

**DETERMINATION OF PHYSICAL PROPERTIES OF SOYBEAN, DESIGN AND
FABRICATION OF IMPROVED SOYBEAN DEHULLER**

BY

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**A DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS
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ABSTRACT

The objective of this study was to investigate the methods for improving dehulling efficiency and throughput of soybean dehuller, which included studying of some physical properties of soybean at different moisture levels related to dehulling, the use of different pre-treatment methods to loosen the seed coat to facilitate its removal during dehulling, and finally to develop an improved manually operated prototype dehuller which can dehul moist grain without clogging and undertake performance test of this dehuller. Four levels of moisture content ranging from 14 to 20 % dry basis (d.b) were used to evaluate the effect of moisture content on physical properties of soybean grains. In this moisture range, mean grain length, width, thickness, arithmetic mean diameter, geometric mean diameter, surface area, porosity and thousand grains weight increased with increasing moisture content. On the other hand, bulk density, true density and sphericity were found to decrease with increase in moisture content. The prototype dehuller was designed and fabricated with a dehulling surface which can dehul moist grain without clogging. The effect of pre-treatment methods on dehulling was carried out to evaluate the dehulling efficiency and throughput of the prototype dehuller. The pre-treatments investigated included boiling the grain at different durations followed by cooling to room temperature and soaking the grain for different durations followed by a rest period to allow surface moisture to be absorbed. The improved dehuller was used to dehull the pre-treated grain and the effect of pre-treatments on dehulling efficiency was evaluated based on the extent of seed coat removal. Also the effect of different pre-treatments on throughput of the dehuller was evaluated. The dehuller was able to achieve dehulling efficiency of 70.62 % for Uyole Soya-1 and 72.57 % for TGX 1895-33F. Throughput obtained was 50.76 kg/h and 55.50 kg/h for Uyole and TGX 1895-33F, respectively.

DECLARATION

I Justine Alfred Mushi, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

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DEDICATION

This Master of Science work is dedicated to the Almighty God for His infinite mercy and protection on me and my family. It is also dedicated to my lovely wife Matilda and my children Margaret, Patricia and Kelvin whom I urge to emulate my success. It is also dedicated to my father, the late Mr. Alfred Mushi, who passed away on 13 December 1977. May the Almighty God rest his soul in peace in the heaven amen. Moreover, it is dedicated to my lovely mother, Mrs. Margaret Kavishe whose moral support and prayers contributed to my success.

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LIST OF ABBREVIATIONS AND SYMBOLS

DE	Dehulling Efficiency
%:	Percent
TADD	Tangential Abrasive Dehulling Device
°C	Degree Celsius
°F	Degree Fahrenheit
mm	Millimetre
g	Gram
R.H	Relative Humidity
d.b	Dry basis
L	Length
W	Width
T	Thickness
<i>et al</i>	And others
W	Initial weight
M_i	Initial moisture content
M_f	Final moisture content
D_a	Arithmetic mean diameter
D_g	Geometric mean diameter
Φ	Sphericity
A	Area
mm ²	Millimetre squared
W_{1000}	Thousand grain weight
C_7H_8	Toluene
ρ_b	Bulk density
ρ_t	True density
v_w	Volume of sample
m ³	metre cubed
v_l	Volume of liquid
m_l	Mass of liquid
m_w	Mass of air dry sample
m_1	Mass of empty bucket
m_2	Mass of bucket and soybean
ϵ	Porosity
mg/g	Milligrammes per gramme
kg/m ³	Kilogramme per metre cubed
cm	Centimetre
tan ⁻¹	Tangent inverse
kg	Kilogramme
kg/h	Kilogramme per hour
Man-h/d	Man-hour per day
rpm	Revolution per minute
M_b	Bending moment
M_t	Torsional moment
τ_b	Bending stress
τ_t	Torsional stress
N/mm ²	Newton per millimetre squared

f_s	Factor of safety
ASME	American Society of Mechanical Engineering Code
d	diameter
k_b	Combined shock and fatigue as applied to bending moment
k_t	Combined shock and fatigue as applied to torsional moment
m_c	Moisture content
R^2	Coefficient of determination
hp	Horse power
C	Throughput capacity

CHAPTER ONE

1.0 INTRODUCTION

1.1 Importance of Soybean

Historians believe that soybean (*Glycine max* (L.) Merrill) is one of the oldest crops grown by human beings. Soybean is strongly believed to have originated from the orient (Laswai *et al.*, 2005a). Soybean is widely believed to have originated 4000-5000 years ago in the North and central regions of China (Liu 1997a) after agriculture evolved making it one of the oldest cultivated crops. Cultivated varieties were introduced to Korea and later to Japan 2000 years ago (Laswai *et al.*, 2005b). In East and South East Asia it is to this day an important component of traditional diets of the regions.

Soybean cultivation reached Africa in the late 1800s; although little is known of the countries to which it was first introduced (Shurtleff and Aoyagi, 2007). It is possible that soybeans were cultivated at an early date on the eastern coast of Africa, since that region had long traded with the Chinese. In about 1907 soybeans were introduced to Mauritius and Tanzania, at that time a German colony (Shurtleff and Aoyagi, 2007).

Among the legumes, soybean is an important crop due to its nutritional value and its wide utilization at household as well as at industrial levels (Perkins, 1995). Soybean is widely known to be cheap, easily available and a good source of rich and cheap protein compared to animal protein and other nutrients (Oyenuga, 1968; Mijindadi, 1987), an attribute that increases the potential of soybean in curbing malnutrition that is currently affecting 30% of the Tanzanian population. About 80 % of Tanzanians live in rural areas where large portion of children under five years old are malnourished (Malema, 2005). Soybean as a cheap source of protein may be a solution to this problem.

In Tanzania, soybean was first introduced at Amani Tanga, by the German traders in 1907 (Myaka *et al.*, 2005). Since its introduction, there have been several efforts to develop soybean for increased production and utilization. These include research such as new cultivar introductions in 1909 and 1939, establishment of collection of cultivars at Amani, several breeding programmes at Nachingwea, Lyamungo, Ilonga, and Katrin - Ifakara and large scale production in Southern Tanzania by Overseas Food Corporation (OFC) in 1947. The varieties of soybean currently grown in Tanzania include Bossier, Bossier IL, Duicker, Sable, EAI 3715, Delma, SAB/7, PERY 41, Uyole soya-1, TGX 1954-1F, TGX 1887-12F and TGX 1895-33F.

