Effect of extrusion cooking on some quality attributes of full-fat soy flour and soy protein concentrate from locally grown Soybean (Glycine Max L.) varieties

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of Requirements for the Degree of Masters of Science in Chemical Engineering (Food Engineering)

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Addis Ababa University
School of Graduate Study
Department of Chemical Engineering

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Approved by the Examining Board

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Dr-Ing. Nurelegne Tefera
Internal Examiner
Dedicated to my dear father
Acknowledgments

Alhamdulilah Rebilalemin Alakulihal Hamden Kihiren Teyeben Wemubareken Fih Alakuluhal

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Abstract

Soybean (*Glycine max L.*) varieties, Clark 63K and SCS1 were obtained from Jimma Agricultural Research Center. Their seed color and shape, seed density; hundred seed mass, hydration and swelling capacities, hydration and swelling indices, hydration and swelling coefficients were studied according to the standard procedures. The seeds were processed and converted into full fat soy flour (FFSF) and soy protein concentrate (FF-SPC) to study the effect of extrusion. The flours and concentrates from each variety were extruded at a barrel temperature of 140 °C, screw speed of 120rpm, and feed moisture of 30%. The effect on extrudates expansion ratio, specific length, proximate composition, flour and extrudate bulk density (BD), water absorption index (WAI), water solubility index (WSI), oil absorption capacity (OAC), emulsion activity (EA) and stability (ES), foaming capacity (FC) and stability (FS) was studied in triplicate samples. The result of the seed analysis of both varieties showed no statistical significant difference except in swelling coefficient. The bulk density of FFSF is significantly higher than that of FF-SPC flour, while FFSF extrudates have lower bulk density than that of the unprocessed flour. WAI of FF-SPC flour and extrudates of both varieties were found to be significantly higher than that of FFSF. WSI of FFSF flour and extrudates of both varieties are significantly higher than that of FF-SPC flour and extrudates. The OAC of FF-SPC flour is significantly higher than that of FFSF in both varieties, while that of the extrudates is significantly lower than that of their corresponding flours. EA and ES of extrudates of clark 63K and SCS1 showed significantly higher values than the corresponding unprocessed flours. In general, the EA of SCS1 products are lower than that of Clark 63K, and the ES of Clark 63K and SCS1 is closer. The FC of FFSF is significantly higher than that of all products of both varieties. The FS of FFSF has been significantly higher than that of FF-SPC while the extrudates of SCS1 showed higher values of FS than that of Clark 63K. Generally, the present study showed that both varieties are suitable for extrusion cooking, with SCS1 slightly better performance. Based on the outcome of the study, the technology for developing an extruded product of soybean varieties has been suggested.

*Key words: Concentrate; extrusion cooking; flour; soybean*
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List of Abbreviations

AACC  Approved method of American association of cereal chemistry
AOAC  Association of official analytical chemistry
CDSB  Cracked dehulled soybean
FFSF  Full fat soy flour
FF-SPC Full fat soy protein concentrates
DF-SPC Defatted soy protein concentrate
DSF   Defatted soy flour
SPC   Soy protein concentrates
SPI   Soy protein isolate
DSF   Defatted soy flour
WAI   Water absorption index
WSI   Water solubility index
TVP   Texturized vegetable protein
TSP   Texturized soy protein
NSI   Nitrogen solubility index
HTST  High temperature short time
WMSB  Whole mill Soybean
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Chapter 1

Introduction

1.1 Background

The soybean [Glycine max (L.) Merrill, family Leguminosae, subfamily Papilionoidae] originated in Eastern Asia, probably in north and central China. Soybeans grow well on almost all types of soil, with the exception of deep sands with poor water retention.

Ethiopia is one of the under developed countries with GDP of $100 per year [Microsoft Encarta 2006]. Consequently, animal products like meat, milk, egg are expensive and unaffordable to the medium income based people.

Even though the majority of our society is not conscious of the nutritional value of the food they eat, in addition to the low economic background this has also its own impact on having a healthy and nutritious food. Therefore, creating the awareness and introducing a highly nutritious and relatively inexpensive product is expected from those who have the knowledge and skill of the science and technology of the food products and processes, so that they can contribute their own in building a healthy and well-developed society.

Therefore, this thesis focuses on one of the major vegetable protein sources of soy product that is extrusion-cooked soy flour and soy protein concentrate. Even though soybean is being cultivated in our country and is being a very good protein source for our diet, our society is not accustomed to use it in adequate amount. Soya bean and its products have protein content of: Soybean whole seed contains about 40-45%, Soy meal/flake 48-55%, soy protein concentrate 69-75 %, soy protein Isolate 89-92%. (Wolf and Cowan, 1971).

Therefore, using soybean and its products in fulfilling the protein requirement of our body and in developing our custom of eating from taste focused eating habit to the nutrition focused one is very important.
In our country soybean is being used in industrial level by a very few companies for example in FAFA food complex the company uses defatted soy flour in fortifying its baby foods products like: FAFA, FAMEX, DUBE, CERIFAM. The other company is Health care manufacturing plc, produces Soybean oil from soybean and they sale the soy meal as a feed especially for chicken feed. In addition to these products they produce baby food called FAMEX fortified with defatted soy flour. But this company is new as well as the first in producing soybean oil locally there is no as such established researches they made. There is also a company called Royal Plc. that produces soy milk curd called TOFU in a small scale home processed type who delivers for super markets in small quantity. This company is also new company with a new product for our country, which shows a bright future in developing our eating culture to nutrition focused food preparation.

Regarding research institutes, Agricultural research institutes focus on getting different brides, which can resist disease and have high yielding. In Ethiopian health and nutrition research institute there is one research made on’ Bioavailability of iron from soybean – fortified wheat flour (Dubbie) in rats’ by Urga et al., 1999. The rest of the researches made are conducted by agricultural research centers based mainly on the agronomy of soybean to adapt our countries soil and environment.

1.2 The scope of the study

In this research by studying the some quality status of our local soybean and by further processing it in to soy flour and soy protein concentrate (SPC) and making different experimental tests in evaluating the quality of the soy flour and SPC of two different varieties will be ready for extrusion cooking process. Then, the SPC and soy flour will be extrusion-cooked will be ready for further analysis to evaluate the effect of extrusion cooking on different quality parameters of the extrudates and to compare the differences between products of the two varieties.

Therefore, within this thesis some very important quality characteristics of four of local soybean based products, that is, Full fat soy flour, Full fat Soy protein concentrate,
extruded full fat SPC and extruded full fat soy flour will be studied. In addition to this, studying the effect of extrusion cooking on the full fat soy protein concentrate and the full fat soy flour of our local soybean varieties will give adequate information for those who want to make further research and/or for those who want to invest their money on soybean products especially extrusion cooked full soy products or soy mix products.

1.3 Objective

I. General objective

The general objective of this research is to study and evaluate the effect of extrusion cooking on full fat soy flour and full fat soy protein concentrate (SPC) from locally grown soybean varieties.

II. Specific objective

In this thesis the material preparation, data collection and analysis will be conducted:

a) To evaluate the quality changes of full fat soy paste during extrusion.

b) To assess the influence of extrusion cooking on the quality parameters of full fat soy protein concentrate.

c) To compare the quality of the extrudates obtained from the local soybean varieties.
Chapter 2
Literature review

2.1 History of soybean

The soybean \textit{Glycine max (L.) Merrill}, family Leguminosae, subfamily Papilionoidae] originated in Eastern Asia, probably in north and central China. It is believed that cultivated varieties were introduced into Korea and later into Japan some 2000 years ago. Soybeans have been grown as a food crop for thousands of years in China and other countries of East and South East Asia and constitute to this day, an important component of the traditional popular diet in these regions (Berk, 1992).

Soybean entered to Ethiopia 50 years ago. Till now there has been a number of studies conducted on different soybean varieties. Through the studies it has been determined suitable conditions and places for the growth of the bean, suitable plantation periods and methods of production, and productive varieties are well known (EIAR, 2007).

Table 2.1 Improved varieties growing in Ethiopia

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<tr>
<td>\textit{TGX-13-3-644}</td>
<td>Long rain fall areas</td>
<td>20-25</td>
<td>60</td>
<td>150</td>
</tr>
<tr>
<td>\textit{Belesa-95}</td>
<td>Long rain fall areas</td>
<td>17-29</td>
<td>60</td>
<td>134-169</td>
</tr>
</tbody>
</table>

(Source: \textit{Manual of crop technology usage, EIAR, 2007})

- 4 -
2.2 Processed soybean products

The processed soybean protein products used as food ingredients in the U.S are conveniently divided into three categories based on protein content: soy flour and grits, protein concentrates, and protein isolates. These three types of soy proteins supplied by the soy industry are considered the starting materials for the variety of soy protein products. In certain instances these materials may be processed further before they are incorporated into a food product e.g. Extrusion of soy flour or spinning of isolates to form simulated meats (Wolf and Cowan, 1971).

Designation of practical fractions of soybean (Smith and Circle, 1972)

Soybean = Protein + Insoluble’s + Soluble + Lipids + Hulls

H = Hulls
L = Solvent – extractable material (Hexane, Ethanol)
P = Alkali-extractable, Acid – perceptible protein
I = Insoluble residue from protein extraction
S = Soluble other than P (Example: “Whey”)

Relationship of commercial soy fractions (Smith and Circle, 1972)

The term Soy should be used by qualifications like:

Soybean = P+I+S+L+H
Soy full-fat flour = P+I+S+L
Soy defatted flour = P+I+S
Soy protein solubles = P+S
Soy protein concentrates = P+I
Soy proteinate isolate = P (isoelectric or salt form)
Soy solubles or “whey” = S
Soy “ whole milk” = P+S+L
Soy protein - lipid complex = P+L
Tofu = P+L
2.2.1 Soy flour and grits
Mature, whole, yellow soybeans are used for human food production. They are cleaned, preferably sorted into uniform size to minimize variations in processing, equilibrated to 10-12% moisture and cracked into six to eight pieces by using corrugated rolls. Preheating enhances loosening of hulls from the cotyledons during cracking and aids their removal by aspiration. The raw cotyledons are then milled into full-fat enzyme active flour (Lusas and Riaz, 1995).

2.2.2 Defatted soy flour
Defatted soy flour is the most widely used soy ingredient in the baking industry. Among soy products, it may be best source of Isoflavones and other micro-ingredients that have been linked to positive health benefits, because it is the least processed form of soy. It contains up to 50% protein, making it a more concentrated source of protein than full fat soy flour (Riaz, 2000).

2.2.3 Soy protein concentrate
According to Berk (1992), historically, the need for the development of soybean protein concentrates stemmed primarily from two considerations:

- To increase protein concentration, and
- To improve flavour.
- To remove flatulent causing components

It is very difficult to avoid the occurrence of the green-beany flavour of soybeans in untoasted full-fat or defatted soy flour, prepared in the conventional way. Beany flavour is one of the major objectionable characteristics, limiting the use of conventional soy flours. One of the objectives of the further processing of flours into concentrates is to extract the particular components, which are responsible for the bitterness and beany taste. The solvents used in the production of concentrates, also efficiently remove the flatus-producing oligosaccharides of soybean flour, raffinose and stachyose (Berk, 1992).
Soy protein concentrate is the product prepared from high quality, sound, clean, dehulled soybean by removing most of the oil and water-soluble non-protein components that shall contain not less than 70% protein (% N X 6.25) (in the case of defatted soy protein concentrate) on moisture–free basis (Smith and Circle, 1972).

2.2.4 Soy protein isolate
Most refined forms of soy proteins are the isolates. They are processed one step further than the concentrates by removing the water-insoluble polysaccharides as well as the water-soluble sugars and other minor constituents (Wolf and Cowan, 1971).

2.2.5 Texturized soybean protein
Texturized soybean protein (TSP) products can be made from defatted soybean meal or flake, soy concentrate, and soy isolate. If defatted soybean meal with specific moisture content is subjected to high shearing forces at high temperature in an extruder, a product with a peculiar laminar structure is obtained. After hydration, this product presents an elastic and chewy texture resembling that of meat. The product is known as “textured vegetable protein (TVP) or textured soybean protein (TSP)” (Berk, 1992).

2.3 Production processes of soy protein concentrate products
2.3.1 Defatted soy protein concentrate
Defatted soy flours, grits, SPCs, and SPIs typically are made from white flakes. White flakes are produced by cleaning, heating and cracking soybeans; removing the hulls by aspiration; flaking the chips to 0.25-0.30 mm thickness and extracting the oil by hexane to 0.5 – 1.0% (Lusas and Riaz, 1995; Fulmer, 1989; Kanzamar et al., 1993; Milligan, 1981). Then after, the meal will be desolventized as in normal processing, moist heat treated to the required NSI, dried and ground (Smith and Circle 1972; Mustakas et al., 1962). Finally, after the moisture level in the flakes has been adjusted it will be ground in a hammer mill so that 97% will pass through a No 100 mesh screen (Lusas and Riaz 1995).
In general concentrates involve counter current extraction. The three defatted soy protein concentrate extraction methods are discussed as follows.

**a) Aqueous alcohol Process**

The preferred alcohol concentration is 60% by weight. Soy proteins appear to be least soluble in about 50% aqueous alcohol; their solubility increases on either side of that concentration. Excess water in the extraction solvent is to be avoided because of additional energy costs for removal and because an extremely wet soy protein cake tends to agglomerate, clogging the process system. The aqueous alcohol removed by evaporation from the alcohol water soy soluble is recycled to the extraction step (Antonio, 2007).

**b) Acid wash process**

The acid wash process yields soy protein concentrate products with a relatively high NSI (about 65-75%) because severe denaturation steps are not introduced in the process and the proteins are neutralized before drying (Smith and Circle, 1972).

![Figure 2.1: Soybean Proteins; Effect of pH on Solubility](Based on Smith and Circle, 1972)
c) Hot Water Leaching Process

Proteins, including soy proteins, are easily denatured by heat and become insoluble in water. Moist heat is more effective for denaturation than dry heat. With water of high temperature, the small molecular weight materials, including soluble sugars, are extracted from the insoluble protein and polysaccharide matrix (Antonio, 2007). Out of the three ways of soy protein concentrate extraction methods Acid wash extraction is prefered due to:

- its being non-flammable,
- non-explosive,
- non-toxic
- Inexpensive solvent: water, and.
- Its ability to give quite high protein solubility index of the neutralized product which is NSI values above 60%, which corresponds to high yield of protein (Berk, 1992).

This process is based on the pH-dependence of the solubility of soybean proteins, discussed above. It will be recalled that the majority of soybean proteins exhibit minimum solubility at pH 4.2 to 4.5 (isoelectric region). Therefore, it is possible to extract the sugars, without solubilizing the majority of the proteins, using, as solvent, water to which an acid has been added so as to keep the pH at the isoelectric region (Berk, 1992)

One obvious difference between the three concentrates above is the water solubility of the proteins. The proteins in the alcohol leached and moist-heat leached concentrates are denatured and insoluble, while protein insolubilization is much less in the acid leached concentrates (Wolf and Cowan, 1971).
2.3.2 **Full fat soy protein concentrates**

Production of full fat soy protein concentrate (FF-SPC) can be produced by cracking and dehulling the soybeans and adding the beans into a hot water at a temperature range of 82-100°C and maintaining that temperature for 10-50 minutes. Then, removing the soybean from the water, washing the soybean with fresh hot water, and drying the washed soybean to desired moisture content of preferably 8-15%. Such kind of SPC production is used to get FF-SPC with a bland taste and light color, to provide SPC with out significant loss of protein and oil, to destroy enzymes like lipoxidase activity (by 99%) which produce off-flavor without producing any darkening in the color of soybean material, to treat the soybean in such a manner as to destroy the anti-nutritional factors such as trypsin inhibitor (by 95%) to remove flatulence producing factors such as stachyose, rafinose etc…, to prepare an intermediate product that can be further processed to get defatted SPC with protein content of 70% and with no oil (Daftary, 1976).

