protein concentrate blend was used. Similarly, Bryant and others (2001) reported that the FAI of the extruded flours was similar to that of the unextruded rice flours. Contrary to the findings of Abdel-Aal and others (1992) and Bryant and others (2001); Horvath and others (1989) reported a decrease in FAC in the extrusion of full fat soybean flour as the extruder barrel temperature increased.

Milk Absorption Capacity (MAC)

One of the most important characteristics which appeals consumers on RTE cereals appeal is the texture after being submerged in milk (Calandro and Murray 1992). Humans tend to like foods, which undergo textural changes during mastication (Lawless 2000). Consumers prefer RTE cereals with the ability to retain their texture after being submerged in milk. Bartolomei and Thesing 1998 defined the time a cereal can retain its desired crispness after being added to milk as the “bowl life”. It is important that extruded products should be mildly thick to retain their integrity in the dry mixture and should not release much flour, which would tend to settle on the bottom of the package. However, the extruded products must not be too soft and slimy but should be soft enough to facilitate easy eating soon after pouring the milk on them (Kalviainen and others 2002). Kalviainen and others (2002) reported that thin and the medium
flakes had stronger milk absorption capacity when they were kiln dried, compared to flakes with no kiln drying and that consumers preferred fragile and mushy extruded products that absorbed plenty of milk with mild taste and which did not need plenty of mastication. Luckett and Wang (2012) reported that all starch-coated cereals had a lower milk absorption value than the uncoated (control) and that among starch coatings, common corn starch and Hylon VII resulted in lower milk absorption than did waxy corn starch.

**Protein Solubility (PS)**

Stutts and others (1988) reported extrusion processing reduced cottonseed protein solubility as measured by three methods (cold water mixed for 30 min, cold water homogenized for 5 s, and hot water refluxed for 1 h). High extruder barrel temperature was reported to decrease PS (Cheryan 1980; Reddy and others 1985). They explained to be due to the complexes formed by tannins and polyphenols with proteins in the flour blend which consequently increases the degree of cross-linking and decreases the solubility of proteins. Similarly, Elzbieta and Khalil (1990) reported that lower protein solubility was associated with higher temperature of extrusion for all extruded beans high starch fraction they worked on in their experiment.

**Water Absorption Index (WAI) and Water Solubility Index (WSI)**

Water Absorption Index (WAI) is the weight of gel obtained per g of dry product and Water Solubility Index (WSI) is the amount of dried solid recovered by evaporating. Ding and others (2005) defined WAI to be the measurement of the volume that occupies the extrudate starch after it is swollen in excess water and maintained the integrity of starch in aqueous dispersion. Water Solubility Index is described as the rate and degree to which the materials dissolve in water (Filli and others 2010). According to Yang and others (2008), WSI can indicate the degradation of molecular components and measures the extent of the conversion of starch
during extrusion as the amount of soluble polysaccharide that was released from the starch component after extrusion. An increase of the feed moisture has been reported to decrease the WSI significantly (Filli and others 2010). Yagci and Gogus (2008) related WAI to the dispersion of starch in excess water which increased as the extent of starch damage is increased as a result of gelatinization and extrusion-induced fragmentation. Increase of feed moisture has been reported to significantly decrease the WAI of extrudate (Filli and others 2010). In the same research, they also observed a decrease in WAI as the level of soybean flour was raised in the blend which they concluded to be as a result of interference of soybean oil with water uptake.

Similarly, Singh and others (2007) noticed a decrease in WAI with increase of pea grits in extrusion of rice which they explained to be due to the starch dilution in rice pea blends. Deshpande and Poshadri (2011) reported an increase of WAI of the three flour blends composed of foxtail millet, rice, amaranth, kabuli channa (Bengal gram), and cowpea at different proportions as the amount of chick pea and cowpea is increased in the composite flour. In the same research, they showed that WSI of the extrudates increased with increase in Bengal gram from 10% to 30% in the flour blend. According to Mercier and Feillet (1975), high amylose leads to high WAI. An increase of WAI as the percentage of cowpea increases in cowpea extrudates has been reported (Pelembe and others 2002). Colonna and others (1989) found that the beginning of dextrinization results in a decrease of WAI. An increase of WSI with severity of screw configuration was observed by Binoy and others (1996). Mezreb and others (2003), Altan and others (2008) and Filli and others (2010) reported an increase of WAI with increase of screw speed in the extrusion of barley-tomato and millet-soybean blends respectively. Water Absorption Index is important in this research because high WAI shows the extent of gelatinization and dextrinization which is a result of good starch digestibility (Guha and others
Water Solubility Index indicates the degree of starch conversion during extrusion (Ding and others 2005).

**In Vitro Starch Digestibility (IVSD)**

Extrusion cooking increased the proportion of rapidly digestable starch which also caused a steep increase in vitro starch digestion (Tiehu and others 2006). Studies had showed that extrusion treatment improved ileal digestibility of starch in winter peas in weaned pigs (Bengala-Freire and others 1991; Tiehu and others 2006). Extrusion of peas was reported to greatly elevate starch and protein digestibility in vitro (Alonso and others 2000a) as a result of a direct effect of the extrusion on the starch granules (Alonso and others 2000b). Severe heat treatments such as extrusion cooking may cause a formation of resistant starch as a result of intimate packing of amylase upon cooling (Vasanthan and Bhaty 1998; Haralampu 2000). Alonso and others (2000b) reported a great IVSD value at high extruder barrel temperature which could be related to the reduction of trypsin and chymotrypsin inhibitory activities at higher extruder barrel temperature which eventually improves the IVSD.

Any product for commercialization needs to be consumer acceptable. The two major attributes are color and texture.

**Color**

It is of paramount importance that food scientists should make sure that newly developed foods should not only be nutritious, but their appearance, color, taste, smell, and flavor should be attractive to consumers. Color is the most important attribute that influences the acceptability of a product by the consumer. A consumer may never try a product whose color is unpleasant (Stewart and Amerine 1982). Color serves as an attraction and acceptability of extruded products to consumers and customers (Harper 1979). Manoharkumar and others (1978) reported that
moisture content and particle size were the variables that effect color of extruded maize using a single-screw extruder. Apruzzese and others (2000) reported that the interaction of temperature and screw speed have effect on the luminance or lightness (L). Ravindran and GamLath (2007) observed slight changes in color of the chichpea-rice blends based snack they develop using extrusion technology, though the slight color changes did not affect consumer acceptability of the product. Limón-Valenzuela and others (2010) observed that extrusion affected color parameters. The values of ‘L’ and ‘a’ of corn starch and quality protein maize flours decreased after the extrusion process. Lightness (L) was reported to be extrusion temperature and moisture content dependent. Lightness (L) increased with increase in moisture content of the extrudated maize grits (Ilo and Berghofer 1999). Changes in the color of extruded products containing starch can indicate the processing intensity of chemical changes or loss of nutritional value of foods (Bastos-Cardoso and others 2007).

**Texture**

Texture is one of the major attributes of a product that attracts buyers. It has been reported that texture correlates well with observed deformation forces and sensory attributes of food products (Hui 1992). Liu and others (2000) used a texture profile analysis on extruded oat-corn puff and found out that springiness, gumminess, fracturability, hardness, and cohesiveness were significantly affected by the variation of screw speed, moisture content, and different percentage of oat flour. Only chewiness was found not affected by the screw speed. Ding and others (2006) conducted a texture analysis on wheat-based expanded snacks and noted that the feed moisture affected the density and expansion of the extrudate which consequently affect the extrudate texture. They reported that low expansion and high density will lead to a harder extrudate. Similar results were reported by Ding and others (2005) and Suksomboon and others
(2011). It was observed that increase in barrel temperature decreased the extrudates hardness (Suksomboon and others 2011).

**Sensory Evaluation**

Tuorila and Cardello (2002) defined sensory science as: “a discipline dealing with human sensory perceptions of and affective responses to food, beverages and their components.” Descriptive and quantitative methods are the two methods for testing products in sensory science (Meilgaard and others 2007).

**Sensory Evaluation of Extruded Product**

Ravindran and GamLath (2007) reported that the incorporation of fenugreek or fenugreek polysaccharide in chickpea-rice blends base snack products had crunchy texture which is a desirable characteristic of a snack product. Through sensory evaluation, they found that up to 15% of fenugreek polysaccharide can be successfully added into the chickpea-rice flour mixture to produce acceptable snack products.

Severe extrusion conditions (high-temperature, low feed moisture and high shear) has been reported to change the dietary fibre content probably due to soluble fibre increase, and the resistant starch and enzyme-resistant glucans formation through possibly transglycosidation (Vasanthan and others 2002). Deshpande and Poshadri (2011) used 25 panelists to conduct a sensory analysis on foxtail millet extruded snack using nine-point hedonic scale. Their results showed that 70% millet and 30% pulses can be mixed with success to give a better acceptable product. Similarly, Suksomboon and others (2011) used the same sensory technique (9-point hedonic scale) with 30 untrained panelists to evaluate the preference of a snack made from purple rice and soybean flour blend. They reported an increase of hardness of the snack as feed moisture increased. However, they noted that increase in barrel temperature decreased hardness
of the snacks. Chanlat and others (2011) observed that feed moisture and screw speed did not affect the hardness of the extruded pre-germinated brown rice snack base using the Pearson’s correlation coefficients. However, they noted that feed moisture significantly affected the brittleness of the product, whereas the screw speed had no effect on the extrudate brittleness. Sensory is important in order to evaluate the preference and overall visual acceptability of millet, bean, and soybean flour blend extruded snack.

**Interaction between carbohydrate and protein**

Some proteins and polysaccharides are used to form food gels in a food. Their mutual interaction is of paramount significance to food texture (Morris 1973). Ravindran and GamLath (2007) reported that the competition for availability of water between starch and protein fractions affect the viscoelastic properties of a dough, which consequently retard starch gelatinization, lower the moisture and expansion in the extrudates. Proteins and polysaccharides can create junctions that are due to non-covalent bonding, and commonly interact often when in proximity to each other (Stainsby 1980). Stainsby (1980) also reported that under suitable conditions of pH and ionic strength, ionic bonding can occur though it is only restricted to charged polysaccharides. Wilson (1978) reported that pectin esters can be used to crosslink with small molecules such as 1:6 of diamine and hexane, but pectin esters were not successful in making gels with protein. Alginate has been successful in hardening photographic gelatin gels which prevent melting and control swelling during the developing processes. Heat treatment of foods rich in reducing sugars may result in Maillard, which occurs between sugars and amino acids, peptides, or proteins effecting changes in the color, flavor, functional properties, and nutritional value of the food (John and Morrisey 1989). Erbersdobler (1977) and Klostermeyer and Reimerdes (1977) reported that Maillard reaction not only destroys essential amino acids in food,
but also reduces protein digestibility. John and Morrissey (1989) listed the factors affecting the rate of maillard browning as:

1) Nature and molar ratio of reactants: low molecular weight compounds tend to be more reactive than high molecular weight compounds as a result of greater steric hindrance in the latter. Lea (1948) gave examples of aldopentoses, monosaccharides, aldoses, glucose which are more reactive to aldohexoses, di-or oligosaccharides, ketoses, and lactose, respectively.