1.2 Justification

The health effects of soybean products have aroused the attention of many researchers and consumers (Hawrylewicz *et al.*, 1995, Hasler, 1998). The advances in soybean production and soybean protein processing technology give soybean protein a broader and more versatile utilization in human foods (Snyder and Kwon, 1987; Hettiarachchy and Kalapathy, 1997, Liu, 1997a). At present there is a big awareness of the potential of soybean and demand has increased greatly although there is still ignorance on how to process and use it as family food.

Soybean processing has over the years been a major challenge to its acceptability and popularity in Tanzania. This is mainly due to lack of simple and efficient small-scale soybean processing technologies suitable for small scale farmers and processors in rural areas (Phirke and Bhole, 1999). One of the operations that pose a challenge for small scale soybean processing is dehulling. Dehulling is a process of paramount importance in soybean processing as it removes the seed coat, which is high in crude fibre and often contains anti-nutritional factors such as trypsin inhibitors, hemagglutinins, goitrogens, and

antivitamins. Both crude fibre and the anti-nutritional factors decrease nutritive value of the grain and if taken in larger amounts, cause health problems that may be fatal for both humans and animals.

Dehulling of soybean is a difficult operation because the seed coat is firmly attached to the cotyledons. Soybean dehulling is commonly done using the wet method whereby the grain is soaked or boiled for a short period, cooled with cold water and then rubbed between the palms to loosen the seed coat. This process is tedious and time consuming.

Attempts have been made to develop better dehulling methods for leguminous and non leguminous crops such as sorghum, canola, cowpeas and soybean (Lazaro *et al.*, 2002). These attempts have included studies on the preconditioning of the crops as well as design of better dehulling equipment such as those using abrasive surfaces (Reichert *et al.*, 1986) but most of the developed methods favour medium to large scale operators, leaving poor farmers with little or no option at all.

Since soybean is well adapted to tropical regimes and insufficient protein of good quality is a limiting factor in developing countries with ever increasing population, appropriate processing to improve the utilization of this legume is of high importance. To improve its utilization in human diet due to increasing need for cheaper and available plant proteins to meet the increasing demand for Tanzanian populace, new developments in soybean processing are required. Soybean seeds are hard to dehull thus the drudgery process of dehulling the seed is also limiting the utilization of soybean into other forms of products apart from cooking the seeds. Processing of soybean seeds into flour using appropriate processing technology that improve dehulling, will improve the utilization of the crop.

The dehulling of soybean is accomplished either traditionally by hand rubbing of boiled grains or mechanically using abrasive dehullers. The traditional method is laborious, time-consuming and inefficient; hence there is a need to develop a simple and cheap machine that can lead to improved dehulling of the soybeans and reduce the hardship and drudgery involved in this process. Abrasive dehulling is faster and less tedious, but it causes excessive losses of cotyledon in the seed coat fraction through kernel breakage. Soybean could be dehulled with less loss and at higher dehulling efficiency than is possible with the current mechanical dehullers if proper pre-treatment procedures and appropriate dehulling equipment could be developed. This could lead to less breakage of the grain during dehulling and hence lower losses. Also faster and complete seed coat removal from the cotyledon could be achieved leading to improved dehulling efficiency and saving on the energy cost. In trying to solve the dehulling problem at the small scale level, manually operated soybean dehuller was designed and fabricated at SUA; however its dehulling efficiency was very low and needed to be improved. The percentage recovery values for the dehuller were reasonable; however there is still a room for further improvement (Silayo, *et. al.*, 2006). This necessitates an improvement of the dehuller to obtain a version with high dehulling efficiency and higher recovery.

1.3 Objectives of the Study

1.3.1 Main objective

The main objective of this study was determination of physical properties of soybean, design and fabrication of improved soybean dehuller

1.3.2 Specific objectives

The specific objectives of this study were to:

- i) Determine the physical properties of different soybean varieties at different moisture content.
- ii) Design and fabricate an improved manually operated abrasive soybean dehuller.
- iii) Carry out performance test of the fabricated dehuller and propose measures for further improvement.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Historical Background of Soybean

Soybeans are typical legume seeds, which differ in size, shape, colour and composition based on the variety. It is widely believed to have originated 4000-5000 years ago in the north and central regions of China, with the first documented use of the plant by a Chinese emperor in 2838 B.C. (Liu, 1997b). From China, soybean cultivation spread throughout Japan, Korea, and Southeast Asia. Soybean was first brought to Europe in 1712 by a German botanist, Engelbert Kaempfer. Later, Carl von Linne gave soybeans a genetic name, *Glycine max*. Soybeans were introduced into the United States in the early 1800s. It was not until the early 1930s when the U.S. started to recognize and exploit their value for feed and food oil. Due to its high protein content and good nutritional value, soybean meal was primarily used as animal feed.

Soybean was introduced in Tanzania in 1907 by German agriculturalists, Whigham (Myaka, 1990, Myaka and Ngeze, 1993). More introductions in the country were made in 1909 and 1939. In 1938 and 1939 a collection of 64 cultivars of soybean from India, South Africa and Far East was established at Amani in Muheza District (Myaka, 1990). Soybean breeding programme in Tanzania started in 1955 and by early 1960s the programme showed good results. Soybean breeding in Tanzania was started with the main focus on breeding and developing improved varieties and agronomic practices suitable to Tanzanian conditions. According to Myaka (1990), achievements on soybean research had been on variety setting that was first done at Agricultural Research Institute (ARI) Ilonga and Katrin from 1960/1961 to 1968/1969 (Myaka, 1990) and from 1966 to 1972/73

respectively. This breeding programme contributed to the release of variety Hermon, 237H/1, 7H/101, 3H/1 and 7H/192 selections (Auckland, 1982).

The second breeding programme began in 1973 at ARI Ilonga, where parental stock consisted of IH/192, 7H/101, Bossier, Hokkaido 48 and improved Pelican were grown. The lines selected were tested from 1976 to 1978 and ended by recommending Bossier and 3H/1 as superior varieties. The new varieties are Ex- Laela in 2002 and Uyole Soya-1 in 2004 (Malema, 2005). In the early 1960s a program of experimental cultivation of soybeans was launched in Tanzania. The objective was to produce a cheap and stable source of protein and energy which could be grown and utilized in rural areas and which was also suitable for infants and young children (Holm *et al.*, 1973).