2.4 **Extrusion cooking**

Extrusion cooking is a thermodynamically efficient industrial method of cooking and drying a wide range of foods based on cereals or vegetable proteins or mixtures of both (Carl et al., 1986).

The extruder consists basically of a sturdy screw or worm rotating inside a cylindrical barrel (Fig. 3.2). The barrel can be smooth or grooved. The screw configuration is such that the free volume delimited by one screw flight and the inside surface of the barrel decreases gradually as one goes from one end of the screw shaft to the other. As a result of this configuration, the material is compressed as the rotating screw conveys it forward. Screws having different compression ratios are used for different applications. The barrel is usually equipped with a number of sections of steam-heated jackets or induction heating elements or cooling jackets. A narrow orifice or "die" is fitted at the exit end of the barrel. The shape of the die opening determines the shape of the extruded product (Berk, 1992)
High temperature and short time (HTST) extrusion cookers are thermodynamically efficient in that they consume much less energy as electricity and/or as steam per ton of material processed to a desired standard than any other industrial cooking method. They are efficient converters of electrical energy into thermal energy (Smith, 1986).

2.4.1 Nature of raw materials used in extrusion cooking process
Extrusion cooking is a specialized form of processing which is unique in food and feed processing because of the conditions that are used to transform the raw materials. It is a relatively low moisture process (10%-40% wet base) compared with conventional baking or dough processing (Guy, 2001).

Extruded products are formed from the natural biopolymers of raw materials such as cereal or tuber flours that are rich in starch, or oil seed legumes and other protein rich sources. The most commonly used materials are wheat and maize flours, but many other materials are also used such as Rice flour, Potato, Rye, Barely, Oats, Sorghum, Cassava, Topioca, Buck wheat, pea flour and other related materials. If the extruded products are manufactured in the form of vegetable protein (TVP) the main ingredients will be selected from protein rich materials such as pressed oil seed cake from Soya, sunflower, rape seed, field bean, fava bean, or separated proteins from cereals such as wheat (gluten). All natural biopolymers in the ingredients listed above can be transformed into a fluid melt in the temperature and moisture ranges used in an extruder.
2.4.2 Role of major food components during extrusion cooking

During extrusion cooking, raw materials undergo many chemical and structural transformations that lead to a variety of unique products. Chemical changes that occur include conversion (gelatinization and melting) of starch, denaturation and cross linking of proteins, complex formation between amylose and lipids, maillard reactions in the presence of sugars, and degradation reactions of polymers and other molecules (Llo et al., 2000).

The structure of extruded products is created by forming a melt fluid from biopolymers and blowing bubbles of water vapour into the fluid to form foam. The film of biopolymers must flow easily in the bubble walls to allow the bubbles to expand as the superheated water is released very quickly at atmospheric pressure (Guy, 2001).

**Starch**

Starch polymers are very good at the above-mentioned function and well expanded cellular structure showing a continuous phase can be made from materials such as wheat, maize, rice or potato.

Under the condition of extrusion cooking (high temperature, pressure and shear forces) starch granules are disrupted and melted at low moisture content or swell and gelatinized at high moisture (Harper, 1992).

**Protein**

Proteins may be used to form structures in extrudates at high concentration in the recipe that is >40%w/w at moisture level of 30-40%w/w. They are globular proteins significantly smaller than starch linked together to form larger structures as they flow through a die channel.
**Oil and Fats**

The level of applied shear on particles of starch, fibers and proteins may be reduced by the presence of oil and fats. These materials serve to lubricate both the interacting particles in the dough mass and the particles that are rubbing against the metal surfaces of screw and barrel. The effect of lubricants is more powerful than that of plasticizers in terms of their active concentration. Oil and fats produce larger effects on the processing of starch at level of 1-2% and higher levels may reduce the degradation of the starch polymers to such an extent that no expansion is obtained from a recipe. In extrusion cooking of cereal starches the mechanical energy input is reduced as oil is added to the recipe (Guy, 2001)

**2.4.3 Effect of Extrusion on nutritional quality of macronutrients**

Extrusion offers food scientists a palette of conditions and ingredients from which new foods may be created. Although snack foods were among the first commercially successful extruded foods, today extruders produce many foods of nutritional importance (Camire, 2001).

**Carbohydrates**

Starch tubers and grains provide important energy in most diets. Sugars provide sweetness and are involved in numerous chemical reactions during extrusion. Human and other mono-gastric species can not easily digest un-gelatinized starch. Extrusion cooking is somewhat unique because gelatinization occurs at much lower moisture level (12-22%) than is necessary in other food operations.

Extrusion may pre-digest starch. Branches on amylopectin molecules are easily sheared off in the barrel. Reduction in molecular weight for both amylase and amylopectin molecules have been reported by Politz and Coworker (1994) and found that larger corn amylopectin molecules were subjected to the greatest molecular weight reduction.
Rapidly digested starch triggers rapid rise in blood sugar and insulin levels after meals. These increases may lead to insulin insensitivity and type II or adult−onset, diabetes. Extrusion conditions can be manipulated to produce digestion-resistant starch (RS) by several mechanisms. As branches are removed from amylopectin molecules, they could react with other carbohydrates in novel linkages that can not be digested by human enzymes (Camire, 2001; Theander and Westerlund, 1987). The adverse nutritional consequences of easily digested starch include increase risk for dental caries and rapid rise in blood glucose levels after eating (Camire, 2001).

Reducing sugars are presumably lost during m aillard reactions with proteins. Sucrose, raffinose, and stachyose decreased significantly in extruded high-starch fractions of Pinto beans (Borejsza and Khan, 1992). Extruded snacks based on corn and soy contained lower levels of both stachyose and raffinose compared to unextruded grits and flour (Omueti and Morton, 1996). The destruction of these flatulence−causing oligosaccharides may improve consumers’ acceptance of extruded legume products.

**Proteins and Amino acids**

Extrusion improves protein digestibility via denaturation, which exposes enzyme−access sites. Most protein such as enzymes and enzyme inhibitors lose activity due to denaturation. The extent of denaturation is typically assessed as change in protein solubility in water or aqueous solutions. These changes are more pronounced under high shear extrusion conditions (Delle Valle et al., 1994). High barrel temperatures and low moisture promote m aillard reactions during extrusion. Reducing sugars, including those formed during shear of starch and sucrose can react with lysine, there by lowering protein nutritional value. Lysine is the limiting essential amino acid in cereals, and further depletion of these nutrients can in pair growth in children and young animals (Camire, 2001). Blends of corn meal, full fat soy flake and soy isolates or concentrates produced nutritious ingredients suitable for reconstitution as porridge or gruel with good retention of lysine (Kon Stance et al., 1998)
Soy protein has been identified as cholesterol-lowering food ingredient. Extrusion texturization of soy isolate did not reduce its effects on rat serum cholesterol, excretion of cholesterol and other steriods in feces, or protein nutrition compared with un-extruded soy (Fukui et al., 1993).

**Lipids**

Although lipids serve as a concentrated form of energy, excess dietary lipids consumption is associated with chronic illnesses such as heart disease, cancer, and obesity. Generally foods containing less than ten percent lipids are extruded because greater quantities of lipids reduce slip within the extruder barrel, making extrusion difficult, particularly for expanded products. Many extruded snack foods are fried after extrusion to remove moisture and modify texture and flavor (Camire, 2001).

Regarding the stability of Omega-3 fatty acids. Which are highly unsaturated lipids, both docosahexaenoic (DHA) and eisosapentaenoic (EPA) acids were retained in chum salmon muscle extruded with 10% wheat flour (Suzuki et al., 1988). Another nutritional issue is the safety of trans fatty acids. Maga (1978) reported that extrusion of corn and soy resulted in formation of corn and soy resulted in formation of only 1.5% trans fatty acids (Camire 2001; Maga, 1978).

Lipid oxidation is a major cause of loss of nutritional and sensory quality in food and feeds. Although we suspect that lipid oxidation does not occur during extrusion due to short residence time, lipid oxidation can occur during storage (Camire, 2001).

According to the review made by Artz et al.,(1992) among the different factors which affect lipid oxidation in extruded foods is screw wear, which results in higher concentration of pro-oxidant minerals(Camire, 2001; Artz et al.,1992). Semwal et al., (1994) found that iron and peroxide values were higher in extruded rice and dhal compared to dried products. Another factor that flavoring oxidation is the formation of air cells in expanded products, leading to increased surface area. However, lipolytic enzymes and other enzymes that promote oxidation may be inactivated during extrusion, and
starch-lipid complex formed in the barrel may be more resistant to oxidation. Packaging under nitrogen or vacuum in opaque containers may further protect extruded foods (Camire, 2001).

**Dietary Fiber**

Dietary fiber is the edible part of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibers promote beneficial physiological effects including laxation, and or blood cholesterol attenuation, and or glucose attenuation (Camire, 2001).

A major difficulty in interpreting research involving fiber and extrusion in the variety of analytical methods used to quantify and characterize different fiber components. For example, measurement of total dietary fiber for food labeling does not detect changes in fiber solubility induced by extrusion. As with starch fragments of larger molecules may be sheared off during extrusion. These smaller molecules may be water soluble on the other hand fragments could unite large insoluble complexes or maillard compounds that may be analyses as lignin. Such physicochemical changes may influence profoundly the health benefits of the extruded food. For example soluble forms of dietary fibers are associated with reduce risks for heart diseases (Camire, 2001).

**2.4.4 Extrusion cooking of soy products**

In the extrusion cooking processes the raw material is converted in to viscous -elastic fluid or “melts” where by the transport mechanism through the extruder changes along the screw from solid flow to fluid flow. As a consequence, the pressure build up during fluid flow, high shear stresses are developed which cause structural transformation in the material. These transformations include loss of crystalline structure, destruction of granular structure, rupture of glycoside bonds and new molecular interactions (Kebed , 2006; Gonzalez et al., 1998).
While texturizing the soy material, extrusion cooking also provides the heat treatment necessary to reduce the microbial load and to inactivate the trypsin inhibitor. (Berk, 1992). The optimum temperature for extrusion cooking of soy products is 132-148 °C (Wolf and Cowan, 1971).

According to Cummings et al (1972), the extrusion vaporization temperature of soybean products must be above the vaporization temperature of water (100 °C) to allow expansion and flash vaporization. Temperature of 120-150 °C are recommended because extrudates processed at lower temperature may become crumbly and disintegrates in boiling water (Rueda et al., 2004).

During extrusion cooking process of soy products more than 90 % of anti-nutritional factors can be inactivated. For example 135 °C is enough to inactivate 95% or more of trypsin inhibitors after extrusion cooking of full fat soy flour as compared to the unprocessed material (Mustakas et al., 1964).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Soy flour</th>
<th>Soy concentrate</th>
<th>Soy isolate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flavor</td>
<td>Moderate to high</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Retort stable</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Flavor development on retorting</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Flatulence</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Form/shape</td>
<td>Granules or chunks</td>
<td>Granules or chunks</td>
<td>Fibers</td>
</tr>
<tr>
<td>Cost (dry basis)</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Recommended hydration level</td>
<td>2:1</td>
<td>3:1</td>
<td>4:1</td>
</tr>
<tr>
<td>Cost of hydrated protein</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Fat retention</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Optimum usage level in meat extension (% hydrated level)</td>
<td>15-20</td>
<td>30-50</td>
<td>35-50</td>
</tr>
</tbody>
</table>

*Source: (Berk. 1992; Campbell, 1981)*
2.5 Soybeans and Soy Products Quality Attributes

There are a number of soybean characteristics that are important for end use and/or storage. The level, plus presence of these characteristics, is generally referred to as “Quality”. Not all soybeans are created equal. Soybean can vary widely in characteristics desired for many soy foods and soy food application. High-quality soybeans have desirable levels of certain characteristics or combination of characteristics. Such characteristics include physical properties, chemical compositions, and functional properties of soy products. (Brumm, 2006)

2.5.1 Physical Properties of Soybeans

a) Hilum Color

Many processors want yellow-hilum soybean (also known as clear or white –hilum), as the darker hila may affect the color or clarity of the final processed product. Certain soy foods are made with yellow-hilum soybeans because it has been traditionally done so, not necessarily because there is a negative impact from colored hila. The hilum color is a genetic characteristic of a soybean variety. Hilum color is identified by visual inspection (Brumm, 2006).

b) Seed Count

Larger seed counts (number of seeds per unit weight) correspond to smaller seeds. Commodity-type soybeans are typically 6,000 to 7,300 seeds/kg. Tofu and soy milk processors often want larger seeds of 4,400 to 5,500 seeds/kg. Miso processors want medium but uniform size beans. In some soy products, it is desirable to minimize the amount of fiber. Larger seeds have fewer hulls and therefore less fiber can be obtained. Seed count is a varietal characteristic that is influenced by growing conditions. Seed count is determined by counting and then weighing (Brumm, 2006).
c) Seed Density

Seed density is a component of grain yield that is correlated positively with seed protein concentration. If genotypic correlations between seed density and yield are low, selection for increased density could provide an efficient way to improve protein concentration without affecting seed yield (Li and Burton, 2002).

2.5.2 Proximate analysis of soybeans and soy products

There are many chemical components of soybean seed that are important for processors. They include proximate analysis factors (moisture, crude protein, fat, fiber) as well as specific chemical components such as lipoxygenase and fatty acids (Brumm, 2006).

Commercial soybean constitutes approximately 8% hull, 90% cotyledon, and 2% hypocotyls and plumule. The constituents of major interest oil and protein make up 60% of the bean, but one third consists of carbohydrates including polysaccharides, stachyose (3.8%), Raffinose (11%), and sucrose (5.0%). Oil and protein contents depend on varieties, soil fertility, and weather conditions (Wolf and Cowan, 1971).

Table 2.3

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Protein (Nx6.25)%</th>
<th>Fat[%]</th>
<th>Carbohydrate [%]</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole bean</td>
<td>40</td>
<td>21</td>
<td>34</td>
<td>4.9</td>
</tr>
<tr>
<td>Cotyledon</td>
<td>43</td>
<td>23</td>
<td>29</td>
<td>5.0</td>
</tr>
<tr>
<td>Hull</td>
<td>8.8</td>
<td>1</td>
<td>86</td>
<td>4.3</td>
</tr>
<tr>
<td>Hypocotyl</td>
<td>41</td>
<td>11</td>
<td>43</td>
<td>4.4</td>
</tr>
</tbody>
</table>
Table 2.4

Proximate composition of soy flours and Concentrates

<table>
<thead>
<tr>
<th>Components</th>
<th>Soy flour and Grits</th>
<th>Soy protein concentrates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Defatted</td>
<td>Full fat</td>
</tr>
<tr>
<td>Protein (Nx6.25)%</td>
<td>51</td>
<td>41</td>
</tr>
<tr>
<td>Moisture [%]</td>
<td>4.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Fat [%]</td>
<td>1.5</td>
<td>21</td>
</tr>
<tr>
<td>Fiber [%]</td>
<td>3.2</td>
<td>2.8</td>
</tr>
<tr>
<td>Carbohydrate [%]</td>
<td>34</td>
<td>25</td>
</tr>
<tr>
<td>Ash [%]</td>
<td>5.8</td>
<td>5.3</td>
</tr>
<tr>
<td>NSI (Nitrogen solubility index)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The major non protein constituents in concentrates are polysaccharides, arabinogalactan, and acid pectin –like polysaccharides, arabinon, and cellulose (Wolf and Cowan, 1971).

2.5.3 Functional Properties

Functional characterization of proteinous products like that of soy products can be generalized as hydration, emulsification, textural, and rheological (Fenemma, 1985). Those characteristics can be measured through their nitrogen solubility, water absorption, viscosity, swelling, gelation, fat absorption, foaming, whipping, adhesion, fiber/texture, aggregation, dough formation, and extrudability. Understanding the functional properties of food products is important in determining the quality of the final product as well as in facilitating processing like: improved machinability, transportation, storage etc. (Raiz, 2008).