2) Moisture content and physiochemical state of the food system: increase of moisture content increases the rate of reaction exponentially up to a maximum, thereafter decreases the rate of the reaction (Labuza and others 1970). The food system, whether crystalline or amorphous may affect the maillard reaction (Supplee 1926). An amorphous food system absorbs more water in the spaces between the molecules at low water activity whereas absorption of water can only take place at the surface of the crystal lattice in a crystalline system (John and Morrissey 1989). Thus, the water is then available for interaction with other food components affecting the rate of maillard reaction (Labuza and Saltmarch 1981).

3) pH: at acid pH values, the rate of browning is low and increases with increasing of pH to a maximum at a pH of 10 (Ashoor and Zent 1984).

4) Miscellaneous factors affecting the rate of maillard browning: copper and iron are believed to increase the maillard reaction while tin and manganese appear to inhibit it (Kato and others 1981).

Protein and carbohydrate interactions form insoluble aggregate which subsequently decrease expansion and air cell diameter and increase density and breaking strength of the
extruded products. Protein-starch interactions are enhanced by the capability of proteins to become unfolded during extrusion which results to decrease in expansion and overall quality (Taylor and others 2006). They recommended maintaining high levels of soluble carbohydrate and protein in order to boost extrudate expansion. Matthey and Hanna (1997) concluded that both whey protein and amylose content should be low in order to achieve a good product expansion after they have extruded starch based snacks containing 30% whey protein concentrate. Parker and others (2000) reported that maillard and isopeptide reactions can lead to protein and carbohydrate insolubility.

The proximate analysis and the determination of expansion ratio, bulk density, water absorption index, water solubility index, moisture retention, mass flow rate, water holding capacity, viscosity, gelatinization, color measurement, texture analysis, sensory evaluation as well as knowing the protein- carbohydrates interactions are crucial to the overall quality of the extruded snack.
CHAPTER III: PHYSIO-CHEMICAL AND SENSORY PROPERTIES OF THE EXTRUDED PRODUCTS

ABSTRACT

Millet, beans, and rice mixed with soymeal flour were processed to produce a snack using a single screw extruder. The proximate analysis of the four flours was examined. Central Composite Design (CCD) models were set with levels of 190 and 275°C for barrel temperature and 60 and 110 rpm for screw speed. The physio-chemical and sensory properties of the extruded products were determined. The data showed that the barrel temperature and screw speed significantly affected all physio-chemical properties tested except for fat absorption capacity and water solubility index. At higher temperatures (275°C), the moisture content, the hardness, and moisture retention of the extruded products were the lowest but the highest in water holding capacity and water absorption index. The lowest screw speed (60 rpm) produced results with the most sensory appealing extruded products. The best extrusion conditions obtained were 60 rpm (screw speed) and 190°C (barrel temperature) in term of mass flow rate, protein solubility, true density, expansion ratio, and sensory properties. The data suggested that best extrusion conditions can be obtained using CCD design to influence the physio-chemical and sensory properties and to prepare a snack food with optimum moisture, texture, and sensory appeal.

INTRODUCTION

Protein malnutrition is responsible for half of the deaths of children under the age of five each year in developing countries. More than 70, 26, and 4% of children with protein-energy malnutrition live in Asia, Africa, and Latin America/Caribbean, respectively (WHO 2000). Snack foods prepared using cereals grains are most preferred by consumers due to good expansion characteristics, although they tend to be lower in certain nutrients including protein
(Meng and others 2010). As a result, a demand for a snack with enhanced nutrition exists (Agriculture and Agri-Food Canada 2008).

Extrusion technology has been widely used in the preparation of cereal-based snack products (Choi and others 2007). Extrusion is believed to yield safe foods that have a long shelf life; hence extrusion is a useful, economical processing technology to prepare food products and to manage food scarcity during drought conditions (Camire 2002). Due to its versatility, low cost, efficiency, product quality and eco-friendliness, extrusion has been in wide use during the past two decades (Guy 2001).

Many authors have supported the idea of developing products using cereal/legume blending to fight problems of hunger and malnutrition in developing countries (Akinyele 1987; Jin and Xiao–lin 1994; Obatolu 2002; Iwe 2003). Several reports have demonstrated that mixing legumes and cereals, which are stable foods in the tropics can supplement each other nutrition-wise (Kokini and others 1992; Delvalle and others 1981). Rinaldi and others (2000) developed an extruded cereal product using wheat flour and enhanced its protein content with wet okara (the residue left after soymilk or tofu production). Extrusion of millet and soybean blends in the production of “fura”, a traditional Nigerian food, has been reported (Filli and others 2010) and Meng and others (2010) also developed a chickpea-flour-based snack. An extruded puffed product has been developed with corn flour supplemented with soybean and safflower pastes to improve the protein content of the extrudates (Martinez-Flores and others 2005). The study of Martinez-Flores and others (2005) also showed that other protein sources, such as defatted wheat germ, casein, and soy paste, when used, can improve the quantity and quality of the protein present in corn-based snack.
Ding and others (2005) reported that screw speed, screw configuration, feed rate, feed moisture, and temperature profile in the barrel section, including the type of extruder, significantly affect the quality of extrudates. Extrusion-cooking parameters, such as barrel temperature, screw speed, moisture content, die diameter, and feed rate, have been reported to influence the physio-chemical characteristics of extrudates (Harper 1989; Ali and others 1996).

A sensory analysis is imperative for the success of a newly developed food product in the market. Consumers are concerned about food flavor and overall visual acceptability of the product (Luckow and Delahunty 2004). Consumer acceptability evaluation is crucial for indicating the degree of liking or preference of a product (Choi and others 2007).

Millet, rice, and bean are staple foods in developing parts of the world including Africa. They are cheap, affordable, and have been used in the making of our snack. In our preparation, the low millet starch content was fortified by the use of rice; while bean and soymeal flour were selected to enhance the protein content of the snack. There are limited studies in the literature on how these four flours can be combined to prepare a snack using an extrusion technology and how their physio-chemical and sensory properties are affected by the extruder conditions such as barrel temperature and screw speed. Hence, the overall objective of this work was to develop a snack with a single-screw extruder using millet (Panicum miliaceum), bean (Vigna unguiculata), rice (Oryza sativa) and soybean (Glycine max) meal flour for protein enrichment and to determine the physio-chemical characteristics and sensory analysis of the developed snack product. Sensory properties were evaluated in terms of color and overall visual acceptability of the extruded products.
MATERIALS AND METHODS

Millet and Bean flour were supplied by the Institut National pour la Recherche Agronomique du Niger (INRAN), Niamey, Niger. Rice flour and sea salt were purchased from a local store. Soybean meal was supplied by GROVAC Systems (McKinney, TX, USA). All chemicals used were reagent grade.

Experimental Design and Extrusion Conditions

Central composite design (CCD) was used to obtain best extrusion conditions to develop a snack made of millet, bean, rice, and soy-flour-based snack. Results from preliminary reported literatures were used to select a suitable extruder operating window. The independent variables considered for this study were screw speed and barrel temperature with two different levels, 60 and 110 rpm, and 190 and 275°C, respectively. Experiments were randomized in order to minimize the systematic bias in the observed responses due to extraneous factors.

Rice (10%), beans (16%), soy (16%), and millet (20%) flours were passed through a 60-mesh sieve (250 microns) to obtain uniform particle size. Flours were mixed with salt (0.5%), glyceryl monostearate (6%), and water (31.5%) in a mixer (KitchenAID Inc., St. Joseph, Michigan, USA). The homogeneously mixed product was extruded at varying barrel temperatures (190-275 °C) and screw speeds (60-110 rpm). The extrudates were dried in a dehydrator (Harvest Saver, Model R-4, Commercial Dehydrator System Inc., Eugene, Oregon, USA) at 40 °C.

A single-screw extruder (Killion Extruders Davis-Standard Corporation, Serial # 30337, Cedar Grove, New Jersey, USA) with 939.8 mm length, 1168.4 mm height, 660.4mm width, three heating zones (feed zone, central zone, and die zone) and a screw and die diameter of 19.1 and 31.8 mm, respectively were employed in this study. The barrel temperature in the die zone
was varied from 190 and 275°C along with the screw speed from 60 to 110 rpm using CCD design whereas the temperatures of feed and central zones were set at 35°C and 15 °C less than in the die zone. An in-built thermostat and a temperature control unit were set to maintain the desired barrel temperature by a circulating tap water.

The raw material was fed into the extruder, which passed through the three temperature control zones. During extrusion, the temperature zones were adjusted at varying levels. The screw speed was varied between 60 and 110 rpm. The extrusion conditions are shown in Table I. The extrudates were collected, dried, and physio-chemical and sensory properties were evaluated.

**Proximate Analysis of the Raw Materials**

**Moisture Content Determination** (Hot air oven method, 44:19 AACC 1983, Vol 1)

Two grams of the sample was weighed, placed into the oven in aluminum pans and heated at 135°C for two hours. The percentage moisture content was calculated using this formula: The percentage moisture content was determined on wet basis.

\[
\text{\% Moisture and volatile matter} = \frac{\text{Loss of moisture}}{\text{Weight of sample}} \times 100
\]

**Protein Content Determination** (Kjeldahl method, 46:10 AACC 1983, Vol 1)

A 0.2 g of sample was added into 350 mL digestion tubes in triplicate. Ten milliliters of concentrated H₂SO₄ and one Kjeldahl tablet (CuSO₄ + K₂SO₄) were added into the digestion tubes and digested for one hour at 420°C in a fume hood to hydrolyse the protein. The digested products were cooled to ambient temperature and distilled using the Keltec 2000 analyzer (Foss
Inc.) with 40% NaOH titrated with 0.1 N HCl and the nitrogen content was measured. Conversion factor of 6.25 was used for titrable nitrogen to convert it to crude protein percentage.

**Lipid Content Determination** (Soxhlet method, 30:25 AACC 1983, Vol 1)

Three to five grams of the sample were weighed in filter paper and rolled to fit into thimbles. The thimbles were placed inside the soxhlet glass tubes. One hundred and fifty to two hundreds mL of petroleum ether were added to the tubes and distilled at 65°C for six hours. The flasks were vacuum distilled in a rotovapor (Buchi Inc) set at 60°C to remove the petroleum ether from the oil. The residual petroleum ether in the oil was removed by evaporation under a fume hood. The lipid content was calculated using the difference in the weights of flasks and present lipid content in percentage.