2.2 Proximate Composition and Benefits of Soybean

The composition of soybeans may vary according to variety and growing conditions. Through plant breeding it has been possible to obtain protein levels between 40% and 45%, and lipid levels between 18 and 20 %. The proximate composition of soybeans, in fairly representative average figures, is shown in Table 1.

Table 1: Proximate Composition of Different Seed Parts of Soybean

Seed part	% of whole seed weight	Protein (N x 6.25)	% (moisture-free bases)		
			Lipid	Carbohydrate (including fibre)	Ash
Cotyledon	90	43	23	43	5.0
Hull	8	9	1	86	4.3
Hypocotyl	2	41	11	43	4.4
Whole seed	100	40	20	35	4.9

Source: Cheftel *et al.* (1985)

In recent years, researchers have kept discovering the benefits of consuming soybean protein in substitute of animal proteins such as decreasing total serum cholesterol and decreasing the risks for several cancers (Messina and Barnes, 1991, Anderson *et al.*, 1995, Messina, 1997). These advantages let soybean protein perform many functions in foods while maintaining their excellent nutritional quality and benefits to human health. Therefore, the food industry and researchers have placed increased efforts in the development of foods containing soybean proteins that are acceptable to human consumption (Faller *et al.*, 1999, Drake *et al.*, 2000, Friedeck *et al.*, 2003). One notable development out of the numerous efforts for soybean-based foods to be acceptable to human consumption is the texturization of extruded soybean protein into meat analogs (Atkinson 1970, Rhee *et al.*, 1981, Snyder and Kwon, 1987).

2.3 Soybean Grain Structure and Composition

2.3.1 Grain structure

Soybeans occur in various sizes, and in many hull or seed coat colours, including black, brown, yellow, green and mottled. The hull of the mature soybean is hard, water resistant, and provides an effective protective layer, which protects the cotyledons and hypocotyl from damage. If the seed coat is cracked, the seed will not germinate. The scar, visible on the seed coat, is called the hilum in which case the colours include black, brown, buff, grey and yellow, and at one end of the hilum is the micropyle, or small opening in the seed coat which can allow the absorption of water for sprouting (**Blackman** *et al.*, 1992).

The structure of soybean kernel varies significantly due to environmental and genetic factors and plays an important role in determining the processing properties of the grain and food quality traits. Seed structure consists of the seed coat and two cotyledons, plus two additional structures of lesser weight; the hypocotyl and plumule. The cotyledons

represent 90% of the seed weight and contain practically all the oil and protein in its palisade-like cells. Microscopic examination of these cells reveals the presence of protein bodies and lipid bodies which constitute storage bodies for proteins and oil, respectively.

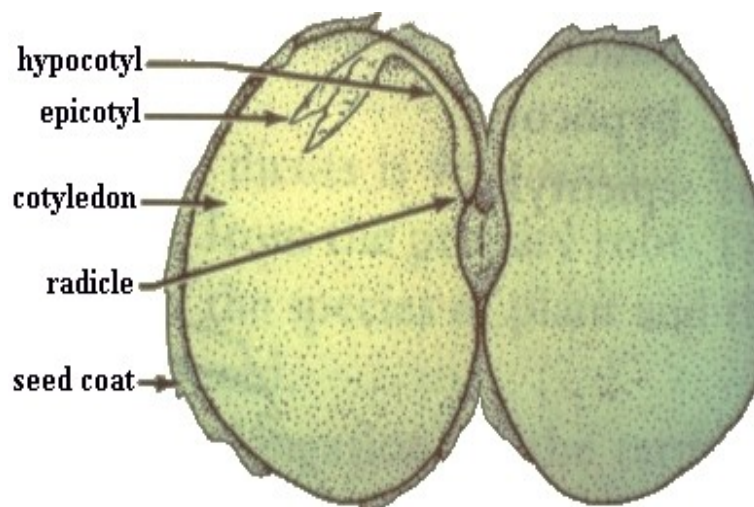


Figure 1: Soybean grain structure

2.3.1.1 Seed coat

The seed coat, which accounts for roughly 8% of the seed weight, holds the two cotyledons together and provides an effective protective layer. The seed coat is marked with a hilum that varies in shape from linear to oval. At one end of the hilum is the micropyle, a tiny hole formed by the integuments during seed development but covered by a cuticle at maturity. At the other end of the hilum, is the raphe, a small groove extending to the chalaza, where the integuments were attached to the ovule proper (Wolf, 2010).

The seed coat consists of three distinct layers: epidermis, hypodermis and inner parenchyma layer. The epidermal layer consists of closely packed, thickly-walled palisade cells. These cells are elongated perpendicular to the surface of the seed and have thickened, pitted walls in the outer part of the cell. The hypodermis consists of a single layer of sclerified cells variously elongated and separated from each other. The unevenly thickened cell walls are thin at the ends of the cell and very thick in the central, constricted portion of the cell. These cells thus form a strong supporting layer with considerable intercellular space (Patel, 1976).

2.3.1.2 Embryo

An embryo is young saprophyte, diploid, result of fertilization. The mature dormant embryo consists of two large fleshy cotyledons (seed leaves), a plumule with two well developed primary leaves enclosing one trifoliate leaf primordium, and a hypocotyl-radical axis that rests in a shallow depression formed by the cotyledon. The tip of the radical is surrounded by an envelope of tissues formed by the seed coat. The lower portion on one side of the seed consists of a large scutellum, an embryonic axis, a plumule and a primary root. The scutellum is the flattened portion that serves as an absorptive organ. The embryo is relatively firmly embedded and difficult to remove by dry milling (Rooney, 1973). However, adding water to the grain causes the germ to swell and to pull away from the cementing layer (Wall and Ross, 1970).

2.3.1.3 Cotyledon

A cotyledon is a food storage tissue, resulting from double fertilization. The cotyledon represents the largest portion of the kernel and consists of an aleurone layer. The peripheral layer of the cotyledon is made up of cells containing a high proportion of protein. The corneous layer beneath the peripheral layer contains less protein and higher

proportion of starch than the peripheral. The corneous layer is also termed, the flinty, hard or horny cotyledon. Inside the corneous layer is found the floury or soft cotyledon, which is lowest in protein (Rooney, 1973, Hulse *et al.*, 1980). Whether a soybean grain is described as floury or corneous depends on the ratio of floury (soft) to corneous (hard) cotyledon components within the kernel. Often the floury soybeans contain yellow pericarp and pigmented thick testa (Rooney, 1973). The relative proportion of the corneous to floury cotyledon is termed the kernel texture or cotyledon texture. Cotyledon texture plays a major role in determining the soybean grain quality and is also used in classification of the grain.