Extrusion cooking process is one of innovative technology that can significantly change the functional properties of different products. By combining variations in plasticizing effect and dextrunization extent in extrusion, it is possible to obtain various polymer structures and molecular weight distributions, leading to a broad diversity in functional
properties of extruded polymeric melts. Generally, extrusion cooking technology offers wide potential for varying the functional properties of polymeric melts, and hence the characteristic of final product (Bouvier, 2001).

a) Foaming property
Foaming property is very important to improve texture, consistency, and appearance of food; such as baked and confectionary goods. Foam ability or foaming power (capacity) corresponds to the ratio of gas volume to liquid volume in foams (Soetrisno, 2007). Foaming, the capacity of proteins to build stable foams with gas by forming impervious protein films, is an important property in some food applications, including beverages, as well as angel and sponge cakes. Soy protein exhibits foaming properties closely correlated to solubility. Studies have shown differences among the foaming properties of various soy protein products, soy isolates are superior to soy flour and concentrates (Kin Selle, 1979; Hettiarachlly and Kalapathy, 1997).

b) Emulsification property
Emulsification property includes fat adsorption, foaming, and whipping abilities. The oil-in-water emulsion stabilized by protein was represented by a bilayer model (Soetrisno, 2007; Elizalde et al, 1988). Protein diffused and reoriented at the oil-water interface, the hydrophilic groups orient toward the water phase and the hydrophobic groups orient towards the oil. The thickness of the interfacial bilayer depends on the water and oil absorption capacity of the proteins and on the concentration of the protein. Emulsion stability is enhanced by high protein and oil concentration (Soetrisno, 2007; Elizalde et al., 1991).

c) Water absorption (WAI) and Water solubility index (WSI)
WAI measures the volume occupied by the starch after swelling in excess water, which maintains the integrity of starch aqueous dispersion (Kebede, 2006; Mason and Hoseney, 1986). The degree of gelatinization is defined as the weight ratio of gelatinized starch to the total weight of the sample (Ilo et al., 1996). Water solubility index was also used as
an index of the extent of molecular degradation and was correlated with intrinsic viscosity for extruded starch (Ollet et al., 1999).

d) **Bulk density**

The bulk density depends on the nature of the solid material as well as the amount of air space within the product. In case of extrusion cooking process, a highly expanded product with plenty of air space has significantly lower bulk density than a product with a little air inclusion. Bulk density is very important from the view point of correct volume of product in the pack and product texture (Sharma et al., 2000).
Chapter 3
Material and Methods

3.1 Experiment location
The experiment on the extrusion process was conducted in Food Process and Technology Department’s laboratory, Faculty of Engineering, Bahir Dar University. Analysis of raw material and product proximate composition, physical and functional properties was done in the Ethiopian Health & Nutrition Research Institute and Addis Ababa University’s Chemical Engineering Department laboratories.

3.2 Materials and equipments

3.2.1 Materials

The selected soybean varieties, namely, Clark 63K and SCS1, were collected from Jimma Agricultural Research Center upon the recommendation of the center. Clark 63K is a released variety, and is being widely cultivated and distributed in Jimma areas and more recently in southern regions of the Gurage Zone. Where as, SCS1 is a new variety in the pipeline to be released.

3.2.2 Equipment

There were a number of equipments used during the experimental work as indicated here under.

- For material preparation: decorticator, dehulling machine, disc mill and sieves were used;
  - full fat soy protein concentrate production: temperature and time controlled boiler was used.
  - batch type centrifuge for WAI and WSI, oil absorption, emulsion activity and stability tests;
  - extrusion cooking machine;
  - drying cabinets and ovens to bring products moisture down to the desired moisture content etc.;
  - temperature and time controlled shaker.
3.3 Experimental design and data collection

The experiments were conducted in a completely randomized design. Samples in triplicate were taken from each of the two soybean varieties. Accordingly, the physicochemical, proximate composition, functional properties of seeds, flours, concentrates, and extrudates were recorded.

3.4 Methods

3.4.1 Sample preparation

3.4.1.1 Cracking and dehulling process

Cracking and dehulling of both varieties were done without any kind of preconditioning. Initially Clark 63K and SCS 1 seeds had moisture contents of 5.94% and 6.43% respectively. After the necessary cleaning process, the raw seed were fed in to decorticator type AB-ALVAN BLANCH No 27/02545 and the beans were cracked almost into pieces. Then the cotyledons and the hull were separated. Finally, the hull was weighed and its percentage as compared to the initial seed weight was calculated. Dehulling was done to reduce the fiber content after cracking and to improve the efficiency of extraction.

Fig 3.1 Clark 63K soybean variety

Fig 3.2 SCS1 soybean variety
3.4.1.2 Full fat soy flour (FFSF)

The two soybean varieties, Clark 63K and SCS1, were cleaned by hand picking and manual aspiration. The cleaned soybean was cracked using decorticator type AB-ALVAN BLANCH No 27/02545. The cracked beans were fed to dehulling machine type ALVAN BLANCH model No 3 Sw/2m. Further, the dehulled material was fed to a disc mill type FRITSCH D555743 Idar - Oberstein Germany, milled and sieved using 710 μ to get uniform particle size. Finally, the full fat soy flour which is the final product was packed in air tight plastic bags and made ready for extrusion cooking process. (See the flow diagram on fig 3.4)

3.4.1.3 Full fat soy protein concentrate (FF-SPC)

FF-SPC of Clark 63k and SCS1 was prepared from cracked, dehulled soybean (CDSB). The CDSB was put in to water at 95 °C and boiled for 40 minutes. The boiled CDSB was filtered and washed with fresh hot water. Then the CDSB was dried to 7-8% moisture content (Daftary, 1976 patent). Finally, the dried CDSB was milled with a disc mill (FRITSCH D55743 Idar- Oberstein Germany 1996), sieved with 710 μ sieve and made ready for extrusion cooking process by packing it in air tight sealing plastic bags. (See the flow diagram on fig 3.5)

3.4.2 Extrusion cooking process

3.4.2.1 Extrusion cooking machine

The extrusion cooking process was performed using a pilot scale co-rotating twin screw food extrusion cooker (model Clextral, BC-21 N° 194, Firminy, France). The barrel has 25mm diameter screws with 300mm useful length and compression ratio of 1:2.9 driven by screw motor type AC ABB. The flour and concentrates were alternatively fed in to the extruder inlet by volumetric feeder type KMV-KT20. Water was injected in to the extruder by positive displacement pump (type Clextral D KM). At the end of the extruder, a die plate with a circular hole of 2mm diameter was fixed. The temperature of the three zones of the extruder and of the product before entering the die can be controlled by Eurotherm controller (Eurotherm Ltd. Worthing, UK) and read on separate control panel board. (See fig. 3.3 )
3.4.2.2 Equipment setting and extrusion cooking process

Prior to the main extrusion cooking process the necessary calibration and adjustment of the material feed rate and water flow rate was performed. First the extruder screw was started ‘ON’ at screw speed of 120 rpm, then water was pumped in to the barrel by setting the barrel temperature around 70\(^0\)C to minimize material loss till the required barrel temperature of 140\(^0\)C (Wolf and Cowan, 1971; Smith and Circle, 1972; Carl W. et al.,1986) was achieved. Next, the material feeding was started at the rate of 23 g/min. As the dough appeared at the die, the barrel temperature was increased to 140 \(^0\)C, and water flow rate was adjusted till the required flow rate attained. The water flow rate was set to get the dough moisture content of 24\% (Guy, 2001). Using the equation [3.1].
Figure 3.4 Full fat soy flour production flow diagram
Figure 3.5 Full fat soy protein concentrate production flow diagram
\[ W = R \frac{M_f - M_i}{1 - M_f} \]  \hspace{1cm} [3.1] 

Where, \( W \) = Water added (g), \( R \) = material feed (g), \( m_f \) = required dough moisture content, \( m_i \) = initial flour moisture content.

As the required operating parameters were ensured and, the operation was stabilized, the extruded product were collected and placed on plastic sheet to be cooled for 30 minutes at room temperature for measurement of weight, length and diameter (Kebed L., 2006; Ibanoglu et al., 2005). The throughput rate was measured to be 48g/min. Finally, the extrudates were dried in a cabinet drier at 40 °C and RH 30% overnight to get moisture content in the range of 4-8 % (Wolf and Cowan, 1971). Then the product was packed in an air tight plastic bag to be ready for further analysis, which was conducted after three weeks. (See the flow diagram on fig. 3.8)

### 3.4.2.3 Determination of extrusion cooking process parameters and product characteristics.

#### 3.4.2.3.1 Power

The power that was consumed during the extrusion cooking operation of each sample type was calculated using equation [3.2] (Sharma et al, 2000).

\[ P(w) = \tau \times N \times \pi^2 \times D^2 \]  \hspace{1cm} [3.2] 

Where, \( P \) = motor power (W), \( \tau \) = Shear stress (N/m²), \( N \) = Screw speed (1/s), \( L \) = Length of filled section (m), \( D \) = screw diameter(m).

#### 3.4.2.3.2 Throughput Rate (g/min)

The throughput rate was determined as the mean value by weighing 5 times the amount of product that came out every 5 seconds from the extruder’s die.
Figure 3.6 Extrusion-cooking process flow diagram
3.4.2.3.3 Specific Mechanical Energy (kJ/kg)

The SME was calculated using the equation [3.3] below. The values of the torque, screw speed could be read from the control panel and the throughput and motor power are determined as described in sections 4.4.2.1 and 4.4.2.2 above (Sharma et al., 2000. Parker et al., 1999).

\[
\text{SME} = \frac{\% \text{Torque}}{100} \times \frac{SS}{SS_{\text{Max}}} \times \frac{\text{Motorpower(kw)}}{\text{Throughput(kg/s)}}
\]  

[3.3]

Where SS = screw speed, SS_max = Maximum screw speed given by the manufacturer (682 rpm), \% Torque = is read directly from control panel (4 bar and that is 66\% of the maximum torque that can be acquired by the machine)

3.4.2.3.4. Determination of Specific heat capacity and final moisture content of the extrudates

The amount of water lost when the extrudates appear at the die and their final moisture content as they come out of the extruder can be calculated from the material and energy balance on the extruder and after calculating the specific heat capacity of the raw materials and the extrudates (Sharma et al., 2000). The specific heat capacity of the FFSF and FF-SPC can be calculated using the result of their proximate analysis. The specific heat capacity of each FFSF and FF-SPC of both Clark 63K and SCS 1 was calculated using eqn. [3.4]

\[
C_p = \sum C_i \times X_i
\]  

[3.4]

Where, \( C_i \) = is the specific heat capacity of each component (Carbohydrate, protein, fat, etc...), \( X_i \) = is the percentage proportion of each component in that specific material.

Then, the specific heat capacity of the extrudates of each raw material was calculated as per the eqn. [3.5]

\[
C_p = C_{pw} \times M + C_{p,ffsf} (1 - M)
\]  

[3.5]

Where, \( C_{pw} \) =Specific heat of water (4.2 KJ/Kg\(^0\)C), \( C_{p,ffsf} \) = Specific heat capacity of full fat soy flour (FFSF), or full fat soy protein concentrate (FF-SPC), \( M \) = moisture content of the paste (weight fraction).
Next, the amount of water lost as the extrudate appeared at the die was calculated as per the eqn. [3.6]

\[ M_s = \left[ \frac{C_p (T_m - 100^\circ C)}{\Delta H_{fg}} \right] \]  

Where, \( M_s \) = kg water lost/kg of extrudates, \( C_p \) = Specific heat of the extrudates (KJ/Kg\( ^\circ \)C), \( T_m \) = melt temperature at the die (140\( ^\circ \)C), \( \Delta H_{fg} \) = Latent heat of water at 100\( ^\circ \)C (2257 KJ/Kg)

Finally, the final moisture content of the extrudates of FFSF and FF-SPC of the two varieties was calculated on 1kg extrudate basis using eqn. [3.7] below.

\[ M_f = \left[ \frac{M_i - M_s}{W_f} \right] \times 100 \]  

Where, \( M_f \) = Final moisture content of the extrudate, \( M_i \) = Moisture content of the paste, \( M_s \) = kg of water lost per kg of the extrudate, \( W_f \) = Final weight of the extrudate after losing some water.

### 3.4.2.3.5 Expansion ratio (Radial)

Sample products were extruded as straight rope for ten seconds interval. Length was measured by pocket size steal tape. The diameter of the extrudate will be measured by caliper. Weight was measured by digital balance. The mean value of length (4 times), weight (4 times) and diameter (10 times) were recorded. The expansion ratio (diametric) was determined as the ratio of the diameter of the extrudate to the diameter of the die hole (Kebede, 2006; Mason Hoseney 1986).

### 3.4.2.3.6 Specific length

Specific length (cm/g) relates extruded product length to its weight and measures the axial expansion of extrudates. Specific length of the extruded products depends on barrel temperature screw speed and feed moisture content (Kebede, 2006).

### 3.4.2.3.7 Bulk density (BD) of the extrudates

Bulk density (g/cm\(^3\)) is determined by filling a container of known volume with a sample followed by weighing. This was important for obtaining the proper fill weight for the package volume (Sharma et al., 2000).
3.4.3 Analytical Methods

3.4.3.1 Proximate analysis

The proximate analysis of raw materials and products was determined using official methods as described in AOAC (2000).

3.4.3.1.1 Moisture content

A clean crucible was dried in an oven at 105 °C for an hour and placed in desiccators to cool, and the weight of crucible (W₁) was determined. 5g of samples was weighed in dry crucible (W₂) and dried at 102 °C for 5 h after cooling to room temperature, and was weighed (W₃) again. At the end the moisture content was determined using Eqn. [3.8]

\[
\text{Moisture content in } \% = \left[ \frac{W_2 - W_3}{W_2 - W_1} \right] \times 100 \quad [3.8]
\]

3.4.3.1.2 Crude protein

Total % nitrogen of the samples was determined according to AOAC (2000). Micro kjeldahl method was used to determine crude protein as % N X 6.25 = % Protein.

3.4.3.1.3 Crude fat

About 5g of sample was extracted with 150 ml petroleum ether for a minimum period of 8 h in a soxhlet extractor. The solvent was removed using a steam bath. The flask containing the extracted fat was dried for about 1 h on steam bath.

\[
\text{Crude fat (on air dried basis), } \% \text{ by weight} = \left[ \frac{W_2 - W_1}{W} \right] \times 100 \quad [3.9]
\]

Where: W₁ = Weight of the extraction flask (g), W₂ = Weight of the extraction flask plus the dried crude fat (g), W = Weight of sample (g)
3.4.3.1.4 Crude ash
A clean and dry porcelain dish containing 2g sample was placed in a muffle furnace (GALLENKAMP, Model FSL 340-0100, U.K.) set at 550ºC for 1hr and then cooled in a desicator and weighed, and the ash content was determined using eqn. [3.10]

\[
ash\% = \left[ \frac{W_2 - W}{W_1 - W} \right] \times 100
\]  

[3.10]

Where, W= Weight in grams of empty dish, W1= Weight in gram of the dish plus sample, W2 = Weight in gram of the dish and ash.

3.4.3.1.5 Crude fiber
The crude fiber was determined using AAOC (2000) official method and the amount was calculated using eqn. [3.11]

\[
Crude\ fiber\ content\ \left( \frac{g}{100} \right) = \left[ \frac{(W_1 - W_2)(100 - m)}{W_3} \right]
\]  

[3.11]

\( W_1 = \) Crucible weight after drying, \( W_2 = \) Crucible weight after ashing, \( W_3 = \) dry weight, \( m = \% \) moisture content of the sample

3.4.3.1.6 Carbohydrate
Carbohydrate content of the samples was determined by subtraction of the above tested parameters from 100% as in eqn. [3.12].

\[
\%\ Carbohydrate = 100 - \left[ \%\text{Moisture} + \%\text{Protein} + \%\text{Fat} + \%\text{Ash} \right] \]  

[3.12]
3.4.3.2 Determination of physicochemical properties

3.4.3.2.1 Hundred seed mass
One hundred seed mass was determined by counting hundred seeds and weighing, and the results are expressed as the mean of triplicates.