**Starch Content Determination** (76: 13 AACC 1983, Vol 1)

Approximately 100 mg of the sample and pure maize flour (with 99% starch content was used as a reference) was separately weighed into glass tubes in triplicate. A 0.2 mL of 80% ethanol was added and vortexed to thoroughly mix the sample with ethanol. A 2 mL aliquot of 2 M KOH was added and the samples re-suspended by stirring for 20 minutes in an ice water bath. Eight milliliters of 1.2 M sodium acetate buffer (pH 3.8) were added to each tube and stirred with a magnetic stirrer at a setting speed of 6. To this solution, 0.1 mL of thermostable alpha-amylase and 0.1 mL of amylo-glucosidase were added, and mixed well. The tubes was placed in a water bath at 50°C and incubated for 30 minutes with intermittent mixing on a vortex mixer. The contents of the tubes were quantitatively transferred into a 100 mL volumetric flask (using a wash bottle) and mixed. An aliquot of the diluted solution was centrifuged at 1,800 g for 10 minutes in order to obtain a clear supernatant. Aliquots in duplicate of 0.1 mL of the diluted solution, distilled water (as a blank) and a standard of D-glucose standard solution was
transferred to a culture tube. Three milliliters of Glucose oxidase/peroxidase (GOPOD) reagent was added, vortexed, and incubated for 20 minutes at 50°C. The absorbance for each sample was monitored at 510 nm against the reagent blank. The percentage starch was calculated using this formula:

\[
\text{% starch} = \frac{A \times F \times \frac{FV \times 0.1 \times 1}{1000} \times \frac{100}{W} \times \frac{162}{180}}
\]

\[
= A \times F \times \frac{FV}{0.9}
\]

Where:

\( A \) = Absorbance (reaction) read against the reagent blank.

\( F \) = Absorbance for 100 ug of D-glucose

\( FV \) = Final volume

\( W \) = Volume of sample analysed

\( 1 / 1000 \) = Conversion from ug to mg

\( 100 / W \) = Factor to express “starch” as a percentage of flour weight

\( W \) = the weight in milligrams (“as is” basis) of the flour

\( 162/180 \) = Adjustment from free D-glucose to anhydro D-glucose (as occurs in starch)

\[
\text{% starch w/w (dry wt. basis)} = \frac{\text{% starch w/w (as is)}}{100} \times \frac{100}{100 - \text{Moisture content (%w/w)}}
\]
**Dietary Fiber Content Determination** (32:05 AACC 1983, Vol 1)

A triplicate of approximately 1 g of the sample was weighed into a 400 mL beaker. Fifty mL at pH 6.8 of phosphate buffer were added to the beaker and pH adjusted to 6.0 ± 0.1. A 0.2 mL heat-stable alpha amylase solution were added. The beaker was covered with aluminium foil and placed into boiling water bath for 15 minutes with gentle shaking at five minutes interval. The solution was cooled to room temperature and pH adjusted to 7.5 ± 0.1 by adding 10 mL 0.275 N NaOH solution. Five mg of pepsin was added to the solution, the beaker covered with aluminium foil and incubated at 60°C with contunious agitation for 30 minutes. The solution was cooled and pH adjusted to 4.5 ± 0.2 by adding 10 mL of 0.325 HCl solution. 0.3 mL of amylloglucosidase were added, the beaker covered with aluminium foil, and incubated for 20 minutes at 60°C with continuous agitation. Two hundreds and eighty mL of 95% ethanol preheated to 60°C were added to the solution and allowed to precipitate at room temperature for 60 minutes. Crucible contents were weighed to the nearest 0.1 mg. Bed of celite was distributed in crucible using stream of 78% ethanol from wash bottle. Precipitates were quantitatively transferred from enzymes digest to crucibles. The residue was successfully washed with three 20 mL portions of 78% ethanol, two 10 mL portions of 95% ethanol, and two 10 mL portions of acetone. The crucible contents residue were dried overnight at 105°C air oven, cooled in desiccator, and weighed to nearest 0.1 mg. crucible and celite weights were subtracted in order to determine the weight of residue. The residue of one sample of set of duplicates was analyzed for protein content determination. The second residue of duplicate was incinerated for 5 hours at 525°C, cooled in desiccator, and weighed to nearest 0.1 mg. Crucible and celite weights were subtracted to determine ash content. Fiber content was calculated based on the formulae below:
Calculations

Uncorrected Average Blank Residue (UABR) = Average blank residue of duplicate blanks in mg

Blank Protein Residue (BPR) = UABR multiply by protein percentage in blank divided by 100.

Blank Ash Residue (BAR) = UABR multiply by percentage ash in blank divided by 100.

Corrected Blank (CB) = UABR-BPR-BAR

Uncorrected Average Sample Residue (UASR) = Average sample residue of duplicate samples in mg.

Sample Protein Residue (SPR) = UASR multiply by percentage protein in sample divided by 100.

Sample Ash Residue (SAR) = UASR multiply by percentage ash in sample divided by 100.

Corrected Sample Residue (CSR) = UASR-SPR-SAR-CB

Percentage Total Dietary Fiber = 100 * CSR/ mg sample.  \hspace{1cm} (3)

Ash Content Determination (08:01 AACC 1983, Vol 1)

Three to five grams approximately (± 0.01g) of the sample were weighed into an ashing dish and placed in muffle furnace at 550°C until light gray ash is obtained. Percentage ash was calculated using this formula:

\[
\% \text{ Ash} = \frac{\text{Weight of residue}}{\text{Weight of sample}} \times 100 \hspace{1cm} (4)
\]
Physio-chemical and Sensory Properties

Expansion Ratio (ER)

The method of Fan and others (1996) was used to determine the expansion ratio. The mean of 10 random measurements of the extrudate diameter was determined using a vernier caliper.

\[
ER = \frac{D}{d}
\]

Where \(D\) = mean diameter of the extrudate in mm

\(d\) = diameter of the die in mm

Bulk Density (BD)

The method of Deshpande and Poshadri (2011) was followed to determine the bulk density. The average diameter and average length of 25 readings of extrudates were measured and the volume of the extrudates computed as: \(\text{vol. (cm}^3) = \pi d^2 L/4\)

Where \(d\) = average diameter of extrudates in cm

\(L\) = average length of extrudates in cm

The bulk density was obtained as:

\[
BD (\text{Kg/cm}^3) = \frac{\text{Mass of extrudate (Kg)}}{\text{Volume of extrudates (cm}^3)}
\]
Moisture Retention (MR)

The feed and extrudate moisture contents were determined by (AACC 1983).

\[
MR = \frac{\text{Product moisture}}{\text{Feed moisture}} \times 100
\]  

Water Holding Capacity (WHC)

Approximately 5 gm of fine ground (pass through a 60 mesh sieve) of extrudate were weighed and allowed to absorb water over night in excess water (7:1). The flour was reweighed after it had drained (Deshpande and Poshadri 2011).

\[
\text{WHC} = \frac{\text{Weight of wet sample} - \text{weight of dry extrudate}}{\text{Weight of dry extrudate}} \times 100
\]

Tap Density (TD) and True Density (TeD)

The tap and true density were determined following the method of Deshpande and Poshadri (2011). The extrudate flour was filled in a 50 mL cylinder up to 20 mL and tapped 10 times. The weight of the 20 mL of extrudates was measured.

\[
\text{TD (gm/cc)} = \frac{\text{Weight of 20 mL (gm)}}{\text{Volume of the sample (20 mL)}}
\]

Approximately 1 gm of ground extrudate was added to a 10 mL cylinder containing toluene. Then the toluene level was raised and measured and an average of three readings of true density was calculated as:
\[ TeD \, (\text{gm/mL}) = \frac{\text{Weight of ground sample of extrudates (gm)}}{\text{Rise in toluene level (mL)}} \]  

(Mass Flow Rate (MFR))

The mass flow rate was determined according to the method of Singh and others (1996). The extrudate was collected in plastic plates for two minutes as soon as it came out of the die and its weight taken instantly after cooling to ambient temperature.

\[ \text{MFR} \, (\text{gm/sec}) = \frac{\text{Weight of sample collected (gm)}}{\text{Time taken to collect sample (seconds)}} \]  

(Fat Absorption Capacity (FAC))

A 0.5 gm of the extrudate powder was mixed with 10 ml canola oil and centrifuged at 750g for 15 min. the supernatant was drained off for 30 min using cheese cloth and the weight gained reported as oil absorption capacity (Sogi and Chandi 2007).

(Milk Absorption Capacity (MAC))

A 4gm sample of extrudate was placed in 30 ml of milk (1% fat) at 8°C for 3 mins, and the extrudated was removed from the milk and drained on a stainless steel mesh 2.8 microns screen for 10 seconds. The percentage milk absorption was calculated by dividing the absorbed milk weight, which was the the weight difference between the original extrudate and the drained extrudate with the original extrudate weight (Luckett and Wang 2012).
**Protein Solubility (PS)**

A 10 mL of the filtrate obtained from the water holding capacity experiment was analyzed for nitrogen using a Kjeldahl method. A nitrogen to protein conversion factor of 6.25 was used to derive the percentage soluble protein (McWatters 2002).

**Water Absorption Index (WAI) and Water Solubility Index (WSI)**

The technique developed for cereals by Anderson and others (1969) was used to measure the WAI and WSI. A 2.5 gm sample of extrudate powder was suspended in 30 mL of distilled water at 30°C in a 50 mL tube, stirred continuously for 30 min, and centrifuged at 3,000g for 10 min. The supernatant was poured carefully into a tared evaporating aluminium dish. The remaining gel was weighed and the WAI calculated from its weight. The amount of dried solids recovered by evaporating the supernatant from the water absorption test was expressed as percentage of dry solids.

\[
\text{WAI} = \frac{\text{Weight of sediment}}{\text{Weight of dry solids}} \quad (12)
\]

\[
\text{WSI} (%) = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of dry solids}} \times 100 \quad (13)
\]

**In Vitro Starch Digestibility (IVSD)**

A solution of defatted extrudate flour and amylase solution with 50mg/mL of 0.2 M phosphate buffer of pH 6.9 and 0.4 mg of pancreatic amylase (1300u/mg) per mL of 0.2 M phosphate buffer of pH 6.9 were prepared, respectively. A 0.5 mL of the amylase solution was added to the extrudate flour suspension at 20°C for 2h. At the end of incubation period, 2 mL of 3, 5- dini-trosalicyclic acid reagent prepared according to the method of Miller (1959) were
added to the mixture and boiled for 5 min. After cooling, the absorbance of the filtrate was measured at 550 nm (Sing and others 1982) with glucose used as a standard instead of maltose and the values were expressed as µg of glucose released per gram of sample. A standard curve with glucose solutions (0, 20, 40, 60, 80, and 100 µg/mL) was prepared.

**Color**

The color of the extruded products was determined using a Minolta colorimeter CR-300 (Minolta Camera Co., Ltd., Chou-Ku, Osaka, Japan) and recorded using L*a*b* color system.

![Color Diagram](image)

**Texture**

Samples containing 5gm of the extrudate were placed in the load cell of an Alliance RT/1 texture analyzer (MTS Systems, Eden Prairie, MN) to determine the shear force of the extruded products. A clean 10-set Kramer shear blade at a pre-load speed of 5.0 mm/s, strain endpoint of 120.0 mm/mm, a post-test speed of 5 mm/s, and a test speed of 10 mm/s was used and the test
was conducted using the MTS compression (2.0) method. The force used by the blade to fracture the extruded products, known as the peak load (N) value, was noted for triplicate samples.