2.3.2 Soybean grain composition and anti-nutritional factors

Anti-nutritional factors are biologically active substances present in grain legumes which inhibit the availability of the desirable elements such as protein. These diverse compounds are one of the limitations to an increased use of grain legumes as feed that both decrease nutritive quality and digestibility of plant proteins and, if taken in larger amounts, cause health problems that may be fatal for both humans and the animals. By this reason, breeding programmes of all grain legumes is aimed at decreasing the content of anti-nutritional factors to a safe level. These anti-nutritional factors include; trypsin inhibitors, hemagglutinins, Phytic acid, Lipoxygenase enzyme and Oligosaccharides.

(a) Trypsin Inhibitors

Among the anti-nutritional factors present in soybean seed, the main ones are protease inhibitors, which are Kunitz trypsin inhibitor, Bowman-Birk inhibitor and lectins. Protease inhibitors represent 6% of the protein present in soybean seed. Approximately 80% of the trypsin inhibition is caused by Kunitz, which strongly inhibits trypsin and therefore reduces food intake by diminishing their digestion and absorption. Another effect of

Kunitz Trypsin Inhibitor is the induction of pancreatic enzyme, hyper secretion and the fast stimulation of pancreas growth, hypertrophy and hyperplasia. Due to this, raw soybean cannot be used for feeding monogastric animals. Heat treatment does not completely eliminate these factors and may decrease protein solubility. Despite the efficiency of thermal treatment to reduce protease inhibitors, residual inhibition (10-20%) is maintained (Carvalho *et al.*, 1998).

(b) Hemagglutinins (lectins)

Hemagglutinins (Lectins) are proteins that are widely distributed in plant kingdom and have unique property of binding carbohydrate containing molecules with a high specificity, causing agglutination of red blood cells. Soybean agglutinin causes the atrophy of the microvilli, reduces the viability of the epithelial cells and increases the weight of small intestine because of hyperplasia of crypt cells (Grant *et al.*, 1987, Pusztai *et al.*, 1990). The inactivation of soybean lectin by a moist heat treatment is parallel with the destruction of trypsin inhibitors. Soybean lectin is quite resistant to inactivation by heat treatment.

(c) Lipoxygenase enzyme

The flavor of soybean products is a major quality concern. Lipoxygenase enzyme activity results in rancidity, poor storage stability, painty, grassy or bean off-odors and off-flavors and bitterness in protein foods and the fishy smell in oil extracted from soybeans. Hydroperoxides formed by lipoxygenase also affect color, by a Millard type reaction interacting with proteins; the texture by cross-linking with protein; and the nutritive value by a decrease of essential fatty acids and certain vitamins (Erikson, 1982). Second products arising from hydroperoxide decomposition also rapidly inactivate or denature protein and amino acids through formation of covalent bonds (Gardner, 1979).

The enzyme has to be inactivated or its activity controlled in order to make soybean-based foods palatable. The enzyme is inactivated by heat treatment or pH control, or both, prior to their disintegration for the extraction of oil or protein. However, such treatment causes the water soluble solids, especially protein, to get bound to the insoluble fibrous solids of soybean. The degree of such binding depends on the severity of the treatment. This leads to a greatly reduced yield of protein in aqueous extract of soybean (soymilk) and a mouth feel that reminds one of the milk of magnesia. Any foods and beverages made from such soymilk are not very acceptable by most people. The challenge thus was to develop a method of processing soybeans neither into soymilk which is neither rancid nor fishy taste nor with chalky mouth feels.

(d) Oligosaccharides

Soybeans contain high amount of oligosaccharides, consisting mainly of raffinose and stachyose. These oligosaccharides are poorly digested and have been implicated as causes for the poor utilization of energy from soybean meal fed to poultry (Lesake *et al.*, 1995). Raffinose and stachyose are heat stable; the attempts have been made to eliminate them by enzymatic action and selecting desirable soybean varieties (Neus *et al.*, 2005).

(e) Phytic acid

Phytic acid is present in soybean seeds and products to the extent of 1-1.5% of dry matter. It is able to chelate mineral elements, such as zinc, magnesium, iron, calcium and potassium and makes these elements longer absorbed from intestines. About two thirds of the total phosphorus from soybean seed is bound to phytic acid (Nelson *et al.*, 1968). Several soybean genotypes have been developed with a low phytic acid content, often featured with lower grain yield and seed viability. More breeding cycles are needed to improve a cultivar performance and keep phytic acid at a low level

(Spear and Fehr, 2007). Beside the mentioned anti-nutritional factors, soybeans contain physiologically active compounds with small or unknown effects, such as tannins, saponins, antivitamin and isoflavones.

2.4 Soybean Processing

There is increasing emphasis on the utilization of grain legumes in formulated foods, particularly in relation to relieving protein shortages in developing countries. As a result, the processing of legumes has become more attractive, and there are continuing efforts to improve the yield of edible grain either through better processing techniques or plant breeding, or both. In many countries, grain legumes are initially processed by seed coat removal and splitting of the cotyledons (Siegel and Fawcett, 1976).

Unlike many other grain legumes, soybean meal is dehulled. This ensures that valuable nutrients such as protein, amino acids and energy are not diluted with indigestible fibre. The removal of hulls, prior to processing, ensures the valuable amino acids are not inactivated by binding to fibre components. Dehulling facilitates reduction of fibre and anti-nutritional factors contents, and improvement in the appearance, texture, cooking quality, palatability, and digestibility of the grain (Deshpande *et al.*, 1982a, Kon *et al.*, 1973). Soybean has been faced with some problems vis-a-vis in the area of improper processing techniques and use of traditional processing equipment, which in most cases could have negative impact in the consumption pattern and rate of production (Emovon, 1987).

Dehulling involves removal of the fibrous seed coat that tightly envelops the cotyledons. In other words, dehulling may be described as the efficient and complete removal of the outer layers enveloping the cotyledons from the kernel leaving a seed coat free cotyledon.

Dehulling is the major primary process and considerably improves the nutritional quality, digestibility and consumer acceptability of soybean products by reducing the fibre content, pigments and getting rid of the anti-nutritional factors present in the grain. For soybean, dehulling is therefore an important and essential part of the milling process for the production of the refined and high quality end product for human consumption (Kurien, 1984).