3.4.3.2.2 Seed density
Seed density was determined according to the method of Alfoso et al. (1998). One hundred seeds were weighed and transferred into 100 ml measuring cylinder containing 50 ml of tap water. The seed were allowed to soak for 10 min for equilibration, and the volume of water displaced was recorded at room temperature. The mass and volume were used to calculate the seed density as g/ml.

3.4.3.2.3 Hydration and swelling coefficient
According to the method reported by Yusuf (1978), the raw bean seeds were soaked in distilled water for 24 h. The volumes of the beans before and after soaking were estimated by water displacement. The hydration coefficient was calculated as the percentage of increase in mass of beans. The swelling coefficient was calculated as a percentage of volume of beans after soaking to before soaking.

3.4.3.2.4 Hydration, swelling capacities and indices
Hydration, swelling capacities and indices were determined by Bishnoi and Khetarpaul (1993). About 100g of beans was put in a measuring cylinder with 100 ml water in it and left overnight at room temperature. The next day swollen seeds were reweighed after draining the water through filter paper. Hydration capacity per seed was determined by dividing the mass gained by the seed and the number of seeds present in sample. Swelling capacity per seed was calculated as the volume gained by the seeds divided by the number of the seeds. Hydration index was calculated as the ratio of the average hydration capacity per seed and the mass of one seed. The swelling index was calculated as the ratio of swelling capacity per seed to volume of one seed (ml).
3.4.3.3 Determination of functional properties of FFSF and FF-SPC flour and extrudates.

3.4.3.3.1 Emulsion activity and stability
Determination of emulsion activity (EA) and stability (ES) was performed according to the Yasumatsu et al. (1972). The emulsion (about 2g sample, 20ml distilled water and 20 ml soybean oil) was prepared in a calibrated centrifuge tube. The emulsion was centrifuged at 2000rpm using a centrifuge (Universal Jambo III (UJ3) Germany, 1972) for 10 min. The ratio of the height of the emulsion layer to the total height of the mixture was calculated as EA expressed in percentage. The emulsion stability was estimated after heating the emulsion contained in a calibrated centrifuge at 800 °C for 30 min in a water bath, cooling for 15 min under running tap water and centrifuging at 200g for 15 min. The emulsion stability, expressed in percentage, was calculated as the ratio of the height of emulsified layer to the total height of the mixture.

3.4.3.3.2 Oil absorption Capacity
Oil absorption capacity was determined according to Beuchat (1977). About one gram of the sample was mixed with 10ml oil (pure soybean oil) for 30 s in a mixer. The samples were allowed to stand at room temperature for 30 min, centrifuged at 5000rpm using a centrifuge (UJ III Germany, 1972) for 30 min, and the volume of the supernatant was noted in a 10ml graduated cylinder. Density of oil was taken as 0.895g/ml. The means of triplicates result was reported (Yusuf et al., 2007).

3.4.3.3.3 Foaming capacity and stability
The method described in Coffman and Gracia (1977) was used, accordingly, 2g sample was whipped with 100ml distilled water for 5min in Panasonic home blender (type Panasonic MX-J120P), and poured in to a 250ml graduated cylinder. The total volume at time intervals of 1min, 30 min, 1 h, 2 ½ h, and 3 h was noted.

3.4.3.3.4 Water absorption index (WAI)
Water absorption index (WAI) and water solubility index (WSI) of the flours, concentrates and extrudates was determined as in Anderson et al (1969). For determination of WAI, 1.25g of extruded and ground sample (100mesh) was suspended in 15ml of distilled water. The sample was incubated at 25 °C with constant stirring for 30 min and then centrifuged at 3000rpm for 5 min using a
centrifuge type UJ III Germany 1972. Supernatant liquid was poured into a tarred evaporating dish and dried at 100 ± 5 °C for 4 h. Weight of the remaining gel was taken as WAI and expressed as g/g of dry sample.

3.4.3.3.5 Water solubility index (WSI)
The supernatant taken from determination of WAI was dried by evaporation at 105 °C for over night. Then WSI was calculated as a ratio of dry residue to the original mass (1.25g) and expressed as mean percentage of dry solid.

3.5 Data analysis
The data obtained from each experiment were analyzed by one way analysis of variance using SPSS version 13.0 statistical analysis software. The means were compared and the statistical significance between them was set at 5% level.
4.1 Cracking and dehulling

The amount of hull removed from the Clark 63K and SCS1 was 12.46% and 8.52% respectively. See table 4.1.

Table 4.1
Amount of hull removed from Clark 63K and SCS1 varieties after cracking and dehulling process

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Proportion of parts of the Soy bean</th>
<th>Clark 63k [%]</th>
<th>SCS 1 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cotyledon and hypocotyls</td>
<td>87.54</td>
<td>91.48</td>
</tr>
<tr>
<td>2</td>
<td>Hull</td>
<td>12.46</td>
<td>8.52</td>
</tr>
<tr>
<td>3</td>
<td>Whole bean</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

4.2 Physico-chemical properties

The general physical characteristics of Clark 63k and SCS1 are listed in table 4.2. Accordingly the result of color and shape, 100 seed mass and seed density are described below.

4.2.1 Color and shape

Regarding the physical characteristics of the two varities (Clark 63k and SCS 1), both varieties have industrial quality characteristics. Basically, industrial quality characteristics of soybeans are yellow in color and spherical in shape (Berk, 1992). Regarding hilum color, SCS1 has Yellow color whereas Clark 63K has black hilum color. Traditionally, many processors prefer yellow hilum color soybeans to avoid any color effect due to a darker hila on the final product (Tofu, Soymilk, Natto, etc.) (Brumm, 2006)

4.2.2 Hundred seed mass and seed density

Hundred seed mass

In case of 100 seed mass, the Clark 63k and SCS 1 are found having about 15.198 gm/100 seeds and 15.531 g/100 seeds, respectively. These values are not significantly different (p<0.05) with each other. As compared to other reports made on dry beans by Shimelis and Rakshit (2005), Clark 63k and SCS 1 have lower 100 seed mass value. On the other hand, Yimer (2007) reported that the
hundred seed mass of locally grown soybean varieties of Awassa and Belessa was 14.05 and 14.18 g/100seeds, respectively. This result shows that Clark 63k and SCS 1 have relatively higher 100 seed mass value than Awassa and Bellessa.

When compared with oil processing seed quality standard (18-19 g/100seeds) (Berk, 1992) and Tofu and milk processing (18.2-22.7 g/100 seeds), the 100 seed mass of Clark 63 K and SCS1 have smaller value. On the other hand, as compared to Natto manufacturing soybean quality standard 9-10 g/100 seeds) it is a larger value. Clark 63K and SCS 1 have 100 seed mass of commodity types (13.7-16.67 g/100seeds) of soybean quality (Brumm, 2006).

Seed Density

The seed densities of Clark63K (1.68g/ml) and SCS1 (1.67 g/ml) are not significantly different (p<0.05). This result is not within the range of the result of ten soybean varieties (1.82 to 2.36 g/cm³) (Latunde-dada, 1991; Yimer, 2007). The seed densities of Clark 63K and SCS 1 are higher than that of dry beans reported by Shimelis and Rakshit (2005) as well as locally grown soybean varieties of Awassa and Bellesa (Yimer, 2007). The seed densities of Clark 63K and SCS1 are very close to the values reported by Li and Burton(2000). Genotypic correlation between seed density and protein is positive, where as correlation between oil and density is negative (Li and Burton, 2002). Therefore, Seed density can be taken as one means of seed variety selection in order to identify a variety with high protein concentration.

Table 4.2
Description of Raw Material Physical Properties

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Hundred seed mass [g]</th>
<th>Seed density [g/ml]</th>
<th>Bean color</th>
<th>Hilum color</th>
<th>Shape</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark 63K</td>
<td>15.20 ± 0.54a</td>
<td>1.17 ± 0.0420b</td>
<td>Yellow</td>
<td>Black</td>
<td>Semi Spherical</td>
<td>medium</td>
</tr>
<tr>
<td>SCS 1</td>
<td>15.53 ± 0.195a</td>
<td>1.17 ± 0.0416b</td>
<td>Light Yellow</td>
<td>Yellow</td>
<td>Spherical</td>
<td>medium</td>
</tr>
</tbody>
</table>

*Means bearing the same letters in the same column are not significantly different from each other at (p<0.05)
*All values are means of triplicates ± SD
4.2.3 Hydration and swelling capacities and indices & hydration and swelling coefficient

The physico-chemical properties of clark63k and SCS1 varieties are presented in table 4.3. Clark 63K variety has been found to have hydration capacity (0.124g/seed), hydration index (0.838), hydration coefficient (140.0%), swelling capacity (0.118g/seed), swelling index (0.936), swelling coefficient (142.2%). While SCS1 variety hydration capacity (0.133g/seed), hydration index (0.869), hydration coefficient (140.1%), swelling capacity (0.127g/seed), swelling index (0.977), and swelling coefficient (150.0%). The hydration capacity, swelling capacity, hydration index, swelling index, hydration coefficient of both varieties are not significantly different (p<0.05). SCS 1 showed greater values of the above characteristics than that of Clark 63K. There is also a significant difference on swelling coefficient between the two varieties (p<0.05). These values are almost similar with those of dry beans reported by shimelis and Rackshit (2005) especially with Redwolaita, Beshbesh and Roba varieties and lower than that of Awash and Mexican. The hydration and swelling coefficient values of Clark 63K and SCS1 are significantly lower than Faba Bean seeds reported by El-Refai et al., (1988) and the hydration capacity, swelling capacity, hydration index and swelling index values are also lower than that of chickpeas reported by Williams et al., (1983). According to Yimer (2007), two soybean varieties (Awassa and Belessa) showed higher values of hydration and swelling capacity, hydration and swelling index and lower value of hydration coefficient than that of Clark 63K and SCS 1. While as the swelling coefficient is similar.

Table 4.3
Physico-chemical properties of soybean varieties

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Hydration capacity [g/seed]</th>
<th>Swelling capacity [ml/seed]</th>
<th>Hydration index</th>
<th>Swelling index</th>
<th>Hydration coefficient</th>
<th>Swelling Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark 63K</td>
<td>0.124±0.00a</td>
<td>0.118±0.00b</td>
<td>0.838±0.00c</td>
<td>0.936±0.000d</td>
<td>1.400±0.000c</td>
<td>1.422±0.056f</td>
</tr>
<tr>
<td>SCS 1</td>
<td>0.133±0.00a</td>
<td>0.127±0.00b</td>
<td>0.869±0.002c</td>
<td>0.977±0.001d</td>
<td>1.401±0.011c</td>
<td>1.500±0.010g</td>
</tr>
</tbody>
</table>

*Means bearing the same letters in the same column are not significantly different from each other at (p<0.05)*
*All values are means of triplicates ± SD*
4.3 Changes during extrusion cooking of FFSF and FF-SPC

4.3.1 Preliminary study on dough formation and characteristics

Before the extrusion cooking process is performed the raw materials dough formation with respect to water absorption and texture characteristics was analysed as indicated in table 4.4

Table 4.4
Dough formation and characteristics of FFSF and FF-SPC flours

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Sample types</th>
<th>% water absorption (v/w)</th>
<th>Dough texture</th>
<th>Dough color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark 63K</td>
<td>FFSF</td>
<td>51.47±0.91a</td>
<td>Sticky</td>
<td>yellow</td>
</tr>
<tr>
<td></td>
<td>FF-SPC</td>
<td>130.33±2.02b</td>
<td>Crumbly</td>
<td>White</td>
</tr>
<tr>
<td>SCS1</td>
<td>FFSF</td>
<td>70.00±1.50c</td>
<td>Sticky</td>
<td>yellow</td>
</tr>
<tr>
<td></td>
<td>FF-SPC</td>
<td>101.83±1.76d</td>
<td>Crumbly</td>
<td>White</td>
</tr>
</tbody>
</table>

*Means differ significantly from each other at p=0.05

*All values are means of triplicates ± SD

From the experiment it was known that when the FFSF was changed to FF-SPC, its dough water absorption capacity increased significantly (p<0.05) by 31.26% (SCS1) and 60.5% (Clark 63k). In addition to that the dough physical character was changed significantly; FFSF has yellowish dough color and is very sticky during mixing. FF-SPC has whitish dough color and its dough has crumbly texture. One of the main reasons for such significant change in color and functional property (texture and water absorption) could be the change in carbohydrate content and protein concentration. The FFSF produced from Clark 63K and SCS 1 initially had carbohydrate and protein of 26.32% and 41.10% & 27.16 and 37.33% respectively. When it was further processed in to FF-SPC, most of the soluble carbohydrate and some pigment were removed, and the protein was significantly concentrated after processing. The amount of carbohydrate and protein was changed in to 15.33%, and 44.09% & 15.11% and 44.37% for Clark 63K and SCS1, respectively. This shows a decrease in total carbohydrates content by 38.33% (Clark 63K) and 44.37% (SCS 1) and a total increase in protein content by 7.28% (Clark 63K) and 13.82% (SCS 1). The results indicated that there is a clear difference between FFSF and FF-SPC in responding towards the specific amount of water available during processing. This in turn changes the functional properties of extrudates compared to that of the raw unprocessed feed material.
Fig 4.1 FFSF of Clark 63K and SCS1

Fig.4.2 FF-SPC of Clark 63K and SCS1
4.3.2 Extrusion Cooking of Full fat soy flour (FFSF)

FFSF’s extrudate was un-puffed product due to higher moisture and fat content of the feed. The addition of lipids in small quantities (<3%) in extrusion cooking has only a low effect on extrudate expansion at the die, while amounts over 5% results in rapid decrease of extrudate expansion (Llo et al., 2000). The extrudate was yellow in color and very fragile like that of ‘Chiko’ due to its high oil content. As it was observed during processing, the FFSF of SCS1 was relatively more fragile than that of Clark 63K. But generally both varieties showed similar behavior towards the selected operation conditions. (See fig.4.3)

![FFSF Extrudates](image)

**Fig. 4.3** FFSF extrudates

4.3.3 Extrusion cooking of full fat soy protein concentrates (FF-SPC)

FF-SPC’s was unpuffed product. The extrudate was white in color and its flow was relatively uniform and consistent. When compared with FFSF, it was relatively resisted the high temperature steam accumulated in the melt. As a result, there was no as such frequent steam flashing off during processing. This flow property was observed in both types of varieties. (See fig.4.4)
4.3.4 Power, Specific mechanical energy (SME) and some physical characteristics of Extrudates

**Power (kw)**

The amount of power consumed during the extrusion cooking process was calculated to be 1.48kw using the equation [3.2] in section 3.3.2.3.1.

**Specific mechanical energy (SME) (kw/kg)**

The SME required during the extrusion cooking process of FFSF and FF-SPC was 214.8kj/kg. During extrusion cooking of maize grits, Smith(1992) investigated that micro-structural change in starch materials as a function of screw configuration, moisture content, and barrel temperature achieving a range of SME values from 180 – 750 kj/kg. In his experiment, it was indicated that the quantity of swollen starch granules increased with increasing SME. But, starch granules became undamaged when SME decreased. While starch solubility increased with increasing SME because of macromolecular degradation of starch (Bouvie, 2001; Smith, 1992).