**Sensory Evaluation**

Hedonic sensory tests were conducted by 38 untrained panelists. The samples were placed on white plates coded with alphabetic letters under normal lighting conditions at room temperature. Sensory attributes, including color (liking and either the color is light or dark) and overall visual acceptability of the extruded products appearance were evaluated using a nine-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely). The nine extruded products were placed at the same time on the table for ranking by the panelists. No identity of the panelists was recorded. Extrudates were considered acceptable if their mean score for overall acceptance was above 6 (like slightly) (Choi and others 2007). The panelists were asked to score the extruded products using a ballot sheet (Appendix A).

**Statistical analysis**

The data reported are means of triplicate observations except for ER and BD which data are means of 10 and 20 observations respectively. A central composite design with two factors and two levels was used. Data were subjected to a two-way analysis of variance (ANOVA) with extruder screw speed and barrel temperature as main effects using JMP Pro 9.0 software (SAS Inst. Inc., Cary, N.C., USA) and Student’s t significance test difference was used to separate means at $P < 0.05$. 
RESULTS AND DISCUSSION

Model Description

Studies were conducted using the central composite design (CCD) in modeling the extrusion conditions to prepare a snack as affected by the process variables screw speed (SS) and barrel temperature (BT) as shown in Table I.

Proximate Analysis of the Raw Materials

The means triplicates of the proximate analysis on dry basis (db) of rice, soy, beans, and millet are shown in Table II. The moisture content was highest in rice flour (15.0) and lowest in soymeal flour (5.7). The rice moisture content was similar to the result of Juliano and Bechtel (1985). Water is important in extrusion cooking since it acts as plastificizer in the extrusion processes (Guy 1994). Moisture content is known to affect gelatinization during extrusion cooking (Andriana and Magdalini 2010). During extrusion process, the feed moisture content gives not only the driving force for the expansion but also contributes to the rheological properties of the melt, which consequently affect expansion. Moisture is considered as the main plasticizer of flours, which enables them to undergo a glass transition and simplifies the deformation of the matrix and its expansion during the extrusion process (Moraru and others 2003). Andriana and Magdalini (2010) reported that samples with high feed moisture content processed at low extrusion temperatures and at higher feed rates would exhibit poor functionality.

Soy and beans flours had the highest protein (N × 6.25) with 52.2 and 25.8%, respectively. Soy protein content was similar to the results reported by Iwe and Ngoddy (1998) who reported 50.9% for soy protein. Some proteins play a foremost role on structure formation of the extrusion-cooked products (Ilo and others 2000). It has been reported (Pomeranz 1991;
Wolf and Conan 1971) that proteins are the most reactant components in foods and some of their reactions are essential for functionality. High temperature can unfold and redistribute protein molecules within the plasticized mass in the extruder barrel and can expose them to thermal denaturation, in which amino acids can be altered or destroyed and can consequently lead to a final extruded product with decreased protein quality (Cumming and others 1973; Nielsen 1976; Dahl and Villota 1991). Extruded product textural quality is affected by the addition of proteins to starches due to increase of cross-linking sites (Onwulata and others 2001).

Soy and beans flours were also rich in total dietary fiber 21.4 and 17.9% respectively and high in ash content with 6.6 and 4.6% db for soy and bean, respectively. Iwe and Ngoddy (1998) reported ash content of the soy used in their research to be 7.0%. Walsh and Woo (2010) concluded that the addition of dietary fiber at approximately 18% in whey protein-extruded products can lead to limited undesirable effects on the physiochemical properties of the extrudates. It was reported that high extruder barrel temperature seemed to produce extruded products with higher ash contents than the low extruder barrel temperature (Rosentrater and others 2005).

The moisture, protein, lipid, and ash contents of beans were similar to the findings of Samma´n and others (1999). Lipid is important in extrusion cooking because it also acts as plastificizer in the extrusion processes (Guy 1994). Plastificizers were reported to be used to control the mechanical energy input in extrusion processes and the functional properties of the extruded products. The plasticizers increase the mobility of the food polymer, and consequently decrease melt viscosity and melting of the biopolymer (Ilo and others 2000). Moreover, fats and oils were reported to affect the textural properties of the extruded product (Harper 1979). Excessive heating destabilizes fat which results in evaporation of fine flavor volatiles and leads
to a sticky mass of the product (Acquistucci 2000). Lipid oxidation is the major chemical challenge for extruded products preservation.

Rice and millet had the highest total starch with 90.1 and 75.4% db respectively. The results of moisture, protein, fat, and ash contents of rice were also similar to that of Heinemann and others (2005). The millet used in this study had 9.4% protein, 6.1% lipid and 2.2% ash db, which was similar to that reported by Inyang and Zakari (2008). During extrusion, starch degradation is necessary for product expansion (Chinnaswamy and Hanna 1988a,b). Tang and Ding (1994) reported that starch extruded at low moisture contents is frequently degraded due to high shear and heat. Extruded starches can improve functionality in food applications. starch conversion such as gelatinization, degradation, and melting has a direct influence on product final texture such as expansion; therefore incorporation of an extruded-raw starch mixture might also have a desirable or unique functionality in certain products (Serap and David 2005). It was reported that the amount of polymer in continuous phase determines the extensibility of bubble cell walls in the foam and therefore the overall expansion of extrudate at the die (Guy 1994). Interaction between lipid content and starch content has significant positive effects on lipid loss (Hoan and others 2010).

**Moisture and Protein Contents of the extruded products**

Mean moisture and protein contents of the extruded products are shown in Table III. No interaction between the barrel temperature and screw speed was observed for protein content (P=0.76). The mean observed values of protein for the extruded products ranged from 19.5 – 20.0 % indicating an increase in protein content with fortification of the blend with soymeal flour. Protein content was measured as nitrogen (N x 6.25) and the protein content was not affected by extrusion temperature since nitrogen is not known to be affected by heat treatment
(Pelembe and others 2002). However, there is a significant difference in the moisture content (P<0.0001) among the extruded products ranging from 6.8-12.7% when the extruder was operated at a screw speed of 85 rpm and barrel temperature of 275°C BT and 110 rpm and 190°C, respectively. The three lowest moisture contents (6.8, 6.9, and 7.9%) were observed at the greatest barrel temperature (275°C). At a higher temperature (275°C), the initial moisture content of the flour mixture fed into the extruder was significantly decreased as it got cooked when compared to other products extruded at lower barrel temperatures (190 and 233°C).

**Physio-chemical and Sensory Properties**

The determination of physio-chemical and sensory properties is crucial to the overall quality of the extruded snack.

Bulk Density (BD) and Expansion Ratio (ER) are important characteristics of extruded products and play a role in the consumer acceptability of the product. BD is linked with the expansion ratio in explaining the degree of puffing in extruded product. It is expected that most extruded products will have a puffed structure to a certain degree (Filli and others 2012). Barrel temperature and screw speed individually affected the BD (P<.0001 and P=0.01 respectively). An interaction between barrel temperature and screw speed was observed on ER (P<.0001). Although the interaction was significant, only the barrel temperature significantly affected ER (P<.0001). The mean values of ER ranged from 0.2-0.3 (Table IV) when the extruder was operated at a screw speed of 110 rpm and a barrel temperature of 232.5°C and at a screw speed of 110 rpm and a barrel temperature of 190°C, respectively. The lowest BD (0.016 kg/cm3) was achieved at a screw speed of 60 rpm and a barrel temperature of 275°C whereas the highest BD (0.036 kg/cm3) was obtained at a screw speed of 85 rpm and a barrel temperature of 232.5°C (Table IV). High density will yield hard extrudate and vice-versa (Ding and others 2006). The
lowest BD (0.016 kg/cm$^3$) was obtained at the highest barrel temperature (Fig.4). This was in agreement with the study of Ding and others (2005) who reported that increasing the barrel temperature reduced BD. However contrary to the view of Ding and others (2005) who also reported an increase in ER with barrel temperature, however, a decrease in ER was observed in this study when the barrel temperature was increased (Fig.5). This can be explained by the fact that the ER is highly dependent on the chemical composition of the raw materials used, and the effects that the processing will have on the transformations of these materials will depend on their composition (Gupta and others 2008). High expansion ratio will yield extruded products with a desirable texture (Hoan and others 2010).

Moisture retention (MR) is the amount of water held by the extruded product when subjected to an applied force has been assessed by an extruder technique by considering the final percent of water retained after an extrusion, as a function of the initial water content (Tomer and others 2001). An interaction between barrel temperature and screw speed was observed for MR (P<.0001). Although the interaction was significant, the screw speed did not have any effect on MR (P=0.07) whereas barrel temperature had a strong correlation ($R^2$ Adj=0.994) to MR. The highest MR (33.3%) was obtained at a screw speed of 110 rpm and at barrel temperature of 190°C and the lowest MR (17.7%) when the extruder was operated at a screw speed of 85 rpm and a barrel temperature of 275°C (Table IV). A 46.3% decrease of MR was achieved as the barrel temperature increased from 190°C to 275°C (Fig.6). A negative correlation ($R^2 = 0.89$) was observed between MR and the barrel temperature (Appendix B). Moisture retention decreased from 32.5% to about 10% as the barrel temperature increased from 180°C to 280°C. It was expected that the MR would decrease as the barrel temperature increased. At higher barrel temperature (275°C), the heat is intense enough to reduce more water from the feed moisture
content of the blended flour as compared to other temperatures (190 and 232.5°C). Moisture has the greatest influence on the quality of finished products, especially in the expansion of puffed products (Miller 1985). Both Water-holding capacity and expansion of extruded products are affected by moisture (Bhattacharya and Hanna 1987).

The data of water holding capacity (WHC) and protein solubility (PS) are shown in Table IV. No interaction between barrel temperature and screw speed was observed on WHC (P=0.78). Although the interaction was not significant, barrel temperature significantly affected and strongly correlated with WHC (P<0.0001 and $R^2$ Adj=0.899). The largest WHC (181.7%) was obtained at a screw speed of 85 rpm and a barrel temperature of 275°C, and the lowest (77.0%) when the extruder was operated at a screw speed of 110 rpm and a barrel temperature of 190°C. A positive correlation ($R^2 = 0.85$) was observed between WHC and barrel temperature (Appendix C). Water holding capacity increased from 80% to 180% as the barrel temperature increased from 180°C to 280°C. It was expected that products extruded at highest barrel temperature (275°C) would have the highest WHC observation. This is because at high barrel temperature, extruded products lost the highest amount of water from the flour blended feed moisture content as a result of excess heat; therefore they were expected to have a better WHC. A 57.6% increase in WHC was achieved at the temperature increased from 190°C to 275°C (Fig.7). Water holding capacity is believed to have an important functional property because of the role it plays in the formation of hydrogen bonds between water and polar residues of protein molecules. Water is absorbed and bound to the starch molecule and results to change in the starch granule structure (Filli and others 2010).