2.5 Soybean Dehulling Methods

2.5.1 Traditional dehulling methods

Traditional foods and traditional food processing techniques form part of the culture of the people. Traditional food processing activities constitute a vital body of indigenous knowledge handed down from parent to child over several generations. Unfortunately, this vital body of indigenous knowledge is often undervalued. Indeed, simple, low-cost, traditional food processing techniques are the bedrock of small-scale food processing enterprises in Africa and their contributions to the economy are enormous (Aworh, 1993).

The basic principle of soybean preparation is based on solving the problem of anti-nutritional factors and removal of bean-off flavours problems. For preparation at small scale utilization level in Africa soybeans are first cleaned by removing damaged grains, dirt, and stones then placed into cotton bags and dropped gradually into boiling water for 25-30 minutes to inactivate the anti-nutritional factors and the bean off-flavours. Drain the blanch water and rinse the blanched beans well. Keep the beans in a bowl with cold water. Scrub the beans between two hands or grinding in a hand operated stone to force the hulls from the cotyledons. Add excess water to make the hulls float, then drain the water with the hulls and repeat operation until most of the hulls are removed from the

cotyledons. These cotyledons can be directly used for preparing many soy foods such as soymilk and tempeh.

Rural development is closely linked with the promotion of small-scale food industries that involve lower capital investment and rely on traditional food processing technologies. They are vital to reducing post-harvest food losses and increasing food availability. Small-scale food industries, involve limited mechanization of the traditional methods of food processing. Unfortunately, rapid growth and development of small-scale food industries in Africa are hampered by adoption of inefficient or inappropriate technologies, poor management, inadequate working capital, limited access to banks and other financial institutions, high interest rates and low profit margins (Taiwo *et al.*, 2002). Small-scale food enterprises rely on locally fabricated equipment and a study of these enterprises in Africa identified lack of spare parts for equipment maintenance and repair as a major problem constraining their growth.

One of the greatest challenges facing food scientists in Africa today is the upgrading of the traditional food processing and preservation technologies (Sanni, 1993). In most cases, the traditional methods of food processing and preservation in Tanzania remain at the empirical level. They are still rather crude, not standardized, and are not based on sound scientific principles making them, in their present form. The processes are often laborious and time consuming and invariably the quality of the products require substantial improvements. Since women are largely involved in traditional food processing, reducing the drudgery associated with traditional food processing operations, through the introduction of simple machines, would make life a lot easier for women with attendant benefits for the well-being of the family and society at large. In upgrading these technologies, the food scientist or technologist is faced with the challenge of modernizing

the processes and equipment while still retaining the traditional attributes of the food products crucial to consumer acceptance.

2.5.2 Mechanical dehulling methods

Numerous methods of varying sophistication exist for mechanical dehulling of soybean. In some cases, the hulls are removed in small commercial or home-scale operations by grinding in a hand operated stone or wooden mill and the hulls are then removed by winnowing (Kurien, 1984). Commercial processes are much more sophisticated, involving power operated grinders and aspirators. Although all dehulling systems operate on the same basic principle of friction between the seed and a surface or another seed, a variety of horizontal and vertical shaft configurations exist. Examples of mill designs include attrition-type dehullers (DeMan *et al.*, 1973), roller mills (Singh and Sokhansanj, 1984) or abrasive dehullers such as the tangential abrasive dehulling device (TADD) (Reichert *et al.*, 1984), which is intended for laboratory analysis. Depending on dehuller configuration, efficiency can be optimized in these systems by adjusting factors such as stone speed, diameter, texture and clearance between the dehulling surfaces. Seed moisture content is another important factor affecting dehulling efficiency.

2.5.2.1 Attrition type dehullers

Attrition type dehullers are particularly suitable for dehulling and splitting grain legumes with loose seed coats. Attrition dehuller is generally applied to a mill in which the dehulling takes place between two steel or stone discs rotating in a horizontal or vertical plane. One of the discs may be stationary and either of the discs may be modified with a variety of impact or cutting surfaces. The Palyi Compact mill is one type of the attrition mill. Two attrition plates, with one plate stationary and the other rotating, provide the

dehulling action in this mill. The distance between the plates can be adjusted to provide variable extraction rates (DeMan *et al.*, 1973).

2.5.2.2 Abrasive type dehullers for soybean

Abrasive dehullers are suitable for dehulling grains with more tightly adhering seed coats (Kurien, 1984). Abrasive dehuler, employs a horizontally or vertically mounted grinding wheels, or an abrasive cone or cylinder, used in preference to roller milling for polishing rice, pearling barley, dehulling sorghum (Reichert, 1982), dehulling millet (Reichert and Youngs 1976), and a wide varieties of grain legumes including soybean (Reichert *et al.*, 1984; Kurien, 1984). The objective of abrasive dehulling is to remove the outer layers (hulls) of the grain, thereby reducing the fibre and ant-nutritional contents (Deshpande *et al.*, 1982a) and improving the appearance, texture, cooking quality, functional properties, palatability and digestibility of the grain (Kon *et al.*, 1973, Deshpande *et al.*, 1982b).

Several laboratory mills have been constructed to simulate the action of abrasive dehulling equipment. The Strong- Scott laboratory peeler or modifications thereof and equipment such as the Satake grain testing mill, are the most commonly used laboratory peelers (Rooney and Sullins, 1969, Convanichi and De Padua, 1973). The dehuller, known as the Tangential Abrasive Dehulling Device (TADD), has been extensively field tested and is now commercially available in Canada. The dehuller is based on the principle of tangential abrasion, which has been used previously by several investigators (Hogan *et al.*, 1964, Normand *et al.*, 1965, Barber, 1972). This principle is embodied in many of the large-scale abrasive dehullers such as the vertical shelling machine or Decomatic dehuller described by Reichert (1982).

The dehuller, (Fig. 2) which is operated by a single person consisted of six principal parts. These include the grain hopper with the guiding base lying at 72° to the horizontal, the feed gate, the rasped aluminium metal sheet wound on a wooden rotating disc with a cranking handle extending outside the main body. Others are “chest” that contains flow channels for guiding the dehulled seeds, the overflow outlet for the dehulled grains as the main product and outlet for hulls, all fitted on a wooden structure supported on wooden stands.