Kebede (2006), in his study on extrusion cooking of Tef varieties observed that torque requirements increased with decreasing dough moisture and barrel temperature. Similar results reported by Li et al., (2004) and Ilo et al., (1996) for maize grit. The variation in SME could be attributed to the
viscosity of the melt (Kebede, 2006). At high moisture content and temperature, the melt had a lower viscosity. Thus, die pressure, torque and SME decreases. Addition of water provides lubrication and results in less viscous melt causing lower resistance for the extruder screw and die which impartin lower SME. As the amount of moisture and oil is higher, and from the obtained values of WAI (water absorption index), it seems that the SME value is lower. Therefore, it needs either decreasing the moisture content or increasing the screw speed or both in order to effect optimum starch gelatinization without causing higher degradation of starch which may cause higher WSI (water solubility index) and sticky product. Physical characteristics of FFSF and FF-SPC extrudates of both Clark 63K and SCS1 are presented in table 4.5

**Expansion ratio (ER)**

The expansion ratio of FFSF and FF-SPC of Clark 63K was 1.1 and 0.98, respectively and the expansion ratio of both products for SCS1 was found to be 0.950 and 0.965, respectively. The result show that, the diameter of FFSF extrudate of Clark 63K has no change, but FF-SPC of Clark 63K and FFSF & FF-SPC of SCS1 indicated a relatively slight shrinkage after being extruded. This may be due to high oil content of the extrudates the biopolymer melt of starch and protein structure was not build in such a way that it can trap air bubbles so that puffed products can be obtained. According to Guy(2001), in order to produce expanded product from soy protein products, protein concentration must be > 40% w/w at moisture content of 30-40% w/w. On the other hand, the maximum fat content must be below 2%. If the oil content is higher than the recommended value, it may reduce the degradation of starch polymers to such extent that no expansion is obtained from a recipe. (Guy, 2001). Plasticizers like water, lipids, low molecular sugars decrease viscosity which in turn reduses the shearing and mechanical energy input in the cooking extruder. This in turn negatively affects melting of structure-forming biopolymers and consequently extrudate expansion (Fan et al., 1996).
Table 4.5

Physical characteristics of full fat soy flour and full fat soy protein concentrate extrudates

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Product characteristics</th>
<th>Clark 63K</th>
<th>SCS 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FFSF</td>
<td>FF-SPC</td>
</tr>
<tr>
<td>1</td>
<td>Length [mm]**</td>
<td>2.470±0.058</td>
<td>2.430±0.058</td>
</tr>
<tr>
<td>2</td>
<td>Weight [gm]</td>
<td>0.089±0.001</td>
<td>0.089±0.02</td>
</tr>
<tr>
<td>3</td>
<td>Diameter [mm]</td>
<td>2.190±0.005</td>
<td>1.97±0.015</td>
</tr>
<tr>
<td>4</td>
<td>Expansion ratio (Radial)(mm/mm)</td>
<td>1.1</td>
<td>0.98</td>
</tr>
<tr>
<td>5</td>
<td>Specific length(cm/gm)</td>
<td>27.81</td>
<td>27.43</td>
</tr>
</tbody>
</table>

* The relatively lower weight value of FFSF of SCS1 is due to power interruption (from EEPCO) before weight measurement was taken, which also caused high value of specific length.
** Cutting was done manually since automatic cutting of the equipment was not possible.

Specific Length

The specific lengths of FFSF and FF-SPC of Clark 63K were found to be 27.81 cm/g and 27.43 cm/g respectively, whereas the specific lengths of that of SCS1 for both products were 35.25 and 28.48 cm/g respectively. Hsieh et al., (1993) explained extrudate specific length is related to the expansion volume. The more the extrudates expanded in either the axial or radial direction, the less dense they become indicating a higher proportion of starch gelatinization (Kebede, 2006; Hsieh et al., 1993).

Specific heat capacity and final moisture content of extrudates

The specific heat capacities of FFSF and FF-SPC of Clark 63K were almost similar with that of SCS1 product. They showed about 24-26% increment from that of the corresponding unprocessed material. When comparing $C_p$ values within flours and within extrudates there is no significant change. But, there are relatively higher values in extrudates of FF-SPC than that of FFSF. The difference however was not caused by the extrusion process. It is caused by the difference in water content of the products. The moisture content of extrudates is lower than that of the flours which makes the components more concentrated (carbohydrates, protein, fat etc.) in the extrudates than in the flours. Therefore the corresponding values of $C_p$ are higher. Basically the $C_p$ value in food products is the function of product composition and temperature. Since processing temperature is
similar for all products of the two varieties, the difference will only be caused by the difference in composition.

The final moisture content of the extrudates was also similar due to similar processing conditions in which all feed materials were subjected. (See table 4.6)

Table 4.6
Specific heat capacity and final moisture content of the extrudates of FFSF and FF-SPC

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Sample type</th>
<th>( C_p ) of the flour [KJ/kg( \cdot ^0)C]</th>
<th>( C_p ) of the extrudates [KJ/kg( \cdot ^0)C]</th>
<th>( M_s ) [kg of lost water /kg of extrudates]</th>
<th>( M_f ) (final moisture of the extrudates) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark 63K</td>
<td>FFSF</td>
<td>2.026</td>
<td>2.6782</td>
<td>0.04746</td>
<td>26.512</td>
</tr>
<tr>
<td></td>
<td>FF-SPC</td>
<td>2.084</td>
<td>2.7188</td>
<td>0.04818</td>
<td>26.456</td>
</tr>
<tr>
<td>SCS 1</td>
<td>FFSF</td>
<td>2.019</td>
<td>2.6733</td>
<td>0.04737</td>
<td>26.519</td>
</tr>
<tr>
<td></td>
<td>FF-SPC</td>
<td>2.093</td>
<td>2.7251</td>
<td>0.04829</td>
<td>26.448</td>
</tr>
</tbody>
</table>

4.4 Proximate composition of FFSF and FF-SPC flour and extrudates of Clark 63K and SCS 1

The proximate composition of FFSF and FF-SPC flour and extrudates of Clark 63K and SCS1 is presented on table 4.7

4.4.1 Carbohydrate

The Carbohydrate content of FFSF for Clark 63K and SCS1 (26.48 and 29.03% respectively) is significantly (p<0.05) lower than that of whole mill soybean (WMSB) of the two varieties (27.97 and 30.53 % respectively). This is due to the removal of the hull which contains polysaccharides (Cellulose) by dehulling process. The carbohydrate content of FF-SPC of Clark 63K and SCS1 (16.53 and 16.44 respectively) is significantly (p<0.05) lower than that of FFSF. This is obviously due to the extraction of soluble carbohydrates in boiling and washing process of the dehulled and cracked soybean. Generally, the carbohydrate content of SCS1 is significantly (p<0.05) higher than that of Clark 63K.
The cause of the relatively higher carbohydrate content of the extrudates than the flours could be due to starch degradation into dextrin and simple sugars like free glucose, this is easily observed in increasing the WSI values of the extrudates, which may be caused an increase the proportion of the carbohydrates. (See fig 4.5)

### Table 4.7
**Proximate Composition of Whole mill soybean (WM), FFSF and FF-SPC flour and Extrudates of Clark 63K and SCS1**

<table>
<thead>
<tr>
<th>Variety</th>
<th>Sample type</th>
<th>Moisture [%]</th>
<th>Crude Fat [%]</th>
<th>Crude Protein [%]</th>
<th>Carbohydrate [%]</th>
<th>Total Ash [%]</th>
<th>Crude Fiber [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clark 63K</strong></td>
<td>WMSB</td>
<td>6.312±0.028</td>
<td>20.855±0.011</td>
<td>39.659±0.143</td>
<td>27.972±0.092</td>
<td>4.786±0.267</td>
<td>6.732±0.013</td>
</tr>
<tr>
<td></td>
<td>FFSF</td>
<td>6.447±0.004</td>
<td>23.076±0.013</td>
<td>42.615±0.223</td>
<td>26.478±0.129</td>
<td>4.717±0.016</td>
<td>3.117±0.392</td>
</tr>
<tr>
<td></td>
<td>FFSF Extr.</td>
<td>4.039±0.129</td>
<td>22.231±0.065</td>
<td>43.748±0.065</td>
<td>27.710±0.082</td>
<td>4.696±0.066</td>
<td>3.417±0.086</td>
</tr>
<tr>
<td></td>
<td>FF-SPC</td>
<td>7.948±0.005</td>
<td>26.950±0.109</td>
<td>47.590±0.000</td>
<td>16.533±0.111</td>
<td>3.253±0.018</td>
<td>5.669±0.425</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extr.</td>
<td>4.034±0.042</td>
<td>26.310±0.214</td>
<td>47.915±0.278</td>
<td>19.729±0.124</td>
<td>3.266±0.035</td>
<td>2.782±0.049</td>
</tr>
<tr>
<td><strong>SCS1</strong></td>
<td>WMSB</td>
<td>6.871±0.007</td>
<td>20.760±0.091</td>
<td>37.495±0.146</td>
<td>30.525±0.170</td>
<td>4.220±0.038</td>
<td>7.001±0.668</td>
</tr>
<tr>
<td></td>
<td>FFSF</td>
<td>6.589±0.000</td>
<td>23.084±0.000</td>
<td>40.415±0.005</td>
<td>29.028±0.297</td>
<td>4.332±0.163</td>
<td>3.140±0.110</td>
</tr>
<tr>
<td></td>
<td>FFSF Extr.</td>
<td>8.176±0.081</td>
<td>22.126±0.055</td>
<td>40.287±0.113</td>
<td>30.826±0.256</td>
<td>4.171±0.869</td>
<td>2.592±0.173</td>
</tr>
<tr>
<td></td>
<td>FF-SPC</td>
<td>8.796±0.051</td>
<td>27.920±0.056</td>
<td>46.960±0.126</td>
<td>16.435±0.115</td>
<td>2.682±0.013</td>
<td>6.003±0.330</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extr.</td>
<td>4.659±0.024</td>
<td>26.700±0.122</td>
<td>47.211±0.067</td>
<td>20.000±0.110</td>
<td>2.863±0.000</td>
<td>3.331±0.338</td>
</tr>
</tbody>
</table>
4.4.2 Protein

The crude protein content of FFSF of Clark 63K and SCS1 (42.62 and 40.42 \% respectively) is significantly (p<0.05) higher than that of WMSB (39.66 and 37.49 \% respectively). This is due to the dehulling process which in turn could concentrate the protein content of FFSF. Similarly, the extraction of soluble carbohydrates also concentrates and increased significantly (p<0.05) the protein content when FFSF is further processed in to FF-SPC of Clark 63K (47.59\%) and SCS1 (46.96\%). As it is clearly shown on the result the protein content of Clark 63K is significantly higher than that of SCS1.

As Singh et al., (2007) explains protein nutritional value is dependent on the quantity, digestibility and availability of essential amino acids. Digestibility is considered as the most important determinant of protein quality in adults, according to FAO/WHO/UNU (1985). Protein digestibility value of extrudates is higher than non-extruded products. The possible cause might be the denaturation of proteins and inactivation of anti-nutritional factors that impair digestion. This may also be the possible reason for the relatively higher value of protein content of the extrudates in the present work. (See fig 4.6)
4.4.3 Fat

The fat content of WMSB of Clark 63K (20.83%) and SCS1 (20.76%) is relatively lower than that of FFSF (23.07 and 23.08% respectively). This is also due to the removal of the hull which could concentrate the fat content. Similarly, the fat content of FF-SPC of the two varieties (26.95 and 27.92%) is significantly (p<0.05) higher than that of FFSF. This is also due to the removal of soluble carbohydrates which could concentrate the fat content. As it can be observed on the fig 4.7 the fat content of the extrudates is lower than that of the flours. This is possibly due to loss of some free oil at the die during extrusion cooking process. Generally, the fat content of WMSB and FFSF of the two varieties are not significantly (p<0.05) different.
4.4.4 Crude fiber

The crude fiber of WMSB of Clark 63K (6.73%) and SCS1 (7.00%) is significantly (p<0.05) higher than FFSF (3.12 and 3.14% respectively) and FF-SPC (5.67 and 6.00% respectively). This is due to high fiber content of the hull. From this result it can also be observed that further processing of FFSF in to FF-SPC can concentrate the insoluble carbohydrate content due to the removal of soluble carbohydrates.

As Singh et al.,(2007) summarized different researchers findings, at mild or moderate conditions, extrusion cooking does not significantly change dietary fiber content but it solubilises some fiber components. At more sever conditions, the dietary fiber content tends to increase. The available reports on effect of extrusion on dietary fibers were conflicting findings. (Singh et al., 2007)

![Fig.4.8 Comparison of crude fiber between products of Clark 63K and SCS1](image)

4.4.5 Total Ash

Ash content is an indirect indicator of the mineral level of food staffs. Ash content of WMSB of the Clark 63K and SCS1 (4.79 and 4.22%, respectively) are not significantly (p>0.05) different from that of FFSF flour (4.72 and 4.33%, respectively). The ash content of FF-SPC flour of Clark 63K and SCS1 (3.25 and 2.68%, respectively) is significantly lower than that of FFSF. This result indicates that some soluble minerals may be washed out during the cooking and washing process of FF-SPC production process. As it can be seen from the graph there is no significant change on the ash content of the extrudates comparing with the unprocessed flours. According to Alonso et al., (2000), extrusion cooking does not significantly affect minerals composition of pea and kidney been seeds,
except for iron. Iron content of the flours is increased after processing and it is most likely to the result of the wear of metallic pieces, mainly screws of the extruder. (See fig 4.9)

![Graph showing comparison of Total Ash content between products of Clark 63K and SCS1](image)

**Fig. 4.9 Comparison of Total Ash content between products of Clark 63K and SCS1**

### 4.5 Functional properties of FFSF and FF-SPC flour and extrudates of Clark 63K and SCS1

#### 4.5.1 Bulk Density (BD)

The bulk densities of FFSF and FF-SPC flours and extrudates of both varieties are presented in table 4.8 and Fig.4.10 FFSF and FF-SPC flour of Clark63K has BD value of 0.6004 g/ml and 0.4319 g/ml, respectively and that of SCS1 is FFSF (0.6255 g/ml) and FF-SPC (0.4353 g/ml). This shows that the bulk density of FFSF significantly (p<0.05) decreased when it was further processed in to FF-SPC. Whereas the bulk density of FFSF and FF-SPC (0.6004g/ml and 0.4319 g/ml, respectively) flours of Clark 63K and that of SCS1 of the same product type (0.6255 g/ml and 0.4353 g/ml, respectively) showed no significant difference (p<0.05) with corresponding product type. Yemer(2007) reported that the BD values of soybean varieties of Awassa and Belessa FFSF are 0.64g/ml and 0.6 g/ml, respectively. The result indicates that the BD values of FFSF of Clark 63K and SCS1 are almost similar to that of Awassa and Belessa. Okaka and Potter (1979) also reported cowpea bulk density of 0.6 g/ml is similar to that of FFSF of SCS1. In the current study FFSF of Clark 63K and SCS1 found to contain higher BD value than what was reported on commercial soy flour (0.38 g/ml) by Edema et
al., (2005). According to Onimawo et al., (1998), Bambara ground nut a bulk density in the range of 0.6-0.75 g/ml. Thus justifying BD values of FFSF of Clark 63 K and SCS1 to be within the range.

The BD of FFSF extrudates of both Clark 63K (0.4796 g/ml) and SCS1 (0.4299) are significantly lower (p=0.05) than that of their corresponding flours (0.6004g/ml and 0.6255g/ml, respectively). The result showed that even though there was no expansion of extrudates, some kind of foam like structure had been created that could decrease the bulk density of the extrudates. According to Guy (1994), foam type of structure could be formed in extrusion cooking at high oil and high moisture content (30-35%), where the starch conversion is not dependent on granular dispersal but on swelling and diffusion mechanism. The BD of FF-SPC extrudates of Clark 63K (0.4338g/ml) and SCS1 (0.4370g/ml) have no significant difference (p=0.05) with that of their corresponding unprocessed flours (0.4319 g/ml and 0.4353 g/ml, respectively). This may be due to the coinciding of lower starch content of FF-SPC flour and the presence of higher amount of water and oil in the given operating condition that consequently inhibit the expansion of the FF-SPC extrudates causing no BD change. Generally, the bulk densities of FFSF and FF-SPC flours and extrudates of both Clark 63K and SCS1 possessed similar characteristic.