There was an interaction between barrel temperature and screw speed (P=0.0004) with respect to PS. The two factors were both strongly correlated to PS ($R^2$ Adj=0.962). The PS
values ranged from 0.26-0.33% at a screw speed of 85 rpm and a barrel temperature of 275°C BT and at a screw speed of 60 rpm and a barrel temperature of 190°C BT respectively (Fig.13). There was a negative correlation (R² = 0.50) between PS and the barrel temperature (Appendix D). Protein solubility decreased from 0.32% to about 0.28% as the barrel temperature increased from 180°C to 280°C. The low PS (0.26%) obtained when the extruder was operated at a screw speed of 85 rpm and a barrel temperature of 275°C BT might be due to the complexes formed by tannins and polyphenols with proteins in the flour blend which consequently increases the degree of cross-linking and decreases the solubility of proteins (Cheryan 1980; Reddy and others 1985). Moreover, the low PS (0.26%) could be as a result of the increase in protein molecular size, which might result from the aggregation of proteins since the more hydrophobic the proteins are, the more easily they will aggregate by hydrophobic interactions (Mei and Tung-Ching 1996). Protein solubility of the extruded products indicates the effect of the extruder barrel temperature and screw speed on protein unfolding and exposing hydrophobic and reactive sites of molecules (Areas 1992) and aggregating and increasing the molecular weight, which resulted in the loss of protein solubility (Baird 1982).

Tap density (TD) and true density (TeD) are an indication of the overall expansion and the changes in cell structure, pores and voids developed in the extrudates as effect of processing as well as raw material parameters (Deshpande and Poshadri 2011). The data TD and TeD are listed in Table IV. Both barrel temperature (P=0.03) and screw speed (P=0.02) significantly affected and strongly correlated (R² Adj=0.709) to TD. Moreover, an interaction was observed between the two factors on TD (P=0.01). The TD values ranged from 0.5-0.6 g/cm³ when the extruded was operated at a screw speed of 60 rpm and a barrel temperature of 190°C and at a screw speed of 60 rpm and a barrel temperature of 232.5°C respectively (Fig.8).
True Density was affected by barrel temperature and screw speed (P=0.03). Although the interaction was significant, barrel temperature did not have any effect on TeD (0.49) while only screw speed affected TeD (P=0.02). The largest TeD (1.6 g/mL) was obtained at a screw speed of 60 rpm and a barrel temperature of 190°C and the lowest (1.2 g/mL) when the extruder was operated at a screw speed of 85 rpm and a barrel temperature of 190°C BT (Fig.9). True density can be used to quantify the structure of a food material by accounting for internal pores (Stroshine and Hamann 1995).

Mass flow rate (MFR) is dependent on the drag flow developed by the rotation of the screw and the pressure developed due to the restriction of the die in a single screw extruder (Mercier and others 1989). The interaction between barrel temperature and screw speed affected MFR (P=0.03). The MFR ranged from 0.1-0.4 gm/sec at a screw speed of 60 rpm and a barrel temperature of 275°C BT and 110 rpm SS and 190°C BT (Table IV). A negative correlation (R² = 0.61) was observed between MFR and the barrel temperature (Appendix E). Mass flow rate decreased from 0.43 gm/sec to about 0.20 gm/sec as the barrel temperature increased from 180°C to 280°C. The lowest MFR values (Fig.10) were obtained when the extruded was operated at the highest barrel temperature (275°C). It was observed that the greatest and lowest MFR value were obtained at the highest and lowest screw speed (110 and 60 rpm), respectively. This was expected as the speed at which the screw was operated, determined how fast the extruded products would come out from the extruder die; therefore the higher the extruder screw speed, the higher the MFR (Bouvier and others 1987; Mercier and others 1989). The mass flow rate is a way of knowing the execution or performance of the extruder during processing.

Fat Absorption Capacity (FAC) denotes the amount of oil which can be bound to matrices in a particular food system and used as the index of hydrophobicity of the food and it is
expressed as the grams of oil bound per gram of the extrudates (Deshpande and Poshadri 2011). Both barrel temperature and screw speed did not affect FAC (P=0.56 and P=0.46) respectively. No interaction between the two factors was observed with respect to FAC (P=0.75). Oil absorption capacity is important because oil plays a role in retaining flavor; in addition it increases the mouth feel of foods (Aremu and others 2007). The values of FAC ranged from 0.4-0.5 gm at a screw speed of 110 rpm and a barrel temperature of 190°C and at a screw speed of 85 rpm and a barrel temperature of 232.5°C, respectively (Table IV and Fig.11). This was in agreement with the studies of Abdel-Aal and others (1992) who observed that extrusion conditions had little effect on Fat Absorption Index (FAI) when rice flour and faba bean protein concentrate blend was used and Bryant and others (2001) who reported that the FAI of the extruded flours were similar to that of the unextruded rice flours. Fat absorption capacity is important because oil plays a role in retaining flavor; therefore increases the mouth feel of extruded products (Aremu and others 2007).

Milk absorption capacity (MAC) denotes the amount of milk which can be bound to matrices in a particular food system. The data of MAC was presented in Table IV. An interaction between barrel temperature and screw speed (P<.0001) was observed with respect to MAC. The two factors strongly correlated to MAC ($R^2$ Adj=0.979). The MAC values ranged from 0.2-0.6 gm/gm at a screw speed of 60 rpm and a barrel temperature of 190°C and at a screw speed of 85 rpm and a barrel temperature of 275°C (Fig.12). There was a positive correlation ($R^2 = 0.68$) between MAC and the barrel temperature (Appendix F). Milk absorption capacity increased from about 0.12 gm/gm to 0.5 gm/gm as the barrel temperature increased from 180°C to 280°C. It was expected that products extruded at highest barrel temperature (275°C) would have the highest MAC observation. This was because at high barrel temperature, extruded products were
the most dehydrated as a result of excess heat; and therefore expected to have a better MAC. Humans tend to like foods, which undergo textural changes during mastication (Lawless 2000). Consumers prefer RTE cereals with the ability to retain their texture after being submerged in milk (Kalviainen and others 2002).

Water absorption index (WAI) and water solubility index (WSI) characterize how extruded products will interact with water and are often important in predicting how the extruded materials may behave if further processed (Kannadhason and others 2009). Water absorption index is the weight of gel obtained per g of dry product and WSI is the amount of dried solid recovered by evaporating the supernatant from the WAI test (Harper 1979). The values of WAI and WSI are presented in Table IV. No interaction between the barrel temperature and screw speed was observed on WAI (P=0.29). Although the interaction was not significant, barrel temperature significantly affected and strongly correlated with WAI (P<0.001 and $R^2$ Adj=0.855), respectively. There was a strong positive correlation ($R^2 = 0.85$) between WAI and the barrel temperature (Appendix G). Water absorption index increased from 13.6 to 17 as the barrel temperature increased from 180°C to 280°C. The greatest WAI (17.3) was obtained at a screw speed of 60 rpm and a barrel temperature of 275°C and the lowest (13.8) when the extruder was operated at a screw speed of 110 rpm and a barrel temperature of 190°C (Fig.14). The highest WAI was obtained at the greatest barrel temperature. This result was in line with the results of Gupta and others (2008) who reported a parallel increase in WAI as the barrel temperature increased. The water absorption index is a measurement of the volume occupied by the extruded product starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion (Qing-Bo and others 2005).
WSI was not affected by barrel temperature and screw speed (P=0.08 and P=0.54), respectively. Also, no interaction between the two factors was observed with respect to WSI (P=0.7844). This result was in disagreement with previous reports (Anderson and others 1969; Harper 1979; Mercier and Feillet 1975; and Ding and others 2005). This might be due to the different ingredients used in other studies since the impact of the extruder process depended on the chemical composition of the raw ingredients (Gupta and others 2008). The values of WSI ranged from 10.6-12.6% at a screw speed of 110 rpm and a barrel temperature of 275°C and at a screw speed of 110 rpm and a barrel temperature of 190°C respectively (Fig.15). Water Solubility Index indicates the degree of starch conversion during extrusion (Ding and others 2005).

The data of in vitro starch digestibility (IVSD) is shown in Table IV. Both barrel temperature and screw speed significantly affected and strongly correlated to IVSD (P<.0001 and R\(^2\) Adj=0.995). Moreover, an interaction was observed between the two factors on IVSD (P<.0001). The IVSD values ranged from 83.9-160.7 µg of glucose/g when the extruder was operated at a screw speed of 85 rpm and a barrel temperature of 190°C and at a screw speed of 110 rpm and a barrel temperature of 275°C respectively. It was observed that greatest IVSD value (160.7 µg of glucose/g) was achieved at the highest screw and barrel temperature 110 rpm and 275°C respectively (Fig.16). This could be related to the reduction of trypsin and chymotrypsin inhibitory activities at higher extruder barrel temperature which eventually improves the IVSD (Alonso and others 2000b). In vitro starch digestibility provides practical and reproducible approaches to study starch digestibility and its relationship with starch molecular structure (Jovin and others 2010).
Color

Any product for commercialization needs to be acceptable to consumers. The two major attributes are texture and color. Color characteristics of extruded products can be affected by various treatments. The data and the effect of barrel temperature and screw speed on color is shown in Table IV and Fig.17, 18, 19 respectively. There was an interaction between barrel temperature and screw speed on color L, a, and b values (P<.0001). The highest L value (54.2) and the lowest (45.7) were obtained when extruded at a screw speed of 60 rpm and a barrel temperature of 232.5°C and at a screw speed of 110 rpm and a barrel temperature of 232.5°C, respectively. A negative correlation ($R^2 = 0.62$) and ($R^2 = 0.58$) was observed between the screw speed and ‘L’ and ‘b’ respectively (Appendix H and Appendix I). ‘L’ decreased from 54 to 48 and ‘b’ decreased from about 8.2 to about 4.2 as the screw speed was from 50 rpm to 120 rpm. The two products were extruded at the same barrel temperature (232.5°C) but different screw speeds. The significant difference in color between the two products was due to the difference in the screw speed indicating that at a low screw speed, the color of the extruded products was lighter or brighter than at a faster screw speed, which was browner or darker. The heat decomposition of the pigments present in the flour blend may responsible for the light color of extruded products (Balasubramanian and others 2012). The largest ‘a’ and ‘b’ values [(2.8 and 8.4) respectively and the lowest (1.6 and 3.1) respectively] were obtained when extruded at a screw speed of 85 rpm and a barrel temperature of 190°C and at a screw speed of 110 rpm and a barrel temperature of 232.5°C, respectively for ‘a’ values and at a screw speed of 60 rpm and a barrel temperature of 232.5°C and at a screw speed of 110 rpm and a barrel temperature of 232.5°C, respectively for ‘b’ values. The same observation as in L values was noted in b values.
The greatest and lowest b values were obtained at lowest and highest screw speed (60 and 110 rpm) respectively.