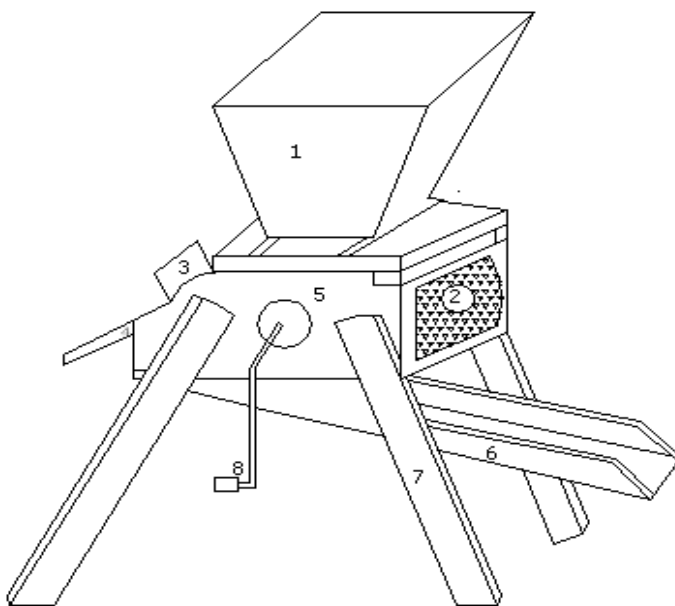


Figure 2: Soybean dehuller designed and fabricated at SUA

Key: 1. Seed hopper 2. Drum 3. Chest 4. Front chute 5. Wood frame
6. Rear chute 7. Legs 8. Handle

The process involves soaking the soybean grains in boiling water for 25-30 minutes. The hot water is then discarded and the beans are cooled in cold water. The cooled soybean grains are loaded into the machine and the drum rotated about its horizontal axis by the handle coupled to the shaft. Water is added during dehulling to flush out the soybeans and

prevent the grains from sticking on the drum. As the drum is rotated, the grains are squeezed between the drum and the chest which contains flow channels for guiding the dehulled grains to the outlets for grains and the hulls are discharged through a separate outlet to the rear of the machine (Silayo *et al.*, 2005).

The weaknesses of the dehuller which existed at SUA were poor dehulling efficiency and the outlet provided between the drum and chest was too narrow in such a way that very small amount of seeds were allowed to pass through. The specifications and working features of the dehuller are presented in Table 2. The problems associated with this dehuller necessitated improvement to obtain a version that will help the farmers to solve the problem of dehulling the grains (Silayo *et al.*, 2005).

Table 2: Specifications and Working Features of the Dehuller Designed and Fabricated at SUA

Overall dimensions (mm)			Weight (kg)	Cylinder diameter (mm)	Cylinder inclination to the hopper (degree)
L	W	H		Drum	
880	370	940	25	210	72

2.6 Soybean Milling

Milling is a process to produce flour involving a number of stages, such as size reduction, sifting and purifying. Several reports have shown the effect of the milling process on antioxidant capacity of cereals and legumes (Liyana-Pathirana and Shahidi, 2007) and dietary fiber (Glitso and Bach- Knudsen, 1999). In general, the purpose of milling the soybean is first to condition the grain in a dry or semi-wet state in such a way that the

different components can be separated as cleanly as possible. Milling embraces a wide range of technologies from simple grinding of the whole grain between stones or pounding in a wooden mortar with a pestle, to the complex continuous systems of precision rolls, sifters and classifiers found in modern wheat roller mills. Modern milling systems seek to separate the grain kernel into three fractions which are hull, germ and the cotyledon. The removal of the hulls lowers fibre content, anti-nutritional factors and decreases the pigmentation of the meal or flour. Elimination of the germ and aleurone layer reduces oil content thus ensures longer stability of the milled cotyledon. Since there is no milling process that is ideal, there is always some overlap of fractions in the products (Kent and Evers, 1994).

2.7 Pre-treatment of Soybean to Improve Dehulling Efficiency

Inefficient mechanical dehulling of soybean is one of the major problems facing the development of soybean processing facilities. This is the area where most soybean research is now concentrated. The dehulling efficiency of soybean grains could be improved by either breeding of varieties with hard cotyledon, which could withstand the force encountered during dehulling without shattering or by introduction of pre-treatment methods which could reduce the adhesion strength between the seed coat and the cotyledon prior to dehulling so that less force could be used to remove the seed coat. In most of the soybean growing areas a range of simple but effective traditional pre-treatment methods of the whole grain before dehulling have been developed (Graham and Vogel, 1978, Malleshi, 1988 and Young *et al.*, 1990). These pre-treatment methods involve steaming, parboiling, drying, soaking in water, alkali or acid solutions, or roasting. All these pre-treatments are aimed at facilitating the removal of the seed coat as completely as possible with least damage and loss of cotyledon.

2.7.1 Boiling

Boiling treatment has been shown to have significant effect on improving the dehulling efficiency of several grains. Sefa Dedeh and Stanley (1979) found that heat treatment of moistened beans and cowpeas made the seed coat much easier to remove due to the fact that the cotyledons tended to shrink more than the seed coat resulting in the seed coat being loosened from the cotyledons and hence easier to remove during dehulling. In boiling treatment the loosening or breaking of the seed coat-cotyledon bond is achieved by the generation of an internal cell pressure or stresses due to hydration or heat treatment or combination of both. A grain kernel undergoes several physical changes when subjected to heat treatment. Moisture absorption or temperature rise causes swelling or expansion, whereas moisture loss or cooling causes contraction or shrinkage. The expansion or contraction of the seed coat will be different from that of the cotyledon. As a result, during boiling treatment internal slips tend to occur which result in partial separation of the seed coat from the cotyledon thus making it possible to use less force to remove it during dehulling.

2.7.2 Soaking

The soaking process is an important step in the production of traditional soybean-derived foods such as soybean milk (Nelson *et al.*, 1976) and tofu (Ciabotti, 2007). In the traditional production process, the seeds are soaked overnight. Water absorption modifies the grain texture, which affects subsequent grinding, soybean milk production or protein extraction steps (Lo, 1968, Pan and Tangratanavalee, 2003). Soaking is also important during the processing of other foods, such as in rice parboiling (Engels, 1986, Ahromrit *et al.*, 2006), in sorghum flour preparation (Adeyemi, 1983), and in the production of canned grains such as corn and peas. Moreover, grain hydration reduces cooking time, minimizes losses, and improves the quality of the obtained products (Wang, 1979). Water absorption

by soybean grain during soaking depends mainly on the time-temperature binomial. The amount of absorbed water increases as soaking time and temperature increase (Wang, 1979, Sopade and Obekpa, 1990, Chopra and Prasad, 1994, Pan and Tangratanavalee, 2003).