Table 4.8

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Sample type</th>
<th>Bulk density [g/ml]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark 63K</td>
<td>FFSF</td>
<td>0.600 ± 0.08</td>
</tr>
<tr>
<td></td>
<td>FFSF Extrudates</td>
<td>0.479 ± 0.29</td>
</tr>
<tr>
<td></td>
<td>FF-SPC</td>
<td>0.432 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extrudates</td>
<td>0.434 ± 0.14</td>
</tr>
<tr>
<td>SCS 1</td>
<td>FFSF</td>
<td>0.626 ± 0.01</td>
</tr>
<tr>
<td></td>
<td>FFSF Extrudates</td>
<td>0.430 ± 0.17</td>
</tr>
<tr>
<td></td>
<td>FF-SPC</td>
<td>0.435 ± 0.01</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extrudates</td>
<td>0.437 ± 0.14</td>
</tr>
</tbody>
</table>

*Means bearing the same letters in the same column are not significantly different from each other at (p<0.05)*

*All values are means of triplicates ± SD*
4.5.2 Water absorption and solubility index

The water absorption index and water solubility index values of FFSF and FF-SPC of Clark 63K and SCS1 are presented in table 4.9 and Fig.4.11 and 4.12

**Water Absorption Index (WAI)**

FFSF and its extrudate of Clark63K showed WAI values of 2.9176 g gel/g solid and 3.0948 gel/g solid respectively. This indicates shows that WAI value of the extrudate is relatively higher than that of the flour. Even though the values significantly different (p<0.05), it shows there was a slight starch gelatinization. According to Gujska and Khan (1991), protein denaturation, starch gelatinization and, swelling of crude fiber, which occur during extrusion could all be responsible for the increasing WAI value of extruded products.(Reyes-Moreno et al., 2002; Gujska and Khan 1991) and Reyes- Moreno et al., (2002) reported that the WAI value of extruded chickpea flour (2.23g/g-3.27g/g) was higher than that of conventional flours (2.12-2.15 g/g). Rued et al., (2003) reported that defatted soy flour that was extruded at 140 °C temperature, 26 % feed moisture content and 125 rpm screw speed had showed WAI value of 5.82g/g. Even if the operation conditions are relatively close to the present work, this value is higher than FFSF and FF-SPC extrudates of Clark 63K and SCS1.
On the other hand the WAI value of FF-SPC extrudate (3.6044 gel/g solid) is lower than that of FF-SPC flour (4.0813 gel/g solid) and the difference is significant (p<0.05). This shows that there was slightly higher starch degradation than gelatinization as compared to that of FFSF extrusion cooking. The WAI values of FFSF (2.9176 gel/g solid) and FF-SPC (4.0813 gel/g solid), significantly differed from each other (p<0.05). This may be due to the relatively higher protein content of FF-SPC than that of FFSF. Protein concentrates absorb more water than their flours (Yusuf et al, 2007). Consequently, since the characteristics of extrudates is highly dependent on the feed material property, it is obvious that the WAI value of extrudates of FFSF (3.0948 gel/g solid) is lower than that of FF-SPC (3.6044 gel/g solid) significantly (p<0.05). This difference could reasonably occur due to the difference in composition between FFSF and FF-SPC. Similar trend is also observed in the case of SCS1, where the WAI values of the different products are: FFSF (2.9041) gel/g solid, FFSF extrudate (3.0784 gel/g solid), FF-SPC flour (4.2093 gel/g solid) and FF-SPC extrudate (3.8893 gel/g solid). The WAI values of FFSF flour and extrudates of Clark and SCS1 (2.9176, 2.9041 and 3.0948, 3.0784, respectively) have no significant difference (p<0.05). Whereas the WAI values of FF-SPC flour and its extrudate of Clark 63K and SCS1 (4.0813, 4.2093 and 3.6044, 3.8893, respectively) have significant difference (p<0.05). The values of FF-SPC flour and FF-SPC extrudate of SCS1 are higher than that of Clark 63K.

**Water Solubility index (WSI)**

The WSI values of FFSF flour and extrudates for Clark 63K and SCS1 are 35.5947%, 26.2627% and 33.3787%, 25.1647% respectively. This showed that WSI values of extrudates are significantly lower (p<0.05) than that of its flour. This indicates that there was lower starch dextrinization or starch gelatinization could reduce the amount of soluble matters during the extrusion cooking process. The WSI value is related to the presence of soluble molecules, which has been related to dextrinization (Reyes-Mareno et al., 2002; Colonna et al., 1983). Reyes-Mareno et al., (2002) reported that conventional chickpea flours had higher WSI value than extruded chickpea flours (27.5-30.8 vs 20.1-26 %). Rued et al., (2003) reported that, defatted soy flour that was extruded in operation condition of 140 0C temperature, 26 % feed moisture content and 125 rpm screw speed had showed WSI value of 21.32% which is lower than that FFSF extrudates of both Clark 63K and SCS1.
The WSI values of FF-SPC flour and FF-SPC extrudates for Clark 63K and SCS1 are 9.5067%, 15.0200% and 8.7467%, 13.6280%, respectively. The results showed that the WSI values of extrudates is significantly (p<0.05) higher than that of flours. This indicates that there was relatively higher starch dextrinization during the extrusion cooking process. This may be caused by the relatively higher amount protein content of the concentrates which cause moisture scarcity on starch granules that can cause harsher condition for starch molecules in the extrusion cooker to be changed in to smaller soluble dextrin. An increase in WSI therefore shows macromolecular degradation with intensity of extrusion condition (Kebed, 2006). Gujska and Khan (1991) reported that extruded chickpea at temperature of 132 °C and moisture contents of 20%, 25%, and 26 % and found WSI of 21.2%, 18.8%, and 16.5% respectively. They suggested that this result is caused by greater shear degradation of starch during extrusion at lower moisture content (Reyes-Moreno et al., 2002; Gujska and Khan, 1991).

The WSI values of FFSF (35.5947%, 33.3787%) and FF-SPC flours (9.5067%, 8.7467%) and FFSF extrudates (26.2627%, 25.1647%) and FF-SPC extrudates (15.0200%, 13.6280%) of Clark 63K and SCS1 respectively are significantly different (p<0.05). The WSI values of FF-SPC flour and extrudates are lower than that of FFSF. This means FFSF is stickier than FF-SPC. This could be due to relatively lower amount of starch presence in FF-SPC than FFSF. High WSI is related to stickiness of extruded products. The WSI values of FFSF flour and extrudates as well as FF-SPC flour and extrudates of SCS1 are significantly (p<0.05) lower than that of Clark 63K.

WAI and WSI values of Clark 63K and SCS1 showed that, SCS1 has better characteristic than that of Clark 63K. WAI and WSI values are important for defining the applications of extrudates as ingredients in predicting how the material might behave if further processed. (Hashimoto and Grossmann, 2003; Sriburi and Hill, 2000)
### Table 4.9
Water absorption and water solubility index of flours and extrudates

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Type of sample</th>
<th>WAI</th>
<th>WSI [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark 63K</td>
<td>FFSF flour</td>
<td>2.918 ± 0.18a</td>
<td>35.594 ± 0.10a</td>
</tr>
<tr>
<td></td>
<td>FFSF Extrudates</td>
<td>3.095 ± 0.05b</td>
<td>26.263 ± 0.72b</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Flour</td>
<td>4.081 ± 0.07b</td>
<td>9.507 ± 0.13c</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extrudates</td>
<td>3.604 ± 0.02c</td>
<td>15.02 ± 0.53d</td>
</tr>
<tr>
<td>SCS 1</td>
<td>FFSF flour</td>
<td>2.904 ± 0.14a</td>
<td>33.379 ± 0.20e</td>
</tr>
<tr>
<td></td>
<td>FFSF Extrudates</td>
<td>3.078 ± 0.04d</td>
<td>25.165 ± 0.46f</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Flour</td>
<td>4.209 ± 0.02d</td>
<td>8.747 ± 0.12g</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extrudates</td>
<td>3.889 ± 0.03d</td>
<td>13.628 ± 0.13h</td>
</tr>
</tbody>
</table>

*Means bearing the same letters in the same column are not significantly different from each other at (p<0.05)

*All values are means of triplicates ± SD

---

![Fig. 4.11 WAI of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1](image1)

![Fig. 4.12 WSI of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1](image2)
4.5.3 Oil Absorption Capacity (OAC)

The OAC of FFSF and FF-SPC flour and extrudates of Clark 63K is 1.730g/g & 2.125g/g and 1.223g/g & 1.402g/g, respectively. That of SCS1 is 1.849g/g & 2.237g/g and 1.641g/g & 1.283g/g, respectively. This result shows that the OAC of extrudates are significantly lower (p<0.05) than their flours. The OAC of FF-SPC is significantly (p< 0.05) higher than that of FFSF for both Clark 63K and SCS1. Olaofe et al., 1994 reported that the OAC of Snake gourd flour and concentrate are 0.54g/g and 1.15g/g, respectively. He explained that the oil absorption value of the flour is lower than Pigeon pea flour (0.897g/g), Pumpkin seed flour (0.87g/g), Gourd seed flour (0.06g/g), Wheat flour (0.842g/g), and Soy flour(0.844 g/g). (Yusuf et al., 2007; Olaofe et al., 1994). From Olaofe’s result it can be seen that the oil absorption of the concentrate is higher than that of the flour. Comparing the oil absorption capacity, FFSF and FF-SPC showed higher OAC for both Clark 63 K and SCS1 than the above mentioned values. Yemer (2007) reported that soybean varieties of Awassa and Belessa flours have oil absorption capacity of 1.82g/g and 1.44g/g respectively. This shows that Awassa is lower than FFSF of SCS1 and higher than that of Clark 63K. Whereas, Belessa is lower than that of FFSF of both Clark 63K and SCS1. The present work showed higher value of OAC than soybean (0,29g/g) reported by Alfore et al.,(2004) and lupin seed (1.67g/g) reported by Sathe et al., (1982) (Yemer, 2007; Alfore et al.,2004 ; Sathe et al., 1982). When the OAC values of Clark 63K and SCS1 is compared SCS1 has significantly higher (p<0.05) oil absorption capacity than that of Clark 63K. (See table 4.10 and fig. 4.13)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Sample type</th>
<th>Oil absorption [g/g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark 63K</td>
<td>FFSF Flour</td>
<td>1.730 ± 0.24&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FFSF Extrudate</td>
<td>1.223 ± 0.24&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Flour</td>
<td>2.125 ± 0.19&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extrudate</td>
<td>1.402 ± 0.30&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>SCS 1</td>
<td>FFSF Flour</td>
<td>1.849 ± 0.24&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FFSF Extrudate</td>
<td>1.641 ± 0.30&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Flour</td>
<td>2.237 ± 0.45&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extrudate</td>
<td>1.283 ± 0.27&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

* All the means with different superscripts differed from each other at p<0.05
Fig. 4.13 OAC of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1

4.5.4 Emulsion activity and stability

Emulsion activity and emulsion stability of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1 are presented in table 4.11 and Fig.4.14 and 4.15

Emulsion Activity (EA)

The emulsion activity of FFSF and FF-SPC flours and extrudates of Clark 63K are 45.24% & 44.58% and 53.66% & 53.12%, respectively. The EA of SCS1 products are 43.74% & 43.74% and 50.79% & 54.29%, respectively. These results showed that, the EA of extrudates are significantly (p<0.05) higher than that of their unprocessed raw flours in case of both Clark 63K and SCS1 varieties. The EA of FFSF and FF-SPC flours are not significantly different (p<0.05) from each other both varieties. But, the EA of FFSF is slightly higher than that of FF-SPC. This could may be due to the higher fiber content of the FF-SPC flours than FFSF plus the effect of the increase in fiber could be more dominant than effect of decreasing in carbohydrate on the FF-SPC flour. According to Yusuf et al., (2007), the protein concentrates has higher emulsion capacity than the flour. He concluded that this observation may be attributed to the presence of carbohydrates and fiber in the flour. The same trend had been reported by Ramanatham et al 1978, who also concluded that the presence of carbohydrate and fiber in ground nut flour have adverse effect on emulsion
capacity. (Yusuf et al., 2007; Romanatham et al., 1978). The EA values of extrudates of FFSF and FF-SPC of both varieties have no significant difference (p<0.05). Therefore, it can be concluded that emulsion activity of FFSF and FF-SPC of Clark 63K is almost similar to that of SCS1.

According to Yemer (2007), Awassa and Belessa varieties soybean flour had emulsion activity of 49.06% and 46.75% respectively. These values are higher than that of FFSF and FF-SPC flours of both Clark 63K and SCS1 varieties. But the EA values of FFSF and FF-SPC flours of Clark 63K and SCS1 are higher than that of fluted pumpkin (20%) (Fagbami and Oshadi, 1991), sesame seeds (27.6%) (Badifu and Okpagher, 1996) and lower than that of pigeon pea (80%) (Onimawo et al., 2006), and lower than bambara ground nut (57%) (Onimawo et al., 1998).

Table 4.11

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Sample type</th>
<th>Emulsion Activity (EA) [%]</th>
<th>Emulsion Stability (ES) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark 63K</td>
<td>FFSF Flour</td>
<td>45.24 ± 0.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>44.07 ± 2.11&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FFSF Extrudate</td>
<td>53.66 ± 1.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>52.75 ± 1.25&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Flour</td>
<td>44.58 ± 1.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>43.52 ± 0.58&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extrudate</td>
<td>53.12 ± 0.64&lt;sup&gt;b&lt;/sup&gt;</td>
<td>52.03 ± 0.70&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>SCS 1</td>
<td>FFSF Flour</td>
<td>43.74 ± 0.77&lt;sup&gt;a&lt;/sup&gt;</td>
<td>44.68 ± 2.57&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FFSF Extrudate</td>
<td>50.79 ± 1.37&lt;sup&gt;c&lt;/sup&gt;</td>
<td>52.38 ± 0.00&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Flour</td>
<td>43.54 ± 0.77&lt;sup&gt;a&lt;/sup&gt;</td>
<td>43.41 ± 2.68&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>FF-SPC Extrudate</td>
<td>54.29 ± 2.64&lt;sup&gt;b&lt;/sup&gt;</td>
<td>51.73 ± 0.67&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Means bearing the same letters in the same column are not significantly different from each other at (p<0.05)*

*All values are means of triplicates ± SD

**Emulsion Stability (ES)**

The ES of FFSF and FF-SPC flours and extrudates of Clark 63K are 44.07% & 43.52% and 53.75% & 52.03%, respectively. The ES SCS1 products are 44.68% & 43.41% and 52.38% & 51.73%, respectively. This shows that the emulsion stability of extrudates both varieties are significantly (p<0.05) higher than that of unprocessed raw flours. On the other hand emulsion stability of FFSF and FF-SPC flours of both varieties are not significantly different (p<0.05). But, ES values of FFSF of flours are relatively higher than that of FF-SPC flour. The same trend is also observed on the extrudates. The extrudates of FFSF and FF-SPC of both varieties are not significantly different (p<0.05). Therefore, Clark 63K and SCS1 had showed almost similar performance in their emulsion stability property.
Emulsion activity of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1

Fig 4.14 EA of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1

Emulsification stability of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1

Fig 4.15 ES of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1
4.5.5 Foaming capacity and stability

Foaming capacity and foaming stability of FFSF and FF-SPC flours and extrudates of Clark63K and SCS1 are presented in table 4.12 and fig 4.16 and 4.17

Foaming capacity of FFSF and FF-SPC flours and extrudates of Clark 63K are 36ml & 10ml and 8ml & 10ml respectively. The foaming capacities of SCS1 products are 32ml & 6ml and 10ml & 6ml respectively. This shows that foaming capacities of full fat soy flours of both varieties are higher than that of their own extrudates, FF-SPC flour, and its extrudates. This could probably be due to the removal of soluble carbohydrates in case of FF-SPC and starch gelatinization and denaturation of proteins in case of extrudates. Soy flour products has higher foaming capacity than concentrates products (Lee and Rhee, 2001). The foaming capacity of Clark 63K and SCS1 FFSF flours are lower than that of snake gourd seed flour (47%) (Yusuf et al., 2007), gourd seed (40%), pumpkin seed (50%) and melon seed (40%) (Grahams and Philips, 1976), Awassa (70%) and Bellesa(66%) soybean varieties (Yemer, 2007).