**Texture**

Texture is also an essential characteristic of food acceptance by consumers (Moskowitz and Drake 1972), and therefore, an important step in quality assessment (Meullenet and others 1998). Fig. 2 shows the shear force of the nine extruded products. It was observed that both barrel temperature and screw speed significantly affected the shear force of the extruded products (P<.0001). The treatments # 3, 4, and 9 extruded at the highest barrel temperature (275°C) had the lowest shear force observations with 318.5, 362.2, and 507.3 N, respectively when compared to other treatment combinations (Fig.2 and Fig.20). It was observed that the shear force of the extruded products decreased with increase of extruder barrel temperature. Similar finding was reported by Suksomboon and others (2011) who reported that increase in barrel temperature decreased the shear force of a snack made from purple rice (Hom Nil) and soybean flour blend.

**Protein Enhancement**

As the demand for a snack with enhanced nutritional value increases, the protein contents of soy and bean flours in the preparation of the snack will help meet this demand. The incorporation of a legume, such as soy and bean, in the snack will contribute to meeting the protein needs of poor people in addition to solving some of the world’s health-related issues (Veronica and others 2006). Choi and others (2007) used defatted peanut as a nutritional ingredient to improve the protein content in the preparation of a snack food. Previous study has shown that legume proteins such as soy, pea, bean levels of up to 30-35% may be added and still maintain high quality final products (Sunderland 1996). In order to increase the protein content
of the extruded product, the soy content of the mixture was increased from 16% to 22 and 30% using the extrusion conditions of treatment # 5. Table VI shows the results of moisture and protein contents, color, and texture of the improved protein-extruded product (22 and 30% soy) based on conditions of treatment # 5 at a screw speed of 60 rpm and a barrel temperature of 233°C. The protein content, color and the texture analysis of the extruded product were significantly different between the extruded products with 22 and 30% soy in the flour blend. It was observed that the protein content of the snack increased from 19.5% to 22.7%. Previous research has shown that increasing soybean in a flour mixture increased the nutrient or protein content of the snack (Edem and others 2001 and Veronica and others 2006). Due to the high temperature-short time process, extrusion technology retains considerable amounts of nutrients and eliminates anti-nutritional factors. Moreover, there was an increase in the textural properties of the snack. This is because as the amount of soy tends to increase in the mixture, the textural properties of the snack increase in shear force. This is in agreement with Veronica and others (2006) who reported that the addition of protein to starch-rich flours produced harder extrudates. It was observed that, except for moisture content, there was a significant difference in protein content, texture, and color of the extruded product with 22 and 30% soy, which increased from 22.7-25.7% (protein), 419.3 to 549.7 N (texture). It is noted that as the soy content increased in the flour mixture, the ‘a’ and ‘b’ values of the color increased, which could be a result of a browning reaction during the defatting process of the soybean. The snack extruded with 30 % soy had greater protein content, a harder texture, and a lighter color compared to the snack extruded with 22% soy.
Sensory Evaluations

A sensory analysis is imperative for the success of a newly developed food product in the market. There was consistency in the overall panel performance when evaluating the extruded products as demonstrated by the ANOVA (analysis of variance) result. It is accepted in many descriptive profiling procedures that sensory panelists are a significant source of variation for all the attributes (Lapvetelainen and Rannikko 2000). The ANOVA result indicated that barrel temperature and screw speed of the extruder affected the appearance and color of the extruded products as shown in Table V. Products 5, 7 and 8 extruded a barrel temperature of 190°C with 6.8, 6.7, and 6.0 for color liking, respectively and 6.6, 6.2, and 5.9 for appearance, respectively had the most appealing appearance and color compared to other products extruded at all other conditions. Products 5, 7, and 8 received best scores since extrudates were considered acceptable if their mean score for overall acceptance was above 6 (like slightly) (Choi and others 2007). It has been reported that, depending on the textural characteristics, a cereal product will show a variety of hues (Lapvetelainen and Rannikko 2000). Fig. 3 shows the photographs of the nine extruded products. It was observed that products 1, 2, and 6 extruded at 232.5°C were browner or darker in color (with average of 7.5, 6.4, and 7.1 respectively) than the other products and were the least desirable in both appearance and color liking (average of 3.0, 4.6, 3.8 for appearance and 3.0, 3.6, and 2.9 for color liking). Chen and others (1991) reported that color changes in extruded products were due to decomposition of pigments and product expansion, which caused color to fade and to react with chemicals and other components in processes such as caramelisation of carbohydrates. Based on the mass flow rate, protein solubility, true density, expansion ratio, and the sensory analysis; treatment # 5, which had the best results, was selected
among the others for further analysis to increase the protein content by increasing the soymeal amount in the flour blend.

**CONCLUSION**

Central composite design was conducted for the extrusion of millet, bean, rice, and soy flour using a single screw extruder. The CCD was observed to be an effective technique to obtain best extrusion conditions. From the data obtained, the two extrusion variables were shown to influence the extrudate physio-chemical and sensory properties both independently and interactively. The extruder barrel temperature was shown to be the most significant factor that affected both the physio-chemical and sensory properties of the extruded products. This study demonstrated that extruded products which, were acceptable to consumers, could be prepared from blends of millet, beans, soy and rice flour under a range of extrusion conditions up to 30% of soy flour. Therefore, this product could be supplied to developing parts of the world that are prone to protein malnutrition especially in Africa.
**Table I: Central Composite Design (CCD) of the Extrusion Experiments in their coded form and natural units**

<table>
<thead>
<tr>
<th>Treatments #</th>
<th>Independent variables in coded form&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Experimental variables in their natural units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SS</td>
<td>BT</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>a</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>a</td>
</tr>
<tr>
<td>8</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

<sup>a</sup> SS = screw speed (rpm), BT = barrel temperature (°C), rpm = revolutions per minute
Table II: Moisture, Protein, Lipid, Total Starch, Total Dietary Fiber, Ash Content in Rice, Millet, Beans, and Soy Flours

<table>
<thead>
<tr>
<th>Composition (%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Flour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rice&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Moisture</td>
<td>15.0 ± &lt;0.1</td>
</tr>
<tr>
<td>Protein</td>
<td>8.8 ± 0.5</td>
</tr>
<tr>
<td>Lipid</td>
<td>2.4 ± 0.3</td>
</tr>
<tr>
<td>Total starch</td>
<td>90.1 ± 0.1</td>
</tr>
<tr>
<td>Total dietary fiber/ gram</td>
<td>4.2 ± 0.1</td>
</tr>
<tr>
<td>Ash</td>
<td>0.5 ± 0.1</td>
</tr>
</tbody>
</table>

<sup>a</sup> Composition is based on dry-weight basis (db).

<sup>b</sup> Values are means ± SE of triplicates. SE = Standard Error
### III: Moisture and Protein Contents of the Nine Extruded Products based on CCD design

<table>
<thead>
<tr>
<th>Treatment #&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Moisture (%)&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Protein (%)&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.8 ± 0.1 d</td>
<td>19.6 ± 0.5 ns</td>
</tr>
<tr>
<td>2</td>
<td>8.9 ± 0.1 e</td>
<td>19.5 ± 0.2 ns</td>
</tr>
<tr>
<td>3</td>
<td>6.9 ± 0.1 g</td>
<td>19.6 ± 0.1 ns</td>
</tr>
<tr>
<td>4</td>
<td>6.8 ± 0.1 g</td>
<td>19.9 ± 0.2 ns</td>
</tr>
<tr>
<td>5</td>
<td>11.6 ± 0.1 b</td>
<td>19.6 ± 0.5 ns</td>
</tr>
<tr>
<td>6</td>
<td>9.1 ± 0.0 e</td>
<td>20.0 ± 0.5 ns</td>
</tr>
<tr>
<td>7</td>
<td>11.3 ± 0.1 c</td>
<td>19.8 ± 0.3 ns</td>
</tr>
<tr>
<td>8</td>
<td>12.7 ± 0.2 a</td>
<td>19.8 ± 0.3 ns</td>
</tr>
<tr>
<td>9</td>
<td>7.9 ± 0.1 f</td>
<td>19.8 ± 0.3 ns</td>
</tr>
</tbody>
</table>

<sup>a</sup> Values are means ± SE of triplicates. SE = Standard Error. Values followed by the same letter in the same column are not significantly different (P < 0.05)

<sup>b</sup> Treatments (SS-BT): 1= 85 rpm-232.5°C, 2= 60 rpm-232.5°C, 3= 110 rpm-275°C, 4= 85 rpm-275°C, 5= 60 rpm-190°C, 6= 110 rpm-232.5°C, 7= 85 rpm-190°C, 8= 110 rpm-190°C, and 9= 60 rpm-275°C

<sup>c</sup> CCD= central composite design, rpm= revolutions per minutes, ns= not significant, SS= Screw speed, and BT= barrel temperature
<table>
<thead>
<tr>
<th>Physico-chemical Properties</th>
<th>Treatments #</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR 28.3±0.3 d 23.3±0.3 e 18.2±0.2 g 17.9±0.1 g</td>
<td>30.5±0.2 b 24.0±0.1 e 29.7±0.2 c 33.3±0.4 a 20.8±0.2 f</td>
</tr>
<tr>
<td>MFR 0.36±0.02 ab 0.38±0.03 ab 0.17±0.00 d 0.15±0.02 de</td>
<td>0.27±0.04 c 0.33±0.01 bc 0.38±0.04 ab 0.43±0.02 a 0.07±0.01 e</td>
</tr>
<tr>
<td>FAC 0.45±0.03 ns 0.42±0.02 ns 0.42±0.03 ns</td>
<td>0.45±0.01 ns 0.44±0.01 ns 0.42±0.00 ns 0.40±0.00 ns 0.42±0.00 ns</td>
</tr>
<tr>
<td>PS 0.27±0.00 g 0.32±0.00 ab 0.28±0.00 f</td>
<td>0.25±0.00 h 0.33±0.00 a 0.3±0.00 de 0.31±0.01 bc 0.3±0.00 cd</td>
</tr>
<tr>
<td>MAC 0.3±0.01 c 0.4±0.01 b 0.6±0.03 a</td>
<td>0.6±0.02 a 0.2±0.00 d 0.2±0.01 d 0.2±0.01 d 0.4±0.01 b</td>
</tr>
<tr>
<td>TD 0.57±0.01 bc 0.61±0.00 a 0.59±0.02 ab</td>
<td>0.53±0.00 d 0.53±0.00 d 0.58±0.00 abc 0.57±0.01 bc 0.58±0.01 abc 0.56±0.01 cd</td>
</tr>
<tr>
<td>TrD 1.38±0.11 bcd 1.31±0.01 bcd</td>
<td>1.48±0.02 abc 1.29±0.00 cd 1.6±0.10 a 1.39±0.07 bcd 1.22±0.06 d 1.30±0.02 bcd 1.49±0.03 ab</td>
</tr>
<tr>
<td>WHC 149.7±11.0 b</td>
<td>153.1±8.0 ab 165.1±4.7 ab 181.7±13.2 a 85.4±7.3 c 156.9±15.8 ab 80.9±6.8 c 77.0±5.0 c 175.9±7.8 ab</td>
</tr>
<tr>
<td>WAI 16.1±0.1 bc</td>
<td>15.3±0.2 c 16.7±0.2 ab 16.3±0.9 abc 13.9±0.0 d 15.8±0.1 bc 13.9±0.2 d 13.8±0.3 d 17.3±0.3 a</td>
</tr>
<tr>
<td>WSI 11.3±0.2 ns</td>
<td>11.5±0.3 ns 10.6±0.0 ns 10.9±1.8 ns 12.3±0.1 ns 10.7±0.2 ns 11.9±0.3 ns 12.6±0.1 ns 11.7±0.3 ns</td>
</tr>
<tr>
<td>BD 0.03±0.003 a</td>
<td>0.02±0.000 b 0.02±0.000 cde 0.01±0.000 de 0.02±0.000 bcd 0.03±0.000 a 0.02±0.000 b 0.02±0.000 b 0.01±0.000 e</td>
</tr>
<tr>
<td>ER 0.18±0.01 c</td>
<td>0.24±0.02 d 0.29±0.01 b 0.29±0.01 b 0.32±0.01 ab 0.17±0.01 d 0.32±0.01 ab 0.34±0.01 a 0.24±0.02 c</td>
</tr>
<tr>
<td>IVSD 153.4±2.8 b</td>
<td>157.2±0.1 ab 160.7±0.9 a 137.3±0.9 c 121.5±0.6 d 158.9±1.1 a 83.9±1.0 f 112.7±1.0 e 111.7±1.0 e</td>
</tr>
<tr>
<td>Color (L) 51.8±0.01 c</td>
<td>50.6±0.01 e 50.6±0.02 d 50.6±0.01 d 50.6±0.01 d 50.6±0.01 d 53.9±0.00 b 54.2±0.00 a 45.7±0.00 g 48.1±0.02 f</td>
</tr>
<tr>
<td>Color (a) 2.1±0.00 e</td>
<td>1.7±0.01 g 2.1±0.01 d 2.8±0.01 a 1.9±0.02 f 2.3±0.02 c 2.5±0.02 b 1.6±0.01 h 1.9±0.02 f</td>
</tr>
<tr>
<td>Color (b) 6.4±0.00 e</td>
<td>6.1±0.00 g 6.4±0.00 d 6.4±0.00 d 7.4±0.00 c 6.3±0.01 f 7.8±0.01 b 8.4±0.01 a 3.1±0.01 i 4.9±0.00 h</td>
</tr>
</tbody>
</table>