2.8 Soybean Physical Properties

The knowledge of some important physical properties such as shape, size, volume, surface area, thousand grain weights, density, and porosity is necessary for the design of various separating, handling, storing and drying systems and in analyzing their behaviour during actual processing situations (Sahay and Singh, 1994; Tabatabaeefar, 2000). The size and shape are, for instance, important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1986). Additionally it is important in designing dehulling and size reduction machinery. The shape of the material is important for an analytical prediction of its drying behaviour (Esref and Halil, 2007).

The size of the grain can be expressed in terms of kernel weight, arithmetic mean diameter, geometric mean diameter, or kernel volume. The shape of the grain may be classified as flat or round depending upon its width and thickness criteria. The term 'sphericity', which is defined as the ratio of the volume of the grain to the volume of a circumscribed sphere, is commonly used to characterize grain shape. Bulk density, true density and porosity are used in design of storage bins and silos, separation of desirable materials from impurities, cleaning, grading and quality evaluation of the products. Beside other factors, both bulk density and true density greatly depend on the cellular structure of the grain. The cellular structure of a biological material has great influence on its mechanical behaviour under load for example during mechanical processing

(Singh, 1985). In recent years, physical properties have been studied for various crops such as groundnut kernel (Olajide and Igbeka, 2003), lentil seed (Amin *et al.*, 2004), sweet corn seed (Coskun *et al.*, 2005), linseed (Selvi *et al.*, 2006), faba bean grain (Altuntaş and Yildiz, 2007), rough rice grain (Ghasemi Varnamkhasti *et al.*, 2008), jatropha seed (Garnayak *et al.*, 2008) and karanja kernel (Pradhan *et al.*, 2008).

2.9 Assessment of the Dehulling Efficiency

Dehulling efficiency is defined as the percent of hull removed from the cotyledon and the yield of the dehulled grain obtained from this process (Ehiwe and Reichert, 1987). Wang (2005) defined dehulling efficiency as the sum of percent whole dehulled grain and split dehulled grain. To determine the dehulling efficiency you need to be able to quantify the effect of seed coat removal from the cotyledon. Numerous methods of varying sophistication have been used to determine the dehulling efficiency in soybean grain. In some cases, the hull is removed in small commercial or home-scale operations by grinding in a hand operated stone or wooden mill, sun drying and the hulls were then separated by winnowing (Kurien, 1984). The crude fibre method of dehulled wheat grain was used by Wesserman *et al.*, (1970) to express the dehulling efficiency as a function of process variables such as milling time, tempering duration and the type of abrasive used. Chemical methods are based on measuring a component that is more concentrated in the seed coat such as crude fibre and ash content (Horgan and Deobold, 1965, Raghavendra Rao *et al.*, 1975).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Determination of Physical Properties of Soybean

3.1.1 Materials

Five soybean varieties namely Bossier, Uyole soya-1, TGX-1954-1F, TGX-1889-12F and TGX-1895-33F were used in this study. The grain samples were obtained from Ilonga Agricultural Research Institute, which is one of the important agricultural institutes in Tanzania. The initial moisture content of the samples was determined by oven drying at 105 ± 5 °C for 24 hours (Balasubramanian, 2001). The samples were manually cleaned to remove foreign matter, dust, dirt, broken and immature grains before samples were prepared for the experiment.

3.1.2 Equipment

The following equipment was used: oven (Model Shenstone, Philip Harris LTD England) for determining moisture content, electronic balance (Model AC 211S Sartorius) for determining the mass of the grains, micrometer screw gauge (G.T. Tools Japan) for grain dimension determination, bicker for bulk density determination and Gallenhamp Kjeldahl apparatus (German) for boiling the samples.

3.1.3 Methods

Moisture-dependent physical properties of soybean grains, namely, linear dimensions (eg. length, width and thickness), sphericity, surface area, thousand grain weight, bulk density, true density, and porosity were determined at moisture levels of 14, 16, 18 and 20 % dry basis (d.b). Three replications of each test were made at each moisture level.

The samples of the desired moisture contents Fig. 3 were prepared by adding the amount of distilled water as calculated from the following relationship (Coskun *et al.*, 2005; Silayo, 2005).

$$Q = \frac{W_i (M_f - M_i)}{100 - M_f} \dots\dots\dots(1)$$

Where:

- Q = The mass of water added (g),
 W_i = The initial weight of the sample (g),
 M_i = The initial % moisture content of the sample (d.b.) and
 M_f = The final % moisture content of the sample (d.b.).



Figure 3: Soybean grain samples

The samples were then poured into separate polyethylene bags labelled according to the variety and moisture level, and the bags were sealed tightly and kept at 5°C in a refrigerator for seven days to enable the moisture to distribute uniformly throughout the sample. Before starting determining the physical properties, the required quantities of soybeans were taken out of the refrigerator and allowed to warm up to room temperature for about two hours.

The physical properties of grain were investigated at four moisture levels between 14 and 20 % dry basis. From the samples, 100 grains were selected at random for determining the physical axial dimensions. For each grain, three linear dimensions were measured, that is length (L), width (W), and thickness (T) using a micrometer screw gauge reading to 0.01 mm accuracy as shown in Fig. 4.

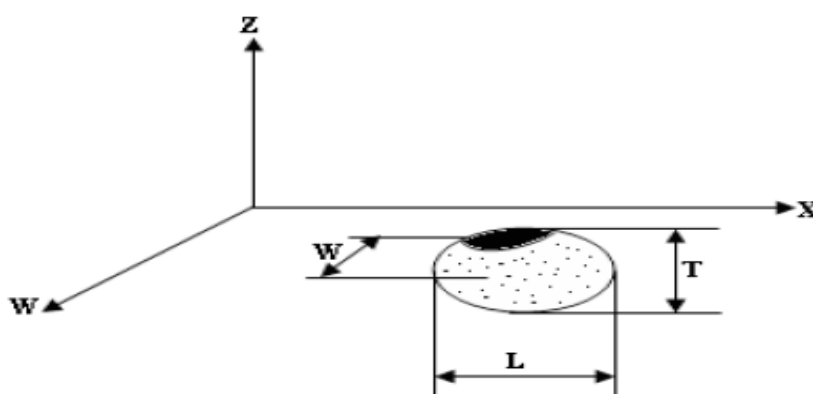


Figure 4: Characteristic dimensions of a soybean grain

Measurements of all size indices were replicated twenty times for Bossier, Uyole soya-1, TGX 1954-1F, TGX 1889-12F and TGX 1895-33F varieties of soybean. These principal dimensions were then used to calculate the arithmetic and geometrical mean diameters of the grain as detailed in sections below:

3.1.3.1 Arithmetic mean diameter (D_a)

The average diameter of the grains was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter D_a of the grains was calculated by using the following relationship (Mohsenin, 1986).

$$D_a = \frac{L + W + T}{3} \dots\dots\dots(2)$$

Where:

D_a = Arithmetic mean diameter (mm)

L = Length (mm)

W = Width (mm)

T = Thickness (mm).