The foam stability of FFSF and FF-SPC flours and extrudates of Clark 63K are 95% & 80% and 75% & 80% respectively. The FS of SCS1 products are 81.25% & 62.5% and 80% & 100 % respectively. This shows that the foam stability of FFSF of both varieties are higher than that of its own extrudates, FF-SPC flour and its extrudates. The foaming capacity and stability of FFSF of Clark 63K is higher than that of SCS1. But Foaming capacity and stability of FF-SPC flour of both varieties are almost similar.
Chatziziontonion et al. (2007) reported that soy flour used as a control which was subjected to water hydrolysis condition had foaming capacity (38.67%) and foaming stability (55.98%). According to Darewicz et al., (2000), foaming capacity of soy proteins was increased during progressive enzymatic hydrolysis due to the increase in solubility and the formation of peptides of reduced molecular weight. These peptides could be transformed and absorbed to the oil-water interface more easily. However, hydrolysis led to decrease foam stability possibility caused by peptides of decreased size and increased flexibility. (Chatziziontonion et al., 2007; Darewicz et al., 2000).

Grahams and Phlips (1996), linked good foamability with flexible protein molecules that can reduce surface tension while highly ordered globular protein, which is relatively difficult to surface denaturation give low foamability. One may therefore, suggest that Snake gourd protein may contain high concentration of flexible protein (Yusuf et al., 2007, Grahams and Phlips, 1996).
Foaming Capacity of FFSF and FF-SPC flour and extrudates of Clark63K and SCS1

Fig 4.16  FC of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1

Foam stability of FFSF and FF-SPC flour and Extrudates of Clark 63K and SCS1

Fig 4.17  FS of FFSF and FF-SPC flours and extrudates of Clark 63K and SCS1
5. Suggested technology for production of extruded products from full fat soy flour

The more successful approaches to soy product texturization can be classified in two categories. The first approach tries to assemble a heterogeneous structure comprising a certain amount of protein fibers within a matrix of binding material. The fibers are produced by a "spinning" process, similar to that used for the production of synthetic fibers for the textile industry. The second approach converts the soy material into a hydratable, laminar, chewy mass without true fibers. Two different processes can be used to produce such a mass: thermoplastic extrusion and steam texturization. The starting material for spun fibers is isolated soybean protein. In contrast, extrusion or steam texturized soy products can be made from flour, concentrate or isolated protein. (Berk, 1992)

In the present work, it was tried to produce extruded product from full fat soy flour and full fat soy protein concentrate using extrusion cooking machine. Extruded products of FFSF and FF-SPC can be produced depending on the market research analysis information in to larger, medium or small scale industries. In this section production of extruded FFSF is presented in preference to FF-SPC due to two reasons. That is, production of extruded FFSF is very easy and uncomplicated technology which can be realized by any small scale industries. In addition to that in the production process of FF-SPC there are high energy consumption steps like the CDSB boiling and additional drying step from that of FFSF production plant. But this does not mean that the FF-SPC production is as such high energy consuming plant as compared to other chemical plants or sugar processing plants, but it is just to say that production of extruded FFSF is easier and encouraging for manufacturers to produce and make it available in market, especially for those industries who already have the equipments. Therefore, in order to facilitate the utilization of soybeans and soy based products it is better to start with the easier plant. Due to these reasons, the material and energy balance, equipment layout, planning of the annual production program, annual main and auxiliary materials consumption, utilities, required man power, and financial information are presented on the next consecutive sub sections.
5.1 Material and Energy balance
5.1.1 Material balance

Data:
- Batch process with 1000 Qtl/day (4167 Kg/hr) soybean
- Maximum acceptable impurity content 5%
- Average hull amount is 8%
- The raw soybean is expected to be industrial quality (spherical in shape and yellow in colour.

Table 5.1
Raw material composition

<table>
<thead>
<tr>
<th>NO</th>
<th>COMPONENTS</th>
<th>FFSF</th>
<th>FFSF Wet Extrudate</th>
<th>Dried Extrudate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carbohydrate</td>
<td>24.86</td>
<td></td>
<td>26.03</td>
</tr>
<tr>
<td>3</td>
<td>Protein [%]</td>
<td>40.03</td>
<td>41.10</td>
<td>3.88</td>
</tr>
<tr>
<td>4</td>
<td>Moisture [%]</td>
<td>6.00</td>
<td>26.5% moisture</td>
<td>21.37</td>
</tr>
<tr>
<td>5</td>
<td>Fat [%]</td>
<td>21.68</td>
<td></td>
<td>21.37</td>
</tr>
<tr>
<td>6</td>
<td>Fiber [%]</td>
<td>2.93</td>
<td>4.41</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Ash [%]</td>
<td>5.25</td>
<td>3.21</td>
<td></td>
</tr>
</tbody>
</table>

Soybean

Cleaning → Cracking → Dehulling → Milling

Impurities

Hull

Milling → Sieving → Extrusion cooking

Overs of the sieve

Packed extrudate

Packing → Drying
Material Balance on from cleaning to dehulling section

\[ S = H + I + CDB \] \[ 4167 \text{ kg/hr} = 333.4 + 208.4 + CDB \]
\[ CDB = 3625.2 \text{ Kg/hr} \]

Material balance on Extrusion cooking processes

Considering 1% material loss during milling, transportation and storage FFSF (milled CDB) will be 3589Kg/hr.

\[ F + W = E \] \[ 0.94 \times F = 0.76 \times E \]
\[ E = 4,439 \text{ Kg/hr} \]
\[ W = E - F = 850 \text{ Kg/hr} \]
Material balance on dryer

\[ M_s = \text{Dry solid matter of feed} = 3262.67 \text{ kg/hr} \]
\[ W_1 = \text{moisture content in feed} = \frac{26.5}{73.5} = 0.361 \text{ kg of water/ kg of solid} \]
\[ W_2 = \text{moisture content in dried extrudate} = \frac{4}{96} = 0.042 \text{ kg of water/ kg of solid} \]
\[ M_s (W_1) + A (H_1) = M_s (W_2) + A (H_2) \]
\[ 3262.67 (0.361) + A (0.012) = 3262.67 (0.042) + A (H_2) \]
\[ A (H_2 - H_1) = 1178 - 137.0 = 1041 \text{ kg/hr} \]

4.1.2 Energy Balance

- Solid matter in DE and WE = 3262.7 kg/hr
- Initial air condition = \( T = 20^\circ\text{C} \), and 50% RH, \( H_1 = 0.0074 \) kg of water/ kg dry air
- Product temperature when it leaves drier = 30 \( ^\circ\text{C} \)
- Heated air entering in to the drier = 40 \( ^\circ\text{C} \) at 25% RH, enthalpy of in let air (ha1) = 71 Kj/kg dry air
- Enthalpy required to heat the air = ha1 - h0 = 71-30 = 41 Kj/kg
- Air temperature leaving the drier = 35 \( ^\circ\text{C} \)
- Latent heat of vaporization at 0\(^\circ\text{C} \) = 2507Kj/kg
- Specific heat of air \( (C_{p,a}) = 0.24 + 0.46 (H) \)
- Specific heat of solid matter of the product \( (C_{p,e}) = 2.547 \text{ kj/kg}^0\text{C} \)
- Specific heat of water \( (C_w) = 4.2 \text{ Kj/kg}^0\text{C} \)
- Energy estimated to be released in order to cook the product in extrusion cooker = 300Kj/Kg considering heat loss insignificant due to high insulation.
• Feed temperature = 20 °C
• \( H_1 \) & \( H_2 \) are absolute humidity of air
• \( A \) is flow rate of air
• Enthalpy of Feed = \( h_{we} \)
• Enthalpy of product = \( h_{de} \)
• Enthalpy of inlet air = \( h_{a1} \)
• Enthalpy of outlet air = \( h_{a2} \)

Energy Balance at drier:

\[
M_s \ (h_{we}) + A \ (h_{a1}) = M_s \ P \ (h_{de}) + A \ (h_{a2})
\]

1. \( h_{we} = C_{ds} \ \Delta T + W_1 \cdot C_w \cdot \Delta T \)
   \[
h_{we} = 2.547 \ (20) + 0.361(4.2)(20)
   = 50.9 + 7.2 = 58.12 \text{ Kj/kg}
\]
2. \( h_{de} = C_{ds} \ \Delta T + W_{w2} \cdot C_w \cdot \Delta T \)
   \[
h_{de} = 2.547 \ (30) + 0.042(4.2)(30)
   = 76.41 + 1.26
   = 77.67 \text{ Kj/kg}
\]
3. \( h_{a2} = C_s \ \Delta T + \lambda \cdot H_2 \)
   \[
h_{a2} = (0.24 + 0.46H_2) \ (35) + 2507.4 \ H_2
\]
ha\textsubscript{2} = 8.4 + 2523.5 H\textsubscript{2} \hfill [5]

Inserting eq. 5 in eq. 4

3262.7 (58.12) + A(71.0) = 3262.7(77.67) + A(8.4 + 2523.5H\textsubscript{2})

\begin{equation}
189,626.4 + 71.0A = 253,414 + 8.4A + 2523.5AH\textsubscript{2} \hfill [6]
\end{equation}

Taking Eq. [3] and inserting it in eq. [6]

\begin{align*}
189,626.4 + 71.0A & = 253,414 + 8.4A + 2523.5(0.012A + 1041) \\
189,626.4 + 71.0A & = 253,414 + 8.4A + 30.28A + 2,626,963.5 \\
32.32A & = 2,690,751.1 \\
A & = 83,253.44 Kg/hr
\end{align*}

Inserting A in eq. 3

H\textsubscript{2} = 0.0245 Kg/ Kg dry air

\begin{equation}
h_{a2} = 8.4 + 2523.5 (0.0245)
\end{equation}

\begin{equation}
h_{a2} = 70.23 Kj/Kg
\end{equation}
## Annual operation consumption

<table>
<thead>
<tr>
<th>Input</th>
<th>Process</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soy bean = 300,000 qtl/yr</td>
<td>Cleaning, cracking, and dehulling</td>
<td>Hul = 10,003.2 qtl/yr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impurities = 16,003.2 qtl/yr</td>
</tr>
<tr>
<td>Water = 4,080 m^3</td>
<td>Milling and sieving</td>
<td>Wet extrudate = 213,072 qtl/yr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moist air = 979.05 tons/yr</td>
</tr>
<tr>
<td>Flour = 174,000 qtl/yr</td>
<td>Extrusion cooking</td>
<td></td>
</tr>
<tr>
<td>Hot air = 47.954 tons/yr</td>
<td>Drying</td>
<td></td>
</tr>
<tr>
<td>Packing film = 241,053.5 Kg/yr</td>
<td>Packing</td>
<td></td>
</tr>
<tr>
<td>Carton box = 2,891,013 pcs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scotch tape = 160,612 roll</td>
<td>Dried and packed FFSF</td>
<td></td>
</tr>
<tr>
<td>Dried and packed FFSF extrudate = 165,284.5 qtl/yr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2 Equipment Layout

Extruded FF-SPC production line

Extruded FFSF production line
5.3 Plant capacity and Production program

5.3.1 Plant capacity

Based on the market study the production capacity of the envisaged extruded full fat soy flour production plant is 165,285 qtl per year. The plant is expected to work for 300 days per annum and in a double shift of 16 hours per day.

5.3.2 Production program

The annual production programme is formulated on the basis of the market forecast and selected plant capacity. It is assumed that the plant will achieve 75% and 85% capacity utilization rate in the first and second year and full capacity will be attained in the third year and onwards. The production programme for extruded full fat soy flour is shown below on table 2A.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Description</th>
<th>1st year</th>
<th>2nd year</th>
<th>3rd year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Capacity utilization rate [%]</td>
<td>75</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Extruded FFSF production [qtl/year]</td>
<td>123,964</td>
<td>140,492.3</td>
<td>165,285</td>
</tr>
</tbody>
</table>

5.4 Raw material and other inputs consumption and estimated annual cost

5.4.1 Raw materials and auxiliary materials

Main Raw materials

The major raw material in production of extruded FFSF is soybean. Therefore, the annual required raw soybean in full plant capacity utilization is 330,000 qtl with 10% waste or spoilage consideration. Annual estimated cost of main raw material is presented in table A1 of appendix A.
**Auxiliary Materials**

The main auxiliary material in extruded full fat flour production is packing film, carton box, and scotch tape. The annual consumption and estimate cost of auxiliary materials is presented on appendix A.

**a) Packing film**

The packaging material selected is food grade double layer Aluminum foil with a capacity designed to fit different types of customers (individuals, hotels, wholesalers etc…) that is, 250gm and 500 gm. Since the 250 gm is fast moving due to its being easy to handle from storage point of view (since it is small quantity, once open it wont stay long) out of the total production quantity 70% will hold for 250gm package and 30% will be for 500gm one. The estimated annual quantity and cost is presented in table A2 of appendixA.

**b) Carton box**

The required carton box to pack the two types of packing capacity films should be designed for suitable handling, stable structure, efficient space utilization etc…. The Annual required quantity and cost of ideal carton box size which is suitable to pack the two types of packets is estimated at 100% capacity utilization rate of the plant in table A3 of appendix A.

**c) Scotch tape**

Scotch tape is used to seal carton boxes after its being filled with the required number of packets. The estimated scotch tape amount and its cost at 100% capacity utilization rate is given in table A4 of appendix A

**5.4.2 Utilities**

Electricity and water are the two major utilities used for production process of extruded FFSF product. The annual consumption and cost estimates at full plant capacity utilization is given in table B1 of appendix B.
5.4.3 Manpower requirement
The total manpower required is 44. This includes 28 skilled and 16 unskilled labors. As shown in table C1 of appendix C and the corresponding annual labor cost is estimated to be 618,000 birr.