a. Means of triplicates Values are means ± SE of triplicates except for ER and BD which are means of 10 and 20 readings respectively. Values followed by the same letter in the same column are not significantly different (P < 0.05).
b. Treatments (SS-BT) : 1 = 85 rpm-232.5°C, 2= 60 rpm-232.5°C, 3= 110 rpm-275°C, 4= 85 rpm-275°C, 5= 60 rpm-190°C, 6= 110 rpm-232.5°C, 7= 85 rpm-190°C, 8= 110 rpm-190°C, and 9= 60 rpm-275°C
c. ns = not significant, CCD= central composite design, rpm= revolutions per minute, SS= Screw speed, and BT= barrel temperature, SE= standard error
d. MR= moisture retention in %, MFR= mass flow rate in g/sec, pH= pH, FAC= fat absorption capacity in %, PS = protein solubility in %, MAC = milk absorption capacity in %, TD = tap density in g/sec, TrD = true density in g, WHC = water holding capacity in %, WAI= water absorption index, WSI= water solubility index in %, BD= bulk density in kg/cm³, and ER= expansion ratio, IVSD= in vitro starch digestibility in µg of glucose per gram of sample
e. Color (L) = brightness with L= 100 is white and L= 0 is black, Color (a+) = red, Color (a-) = green, Color (b+) = yellow, and Color (b-) = blue
Table V: Sensory Evaluation\(^a\) of the Nine\(^b\) extruded Products based on CCD design

<table>
<thead>
<tr>
<th>Treatment #</th>
<th>Color Liking(^c)</th>
<th>Color light or Dark(^d)</th>
<th>Appearance(^e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.0 d</td>
<td>7.5 a</td>
<td>3 e</td>
</tr>
<tr>
<td>2</td>
<td>3.6 cd</td>
<td>6.4 bc</td>
<td>4.6 cd</td>
</tr>
<tr>
<td>3</td>
<td>4.8 b</td>
<td>4.4 d</td>
<td>3.7 de</td>
</tr>
<tr>
<td>4</td>
<td>4.9 b</td>
<td>4.8 c</td>
<td>4.8 c</td>
</tr>
<tr>
<td>5</td>
<td>6.7 a</td>
<td>3.1 e</td>
<td>6.6 a</td>
</tr>
<tr>
<td>6</td>
<td>2.9 d</td>
<td>7.1 ab</td>
<td>3.8 de</td>
</tr>
<tr>
<td>7</td>
<td>6.0 a</td>
<td>3.3 e</td>
<td>6.2 a</td>
</tr>
<tr>
<td>8</td>
<td>6.8 a</td>
<td>2.8 e</td>
<td>5.9 ab</td>
</tr>
<tr>
<td>9</td>
<td>4.5 bc</td>
<td>6.3 c</td>
<td>5.1 bc</td>
</tr>
</tbody>
</table>

a. Values are means. Values followed by the same letter in the same column are not significantly different (P < 0.05)

b. For color liking and visual appearance: 9 = Like extremely, 8 = Like very much, 7 = Like moderately, 6 = Like slightly, 5 = neither like nor dislike, 4 = Dislike slightly, 3 = Dislike moderately, 2 = Dislike very much, 1 = Dislike extremely

c. For color either light or dark: 9 = Dark extremely, 8 = Dark very much, 7 = Dark moderately, 6 = Dark slightly, 5 = neither dark nor light, 4 = Light slightly, 3 = Light moderately, 2 = Light very much, 1 = Light extremely

d. Treatments (SS-BT): 1 = 85 rpm-232.5°C, 2 = 60 rpm-232.5°C, 3 = 110 rpm-275°C, 4 = 85 rpm-275°C, 5 = 60 rpm-190°C, 6 = 110 rpm-232.5°C, 7 = 85 rpm-190°C, 8 = 110 rpm-190°C, and 9 = 60 rpm-275°C

e. CCD= central composite design, rpm= revolutions per minutes, SS= Screw speed, and BT= barrel temperature
Table VI: Protein Improvement of the extruded product using the treatment # 5 with 22% and 30% soy

<table>
<thead>
<tr>
<th>Amount of Soy (%)</th>
<th>Moisture (%)</th>
<th>Protein (%)</th>
<th>Color</th>
<th>Texture (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>L</td>
<td>a</td>
</tr>
<tr>
<td>22</td>
<td>14.5 ± 0.3 a</td>
<td>22.7 ± 0.2 b</td>
<td>53.1 ± 0.01 b</td>
<td>2.8 ± 0.01 b</td>
</tr>
<tr>
<td>30</td>
<td>14.5 ± 0.2 a</td>
<td>25.7 ± 0.4 a</td>
<td>55.5 ± 0.01 a</td>
<td>3.1 ± 0.00 a</td>
</tr>
</tbody>
</table>

a. Values are means ± SE of triplicates. SE = Standard Error. Values followed by the same letter in the same column are not significantly different (P < 0.05)
Fig. 1. A single-screw extruder (Killion Extruders Davis-Standard Corporation, Serial # 30337, Cedar Grove, New Jersey, USA)
Fig. 2: Shear Force\(^a\) (N) of the Nine\(^b\) Extruded Products\(^c\) based on CCD design

\(\text{a. Values are means ± SE of triplicates. CCD= central composite design, and SE = standard error. Values followed by the same letter in the same column are not significantly different (P < 0.05)}\)

\(\text{b. Treatments (SS-BT) : 1= 85 rpm-232.5°C, 2= 60 rpm-232.5°C, 3= 110 rpm-275°C, 4= 85 rpm-275°C, 5= 60 rpm-190°C, 6= 110 rpm-232.5°C, 7= 85 rpm-190°C, 8= 110 rpm-190°C, and 9= 60 rpm-275°C}}\)

\(\text{c. rpm= revolutions per minutes, SS= screw speed, and BT= barrel temperature}\)
Fig. 3: Photographs of the Nine Extruded Products based on CCD design

a. Treatments (SS-BT): 1= 85 rpm-232.5°C, 2= 60 rpm-232.5°C, 3= 110 rpm-275°C, 4= 85 rpm-275°C, 5= 60 rpm-190°C, 6= 110 rpm-232.5°C, 7= 85 rpm-190°C, 8= 110 rpm-190°C, and 9= 60 rpm-275°C

b. CCD= central composite design, rpm= revolutions per minutes, SS= Screw speed, and BT= barrel temperature
Fig. 4. Effect of barrel temperature (BT) and screw speed (SS) on bulk density (BD) of extruded products

Fig. 5. Effect of barrel temperature (BT) and screw speed (SS) on expansion ratio (ER) of extruded products
Fig. 6. Effect of barrel temperature (BT) and screw speed (SS) on moisture retention (MR) of extruded products

Fig. 7. Effect of barrel temperature (BT) and screw speed (SS) on water holding capacity (WHC) of extruded products
Fig. 8. Effect of barrel temperature (BT) and screw speed (SS) on protein solubility (PS) of extruded products

Fig. 9. Effect of barrel temperature (BT) and screw speed (SS) on tap density (TD) of extruded products
Fig. 10. Effect of barrel temperature (BT) and screw speed (SS) on true density (TeD) of extruded products

Fig. 11. Effect of barrel temperature (BT) and screw speed (SS) on mass flow rate (MFR) of extruded products
Fig. 12. Effect of barrel temperature (BT) and screw speed (SS) on fat absorption capacity (FAC) of extruded products.

Fig. 13. Effect of barrel temperature (BT) and screw speed (SS) on milk absorption capacity (MAC) of extruded products.
Fig.14. Effect of barrel temperature (BT) and screw speed (SS) on water absorption index (WAI) of extruded products

Fig.15. Effect of barrel temperature (BT) and screw speed (SS) on water solubility index (WSI) of extruded products
Fig.16. Effect of barrel temperature (BT) and screw speed (SS) on in vitro starch digestibility (IVSD) of extruded products.

Fig.17. Effect of barrel temperature (BT) and screw speed (SS) on color ‘L’ of extruded products.
Fig. 18. Effect of barrel temperature (BT) and screw speed (SS) on color ‘a’ of extruded products

Fig. 19. Effect of barrel temperature (BT) and screw speed (SS) on color ‘b’ of extruded products
Fig. 20. Effect of barrel temperature (BT) and screw speed (SS) on texture of extruded products
Central composite design (CCD) was conducted for the extrusion of millet, bean, rice, and soy flour using a single screw extruder. The CCD was found to be effective technique to determine the physio-chemical properties of extruded products. From the data obtained, it showed that the two extrusion variables were found to influence the extrudate properties both independently and interactively. The extruder barrel temperature was found to be the most significant factor that affected both the physio-chemical and sensory properties of the extruded product. This study demonstrated that extruded products which were acceptable to consumers could be prepared from blends of millet, bean, soy and rice flours under a range of extrusion conditions up to 30% of soy flour, therefore this product could be supplied to the developing parts of the world which are prone to protein malnutrition including in Africa.
REFERENCES


Binoy, KG, Aaron, JO, Gour, SC. 1996. Reverse screw Element(s) and Feed Composition effect during Twin-Screw Extrusion of Rice Flour and Fish Muscle Blends. J Food Science 61: 590-595.