5.5 Financial analysis

5.5.1 Purchased equipment cost

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Equipment</th>
<th>Specification</th>
<th>Quantity</th>
<th>Price [birr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cleaning machinery</td>
<td>40 qtl/hr</td>
<td>1</td>
<td>1,000,000</td>
</tr>
<tr>
<td>2</td>
<td>Bean Weigher</td>
<td>40 qtl/hr</td>
<td>1</td>
<td>200,000</td>
</tr>
<tr>
<td>3</td>
<td>Milling</td>
<td>30 qtl/hr</td>
<td>1</td>
<td>500,000</td>
</tr>
<tr>
<td>4</td>
<td>Sieving machine</td>
<td>20qtl/hr</td>
<td>1</td>
<td>500,000</td>
</tr>
<tr>
<td>5</td>
<td>Extrusion cooker</td>
<td>30 qtl flour/hr</td>
<td>1</td>
<td>1,750,500</td>
</tr>
<tr>
<td>5</td>
<td>Flour weighers</td>
<td>30qtl/hr</td>
<td>1</td>
<td>200,000</td>
</tr>
<tr>
<td>6</td>
<td>Blower</td>
<td>5m³/hr</td>
<td>1</td>
<td>300,000</td>
</tr>
<tr>
<td>7</td>
<td>Screw conveyor</td>
<td>U shaped</td>
<td>2</td>
<td>100,000</td>
</tr>
<tr>
<td>8</td>
<td>Drier</td>
<td>1050 kg/hr evaporating capacity</td>
<td>1</td>
<td>900,000</td>
</tr>
<tr>
<td>9</td>
<td>Flour silo</td>
<td>100m³ 10m 4m</td>
<td>2</td>
<td>200,000*</td>
</tr>
<tr>
<td>10</td>
<td>Product Silo</td>
<td>150 m³ 10m 4.5m</td>
<td>2</td>
<td>250,000*</td>
</tr>
<tr>
<td>11</td>
<td>Packing machine</td>
<td>229 pkt/min</td>
<td>1</td>
<td>900,000</td>
</tr>
</tbody>
</table>

Purchased Equipment cost 6,900,000 birr

* The cost of silos taken from local company that can produce such kind of equipments from stainless steel.
5.5.2 Estimation of total capital investment

<table>
<thead>
<tr>
<th>Components</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Purchased equipment (delivered)[PE]</td>
<td>6,900,000.00</td>
</tr>
<tr>
<td>2. Purchased equipment installation 39%PE</td>
<td>2,691,000.00</td>
</tr>
<tr>
<td>3. Instrumentation (installed)13% PE</td>
<td>897,000.00</td>
</tr>
<tr>
<td>4. Piping (installed)31% PE</td>
<td>2,139,000.00</td>
</tr>
<tr>
<td>5. Electrical(installed) 10% PE</td>
<td>690,000.00</td>
</tr>
<tr>
<td>6. Building 29% PE</td>
<td>2,000,000.00</td>
</tr>
<tr>
<td>7. Yard improvement 10%</td>
<td>690,000.00</td>
</tr>
<tr>
<td>8. Service facilities 55%PE</td>
<td>3,795,000.00</td>
</tr>
<tr>
<td>9. Land 6%</td>
<td>414,000.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Direct plant cost (D)</th>
<th>13,316,000.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Engineering and supervision, 32%D</td>
<td>4,261,120.00</td>
</tr>
<tr>
<td>11. Construction expenses, 34 %D</td>
<td>4,527,440.00</td>
</tr>
</tbody>
</table>

| Total Indirect plant cost (I)                      | 8,788,560.00 |

<table>
<thead>
<tr>
<th>Total Direct and Indirect plant cost (D+ I)</th>
<th>22,104,560.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. Contractor’s fee 5%(D+I)</td>
<td>1,105,228.00</td>
</tr>
<tr>
<td>13. Contingency, 10%(D+I)</td>
<td>2,210,456.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed capital investment (FC)</th>
<th>25,420,244.00</th>
</tr>
</thead>
</table>

| Working capital (25%FC)                            | 6,355,061.00 |

| Total capital investment                            | 31,775,305.00 birr |
5.5.3 Determination of unit product cost

Table 5.4
Annual estimate direct production cost

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Description</th>
<th>Sub- totals [birr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Raw material cost</td>
<td>264,000,000.00</td>
</tr>
<tr>
<td>2.</td>
<td>Auxiliary materials</td>
<td>32,409,341.00</td>
</tr>
<tr>
<td>3.</td>
<td>Utilities</td>
<td>20,986.00</td>
</tr>
<tr>
<td>4.</td>
<td>Direct labor</td>
<td>618,000.00</td>
</tr>
<tr>
<td></td>
<td>Grand total</td>
<td>297,048,327.00</td>
</tr>
</tbody>
</table>

- 300 working days/year

- Full capacity production = 165,284.50 qtl/year

- Direct production cost =60% Total product cost (TPC) =297,048,327.00 birr

- TPC = 495,080,545.00 birr

I. Manufacturing cost
   a) Direct production costs = 297,048,327.00 birr
   b) Fixed charges 3% TPC = 14,852,416.35 birr
   c) Plant over head costs 3% TPC = 14,852,416.35 birr

II. General expenses
   a) Administrative costs 1% TPC = 4,950,805.45 birr
   b) Distribution and selling costs 1% TPC = 4,950805.45birr

III. Total product cost = Manufacturing cost + General expenses = 495,080,545.00 birr/year

III. Unit product cost = 495,080,545.00 birr/year/16,528,450 Kg/year = 29.95 birr/kg

IV. Selling price with minimum profit of 15% = 34.44 29.95 birr/kg

V. Total income pre year = 16,528,450 Kg/year X 34.44birr/kg = 569,239,818.00 Birr/year

VI. Profit before tax = Total income – Total product cost = 569,239,818.00-495,080,545= 74,159,273 birr/year

VII. The amount of production needed to get the break even point is:

   (General expenses + fixed charges + Plant overhead costs) + 29.95n =34.44n

39,606,443.6 = 4.49n

Break even capacity (n) = 8,821,034.21 kg/year this will be 53.3% of the plant Capacity
6. Conclusion and Recommendation

6.1 Conclusion
In this study it is demonstrated that Clark 63K and SCS1 have competent nutritional value as compared to expected nutritional composition of soybean products. Totally there were about 65 tests which were made on the seeds, flours (FFSF and FF-SPC), and extrudates (FFSF and FF-SPC) of Clark 63K and SCS1 in the study. Out of these tests it was demonstrated that SCS1 showed 35.4% almost similar performance, 27.7% lower performance 37% higher performance than that of Clark 63K. This can lead us to say SCS1 can perform either equally and/or better than Clark 63K. This shows that agricultural researchers and hybriders are working on better quality soybean varieties. In addition to agronomical criteria, the findings of this research can be an input to variety releasing body that can help them to make a better decision. Other than this, it is also observed that understanding and having a factual knowledge on the characteristics of soybean seeds, flours, and extrudates has a great help on planning processing methods, designing processing equipments, selecting transportation, storage and packaging methods.

In the present work, it was demonstrated that extrusion cooking process can significantly change the functional properties of soy products (FFSF and FF-SCP) in addition it is clearly observed that further processing of full fat soy flour into full fat soy protein concentrate can give a better functional properties like higher WAI and OAC which makes FF-SPC a better product to use on stakes, nuggets and other fried products. Moreover, it could be demonstrated that boiling and washing process steps can significantly decrease the soluble carbohydrates of cracked and dehulled soybeans. In addition, from this research work and other sources it is understood that the effect of extrusion cooking on functional properties can be changed in a wide range by changing the different operational parameters. Therefore, the findings of the present work can not be taken as final output in order to describe the functional properties of FFSF and FF-SPC extrudates.

6.2 Recommendation
In this research work the selected soybean varieties’ some quality characteristics of the seeds, full fat flours, full fat concentrates, and extrudates were studied. During the research working period, a great number of information and knowledge was taken from this study and different sources as well.
Based on the gathered information and the taken understanding, utilization of soybeans and soy based products are very nutritious and healthful for human consumption. But, as it is well known that the consumption of soybeans and soy products in our country is very low and in addition to that animal based protein sources are expensive, therefore giving a better attention to vegetable proteins sources is unquestionable. Soybean is one of the best vegetable protein sources. Therefore, it is recommendable to incorporate soybean and soy products in different forms either as new products and/or looking for new ways of incorporating them in Ethiopian traditional foods is very important.

Therefore, based on the findings of this research work and the general understandings taken on this specific legume, the following recommendations are forwarded.

1. Further study on determining the optimum operating conditions to get better functional properties of FFSF and FF-SPC using different methods of experimental design like Fractional Factorial Design, Response surface Methodology (RSM) etc…

2. Developing extrusion cooked products from defatted soy protein concentrates with the same operation condition and comparing its quality with that of FF-SPC.

3. Study the shelf life of extruded products of FFSF and FF-SPC using different packing materials like waxed paper, polyethylene, and polypropylene, films laminated or coated with Aluminum etc…

4. Study and proposing suitable and economical product transportation and storage equipments and methods for production of extruded products of FFSF and FF-SPC in small and medium scale industries.

5. Sensory evaluation of extruded products of FFSF and FF-SPC by applying them in breads, traditional stews like 'Key wot,' ‘Minchet abish wot’, ‘Sigo wot’ etc… and developing canned food that can be easily utilized especially in places where a number of people can be fed and nutritioned for example in hospitals, universities, sport clubs, etc…
6. Application of FFSF and FF-SPC flours and extrudates on local foods like Tef flour dough and studying the rheological properties of the dough, their effects on yield of Injera and the quality (color, texture, hardness, elasticity etc...) of the Injera itself.
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Appendices

Appendix A: Annual Main and Auxiliary materials consumption and estimated costs

Table A1
Annual raw material requirement and cost estimates

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Description</th>
<th>annual soybean consumption [qtl]</th>
<th>raw material spoilage/damaged/Wasted (10%)</th>
<th>Total Raw material amount Per year</th>
<th>Unit price per qtl [birr]</th>
<th>Total price [birr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soybean</td>
<td>300000</td>
<td>30,000</td>
<td>330,000</td>
<td>800</td>
<td>264,000,000</td>
</tr>
</tbody>
</table>

Sub-total: 264,000,000

Table A2
Annual packing film requirement and its cost estimates

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Packaging capacity [gm]</th>
<th>Total production per year [Kg/yr]</th>
<th>Number of pkts required [pcs/yr]</th>
<th>Waste allowance 2%</th>
<th>Total Number of pkts/yr required</th>
<th>Wt. of single packet [kg/pkt]</th>
<th>Total wt. of packing film required/yr</th>
<th>Unite price [Birr/kg]</th>
<th>Total cost [Birr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250</td>
<td>11,401,178.6</td>
<td>45,604,714</td>
<td>912,094.3</td>
<td>46,516,808.3</td>
<td>0.004</td>
<td>186,067.2</td>
<td>67.5</td>
<td>12,559,536.00</td>
</tr>
<tr>
<td>2</td>
<td>500</td>
<td>4,886,219.4</td>
<td>9,772,440</td>
<td>195,549</td>
<td>9,967,989</td>
<td>0.006</td>
<td>59,808</td>
<td>67.5</td>
<td>4,037,040.00</td>
</tr>
</tbody>
</table>

Sub-total: 16,596,576.00
### Table A3

**Annual requirement of carton box and cost estimate**

<table>
<thead>
<tr>
<th>Packaging capacity [gm]</th>
<th>Number of pkts per carton box LxWxH [Cm]</th>
<th>Carton size LxWxH [Cm]</th>
<th>Amoung of product per box [kg]</th>
<th>Annual production [Kg]</th>
<th>Carton box per annum</th>
<th>5% waste</th>
<th>Total annual carton box required</th>
<th>Carton box unit price [birr/pcs]</th>
<th>Total Price [birr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>5x2x2</td>
<td>40x24x30</td>
<td>5.0</td>
<td>11,401,178.6</td>
<td>2,280,236</td>
<td>114,312</td>
<td>2,400,548</td>
<td>3.75</td>
<td>9,002,055</td>
</tr>
<tr>
<td>500</td>
<td>4x3x2</td>
<td>40x42x30</td>
<td>8.0</td>
<td>4,886,219.4</td>
<td>610,777</td>
<td>30,539</td>
<td>641,316</td>
<td>4.0</td>
<td>2,565,264</td>
</tr>
<tr>
<td><strong>Sub-total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>11,567,319</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table A4

**Annual requirement of Scotch tape and cost estimate**

<table>
<thead>
<tr>
<th>Packaging capacity [gm]</th>
<th>Number of carton box per annum</th>
<th>Length of Scotch tape needed to seal one carton* [m]</th>
<th>Length of scotch tape needed per yr [m]</th>
<th>Estimated waste amount [0.5%] [m]</th>
<th>Total length of scotch tape needed [m]</th>
<th>Length of one role scotch tape [m]</th>
<th>Required number of roles</th>
<th>Unit price of one role [birr]</th>
<th>Total price of roles [birr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>2,400,548</td>
<td>1.00</td>
<td>2,400,548</td>
<td>12,003</td>
<td>2,412,551</td>
<td>18</td>
<td>134,031</td>
<td>25</td>
<td>3,350,775.00</td>
</tr>
<tr>
<td>500</td>
<td>641,316</td>
<td>1.00</td>
<td>641,316</td>
<td>3,207</td>
<td>644,523</td>
<td>18</td>
<td>35,807</td>
<td>25</td>
<td>895,170.83</td>
</tr>
<tr>
<td><strong>Sub-total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>4,245,946.00</strong></td>
</tr>
</tbody>
</table>

*The length of scotch tape required per carton box is estimated considering the total length and 10cm tolerance of the long side of the box.
Appendix B Annual utilities requirement and estimated costs

Table B1
Annual utilities requirement and estimated cost

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Description</th>
<th>Unit of measure</th>
<th>Qty/yr</th>
<th>Unit cost [birr]</th>
<th>Total cost [birr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electricity</td>
<td>Kwh</td>
<td>10,000</td>
<td>0.4736</td>
<td>4,736.00</td>
</tr>
<tr>
<td>3</td>
<td>Water</td>
<td>m³</td>
<td>5000</td>
<td>3.25</td>
<td>16,250.00</td>
</tr>
</tbody>
</table>

Sub-total 20,986.00

Appendix C: Required manpower and estimated annual labor cost

Table C1
Manpower requirement and estimated labor costs

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Job position</th>
<th>No</th>
<th>Monthly salary/person [Birr]</th>
<th>Annual Salary [Birr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Managing Director</td>
<td>1</td>
<td>7,000</td>
<td>84,000</td>
</tr>
<tr>
<td>2</td>
<td>Secretary of MD</td>
<td>1</td>
<td>8,000</td>
<td>9,600</td>
</tr>
<tr>
<td>3</td>
<td>Finance and Administration Head</td>
<td>1</td>
<td>3,000</td>
<td>36,000</td>
</tr>
<tr>
<td>4</td>
<td>Accountants</td>
<td>2</td>
<td>2,000</td>
<td>48,000</td>
</tr>
<tr>
<td>5</td>
<td>Personnel</td>
<td>1</td>
<td>1,000</td>
<td>12,000</td>
</tr>
<tr>
<td>6</td>
<td>Commercial Head</td>
<td>1</td>
<td>3,000</td>
<td>36,000</td>
</tr>
<tr>
<td>7</td>
<td>Sales personnel</td>
<td>2</td>
<td>1,500</td>
<td>36,000</td>
</tr>
<tr>
<td>8</td>
<td>Purchaser</td>
<td>1</td>
<td>1,200</td>
<td>14,400</td>
</tr>
<tr>
<td>9</td>
<td>Production Head</td>
<td>1</td>
<td>3,000</td>
<td>36,000</td>
</tr>
<tr>
<td>10</td>
<td>Shift leaders</td>
<td>2</td>
<td>1,200</td>
<td>28,800</td>
</tr>
<tr>
<td>11</td>
<td>Cleaning section operators</td>
<td>2</td>
<td>500</td>
<td>12,000</td>
</tr>
<tr>
<td>12</td>
<td>Milling and sieving machine operators</td>
<td>2</td>
<td>700</td>
<td>16,800</td>
</tr>
<tr>
<td>13</td>
<td>Extrusion cooking machine operator</td>
<td>2</td>
<td>800</td>
<td>19,200</td>
</tr>
<tr>
<td>14</td>
<td>Drier operator</td>
<td>2</td>
<td>700</td>
<td>16,800</td>
</tr>
<tr>
<td>15</td>
<td>Packing Machine operator</td>
<td>2</td>
<td>700</td>
<td>16,800</td>
</tr>
<tr>
<td>16</td>
<td>Packers</td>
<td>10</td>
<td>300</td>
<td>36,000</td>
</tr>
<tr>
<td>17</td>
<td>Technique head</td>
<td>1</td>
<td>3,000</td>
<td>36,000</td>
</tr>
<tr>
<td>18</td>
<td>Mechanic</td>
<td>1</td>
<td>1,500</td>
<td>18,000</td>
</tr>
<tr>
<td>19</td>
<td>Electrician</td>
<td>1</td>
<td>1,500</td>
<td>18,000</td>
</tr>
<tr>
<td>20</td>
<td>Quality control head</td>
<td>1</td>
<td>2,500</td>
<td>30,000</td>
</tr>
<tr>
<td>21</td>
<td>Chemists</td>
<td>1</td>
<td>1,800</td>
<td>21,600</td>
</tr>
<tr>
<td>17</td>
<td>Drivers</td>
<td>2</td>
<td>700</td>
<td>16,800</td>
</tr>
<tr>
<td>18</td>
<td>Guards</td>
<td>2</td>
<td>500</td>
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Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other University, and that all sources of materials used for the thesis have been duly acknowledged.

Name: Fouzia Muhsin Abdurahman

Signature: -------------------------------

Place: Addis Ababa, Ethiopia

Date of submission: -------------------------------

This thesis has been submitted for examination with our approval as University advisor.

Name: Ato Adamu Zegeye

Signature: -------------------------------