87


Meilgaard, M, Civille, GV, and Carr, BT. 2007. Sensory evaluation techniques CRC.


Moskowitz, HR, Beckley, JH, Resurreccion, AVA. 2006. Sensory and consumer research in food product design and development Wiley Online Library.


Sing, U, Kherdekar, MS, Jambunathan, R. 1982. Studies on Desi and Kabuli Chickpea (Cicer arietinum L.) cultivars. The levels of Amylase inhibitors, levels of Oligosaccharides and In Vitro Starch Digestibility. J of Food Science 47: 510-512.


Tran, QD, Hendriks, WH, Van der Poel, AFB. 2011. Effects of drying temperature and time of a canine diet extruded with a 4 or 8mm die on physical and nutritional quality indicators. Animal Feed Science and Technology 165: 258–264.


Appendix A

Sensory Ballot Sheet for Consumer Acceptance of the Extruded Products

Please observe these samples. All things considered, which statement best describes your **OVERALL COLOR LIKING IMPRESSION** of these products?

<table>
<thead>
<tr>
<th>Dislike Extremely</th>
<th>Dislike Very Much</th>
<th>Dislike Moderately</th>
<th>Dislike Slightly</th>
<th>Neither Dislike nor Like</th>
<th>Like Slightly</th>
<th>Like Moderately</th>
<th>Like Much</th>
<th>Like Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which statement best describes your impression of the **OVERALL VISUAL APPEARANCE** of these products?

<table>
<thead>
<tr>
<th>Dislike Extremely</th>
<th>Dislike Very Much</th>
<th>Dislike Moderately</th>
<th>Dislike Slightly</th>
<th>Neither Dislike nor Like</th>
<th>Like Slightly</th>
<th>Like Moderately</th>
<th>Like Much</th>
<th>Like Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which statement best describes your impression of the **OVERALL COLOR (Either Light or Dark)** of these products?

<table>
<thead>
<tr>
<th>Dark Extremely</th>
<th>Dark Very Much</th>
<th>Dark Moderately</th>
<th>Dark Slightly</th>
<th>Neither Dark nor Light</th>
<th>Light Slightly</th>
<th>Light Moderately</th>
<th>Light Very Much</th>
<th>Light Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

94
Appendix B

Bivariate Fit of Moisture Retention by Barrel Temperature

Linear Fit
MR = 58.530559 - 0.1436692*BT

Summary of Fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSquare</td>
<td>0.887812</td>
</tr>
<tr>
<td>RSquare Adj</td>
<td>0.883325</td>
</tr>
<tr>
<td>Root Mean Square Error</td>
<td>1.841793</td>
</tr>
<tr>
<td>Mean of Response</td>
<td>25.10353</td>
</tr>
<tr>
<td>Observations (or Sum Wgts)</td>
<td>27</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
<td>671.11609</td>
<td>671.116</td>
<td>197.8409</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>84.80504</td>
<td>3.392</td>
<td>Prob &gt; F</td>
</tr>
<tr>
<td>C. Total</td>
<td>26</td>
<td>755.92113</td>
<td></td>
<td>&lt;.0001*</td>
</tr>
</tbody>
</table>

Parameter Estimates

| Term    | Estimate  | Std Error | t Ratio | Prob>|t| |
|---------|-----------|-----------|---------|-----|
| Intercept | 58.530559 | 2.402798  | 24.36   | <.0001* |
| BT      | -0.143669 | 0.010214  | -14.07  | <.0001* |
Appendix C

Bivariate Fit of Water Holding Capacity by Barrel Temperature

![Linear Fit Graph]

**Linear Fit**

\[ WHC = -119.2976 + 1.0980621 \times BT \]

**Summary of Fit**

- RSquare: 0.851879
- RSquare Adj: 0.842622
- Root Mean Square Error: 16.85291
- Mean of Response: 136.1849
- Observations (or Sum Wgts): 18

**Analysis of Variance**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
<td>26135.627</td>
<td>26135.6</td>
<td>92.0202</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>4544.331</td>
<td>284.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>17</td>
<td>30679.957</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Parameter Estimates**

| Term   | Estimate | Std Error | t Ratio | Prob>|t| |
|--------|----------|-----------|---------|------|
| Intercept | -119.2976 | 26.92757  | -4.43   | 0.0004* |
| BT     | 1.0980621 | 0.114468  | 9.59    | <.0001* |
Appendix D

Bivariate Fit of Protein Solubility by Barrel Temperature

Linear Fit

PS = 0.4025533 - 0.0004635*BT

Summary of Fit

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
<td>0.00465680</td>
<td>0.004657</td>
<td>15.5801</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>0.00478231</td>
<td>0.000299</td>
<td></td>
<td>Prob &gt; F</td>
</tr>
<tr>
<td>C. Total</td>
<td>17</td>
<td>0.00943912</td>
<td></td>
<td></td>
<td>0.0012*</td>
</tr>
</tbody>
</table>

Parameter Estimates

| Term   | Estimate  | Std Error | t Ratio | Prob>|t| |
|--------|-----------|-----------|---------|------|
| Intercept | 0.4025533 | 0.027624  | 14.57   | <.0001* |
| BT     | -0.000464 | 0.000117  | -3.95   | 0.0012* |
Appendix E

Bivariate Fit of Mass Flow Rate by Barrel Temperature

Linear Fit
MFR = 0.9166932 - 0.0027311*BT

Summary of Fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSquare</td>
<td>0.612596</td>
</tr>
<tr>
<td>RSquare Adj</td>
<td>0.588383</td>
</tr>
<tr>
<td>Root Mean Square Error</td>
<td>0.079941</td>
</tr>
<tr>
<td>Mean of Response</td>
<td>0.28125</td>
</tr>
<tr>
<td>Observations (or Sum Wghts)</td>
<td>18</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
<td>0.16168297</td>
<td>0.161683</td>
<td>25.3005</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>0.10224794</td>
<td>0.006390</td>
<td>Prob &gt; F</td>
</tr>
<tr>
<td>C. Total</td>
<td>17</td>
<td>0.26393090</td>
<td></td>
<td>0.0001*</td>
</tr>
</tbody>
</table>

Parameter Estimates

| Term    | Estimate | Std Error | t Ratio | Prob>|t| |
|---------|----------|-----------|---------|-----|
| Intercept | 0.9166932 | 0.127729  | 7.18    | <.0001* |
| BT       | -0.002731 | 0.000543  | -5.03   | 0.0001* |
Bivariate Fit of Milk Absorption Capacity by Barrel Temperature

Linear Fit
MAC = -0.584349 + 0.003941*BT

Summary of Fit
RSquare = 0.677678
RSquare Adj = 0.664785
Root Mean Square Error = 0.098017
Mean of Response = 0.332585
Observations (or Sum Wgts) = 27

Analysis of Variance
Source       DF  Sum of Squares  Mean Square  F Ratio  Prob > F
Model        1   0.50498495    0.504985     52.5621  <.0001*
Error        25  0.24018474    0.009607
C. Total     26  0.74516969

Parameter Estimates
Term       Estimate  Std Error  t Ratio  Prob>|t|
Intercept  -0.584349  0.127873  -4.57    0.0001*
BT          0.003941  0.000544   7.25    <.0001*
Appendix G

Bivariate Fit of Water Absorption Index by Barrel Temperature

Linear Fit
WAI = 7.5793037 + 0.0337907*BT

Summary of Fit

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RSquare</td>
<td>0.850823</td>
</tr>
<tr>
<td>RSquare Adj</td>
<td>0.841499</td>
</tr>
<tr>
<td>Root Mean Square Error</td>
<td>0.520785</td>
</tr>
<tr>
<td>Mean of Response</td>
<td>15.44128</td>
</tr>
<tr>
<td>Observations (or Sum Wgts)</td>
<td>18</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
<td>24.749954</td>
<td>24.7500</td>
<td>91.2550</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>4.339480</td>
<td>0.2712</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>17</td>
<td>29.089434</td>
<td></td>
<td></td>
<td>&lt;.0001*</td>
</tr>
</tbody>
</table>

Parameter Estimates

| Term   | Estimate | Std Error | t Ratio | Prob>|t| |
|--------|----------|-----------|---------|------|
| Intercept | 7.5793037 | 0.832111 | 9.11   | <.0001* |
| BT     | 0.0337907 | 0.003537 | 9.55   | <.0001* |
Appendix H

Bivariate Fit of color 'L' by Screw Speed

Linear Fit
color L = 58.843259 - 0.0961778*SS

Summary of Fit

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RSquare</td>
<td>0.620947</td>
</tr>
<tr>
<td>RSquare Adj</td>
<td>0.605785</td>
</tr>
<tr>
<td>Root Mean Square Error</td>
<td>1.594057</td>
</tr>
<tr>
<td>Mean of Response</td>
<td>50.66815</td>
</tr>
<tr>
<td>Observations (or Sum Wgts)</td>
<td>27</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
<td>104.06436</td>
<td>104.064</td>
<td>40.9538</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>63.52545</td>
<td>2.541</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>26</td>
<td>167.58981</td>
<td></td>
<td></td>
<td>&lt;.0001*</td>
</tr>
</tbody>
</table>

Parameter Estimates

| Term | Estimate | Std Error | t Ratio | Prob>|t| |
|------|----------|-----------|---------|------|---|
| Intercept | 58.843259 | 1.313777 | 44.79   | <.0001* |
| SS    | -0.096178 | 0.015029 | -6.40   | <.0001* |
Appendix I

Bivariate Fit of color 'b' by Screw Speed

Linear Fit
color 'b' = 11.068148 - 0.0562222*SS

Summary of Fit

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RSquare</td>
<td>0.582624</td>
</tr>
<tr>
<td>RSquare Adj</td>
<td>0.565929</td>
</tr>
<tr>
<td>Root Mean Square Error</td>
<td>1.009448</td>
</tr>
<tr>
<td>Mean of Response</td>
<td>6.289259</td>
</tr>
<tr>
<td>Observations (or Sum Wgts)</td>
<td>27</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
<td>35.560556</td>
<td>35.5606</td>
<td>34.8980</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>25.474630</td>
<td>1.0190</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>26</td>
<td>61.035185</td>
<td></td>
<td></td>
<td>&lt;.0001*</td>
</tr>
</tbody>
</table>

Parameter Estimates

| Term  | Estimate | Std Error | t Ratio | Prob>|t| |
|-------|----------|-----------|---------|------|---|
| Intercept | 11.068148 | 0.831959 | 13.30 | <.0001* |
| SS     | -0.056222 | 0.009517 | -5.91  | <.0001* |