3.1.3.2 Geometric mean diameter (D_g)

The geometric mean diameter (D_g) of the individual grain kernel was calculated by using the following relationship (Mohsenin, 1986):

$$D_g = (LWT)^{1/3} \dots\dots\dots(3)$$

Where:

D_g = Geometric mean diameter (mm)

L = Length of the grain, (mm)

W = Width of grain (mm) and

T = Thickness of the grain (mm).

3.1.3.3 Sphericity (Φ)

The grain shape was expressed in terms of its sphericity index (Φ), which expresses the shape character of the grain relative to that of a sphere of the same volume. It was assumed that the volume of the solid is equal to the volume of a triaxial ellipsoid with intercepts L, W, T, and that the diameter of the circumscribed sphere is the longest intercept L of the ellipsoid (Mohsenin, 1986). For the sphericity index, the average dimensions obtained for the 20 grains selected at random were used to compute the index using the following equation:

$$\Phi = \left[\frac{(LWT)^{1/3}}{L} \right] \times 100 \dots\dots\dots(4)$$

Where:

Φ = Sphericity (%)

$LWT^{1/3}$ = Geometric mean diameter in (mm) and L, W, T is the length, width and thickness of the grain respectively in (mm).

3.1.3.4 Surface area (A)

The surface area of soybean grain was calculated by analogy with a sphere of the same geometric mean diameter, using the following equation (Sacilik *et al.*, 2003; Altuntas *et al.*, 2005).

$$A = \pi D_g^2 \dots\dots\dots(5)$$

Where:

A = Surface area in (mm)²

D_g = Geometric mean diameter (mm)

3.1.3.5 One thousand grain weight (W1000)

The thousand grains weight was determined using an electronic balance having an accuracy of 0.001g. To evaluate the thousand grain weight, 100 grains were randomly selected from the bulk sample and weighed on the balance and the result multiplied by 10 to give a weight of 1000 grains.

3.1.3.6 True density

The true density of the grain is defined as the ratio between the mass of soybean grains and the true volume of the grains. The liquid displacement method using the toluene (C_7H_8), as described by Baryeh (2001), was used to determine the true density of soybean samples. Hundred kernels sample displacement was measured with aid of toluene and a measuring cylinder. To calculate true density, the dry weight of the samples was first determined using an electronic balance reading to an accuracy of 0.001g. The samples were then submerged in toluene and the displacement volume was determined. The true density of samples was calculated by using the following equation (Baryeh, 2001);

$$\rho_t = \frac{m_w}{V_w} \dots\dots\dots(6)$$

Where:

- ρ_t = True density kg/m^3
- m_w = Mass of air dry sample (kg)
- V_w = Volume of sample (m^3)

3.1.3.7 Bulk density (ρ_b)

The bulk density was determined using the mass/volume relationship, by filling an empty plastic container of predetermined volume by pouring the grains from a constant height

until the sample overflowed. After filling the container, excess grains are removed by striking off excess grains using straight edge and then weighing using a precision electronic balance reading to 0.01g accuracy. The procedure was replicated three times. The bulk density was calculated using the following equation (Ghasemi Varnamkhasti *et al.*, 2008):

$$\rho_b = \frac{m_2 - m_1}{V} \dots\dots\dots(7)$$

Where:

ρ_b = Bulk density (kg/m³)

m_1 = Mass of empty container (kg)

m_2 = Mass of container with soybeans (kg)

V = Volume of container (m³)

3.1.3.8 Porosity (ϵ)

An important characteristic of porous and thus of granular bulk materials is their porosity, which is the ratio of free space between the soybean grains to total of bulk grains. Also it is the ratio of inter granular space to the total space occupied by the grain. Porosity plays an important role in drying and ventilation processes, since the air resistance of a bulk layer and the corresponding movement of air depends greatly on the porosity. It is expressed as the percentage of volume of the voids in the grain sample at given moisture content. The porosity of the grains was calculated from bulk and true densities using the following relationship (Mohsenin, 1970).

$$\epsilon = \left(1 - \frac{\rho_b}{\rho_t} \right) \times 100 \dots\dots\dots(8)$$

Where:

- ε = Porosity in (%),
- ρ_b = Bulk density in (kg/m³)
- ρ_t = True density in (kg/m³).

3.2 Design of an Improved Prototype Dehuller

3.2.1 Design considerations

The objective of this section was to design, construct and evaluate a soybean prototype dehuller for dehulling moist soybean grains, which could overcome the problems encountered by the previous design (Fig. 1). Successful development of an efficient small scale dehuller for moist grains will eliminate much of the drudgery that is currently associated with traditional processing of soybean and also will increase the acceptability of soybean products. A number of points were considered during the design. These included the cost of construction, power requirement and labour requirement in operating the machine. Also, considered in the design was the ease of replacement of component parts in case of damage or failure.

3.2.2 Design calculations

3.2.2.1 Design of transmission shaft against static load

Transmission shaft is usually a rotating machine component, circular in cross-section, which supports transmission elements like gears, pulleys, sprockets and handles and transmits power. Such shafts are subjected to tensile, bending or torsion shear stresses, or a combination of these. The design of a transmission shaft consists of determining the correct shaft diameter from strength and rigidity considerations. The material used was mild steel. Most transmission shafts supporting gears and pulleys are subjected to a combined load of bending and torsional moments. The bending load comprises of vertical and horizontal components. As the shaft material used was ductile, the principal shear-

stress theory of failure was used to determine the shaft diameter. It was considered that the shaft will be subjected to bending moment (M_b), torsional moment (M_t), bending stress (σ_b) and torsional stress (τ) given by the following equation (Bhandari, 1983):

.....(9)

.....(10)

The maximum shear stress in the shaft can be determined by using a Mohr's circle as shown in Fig. 5.

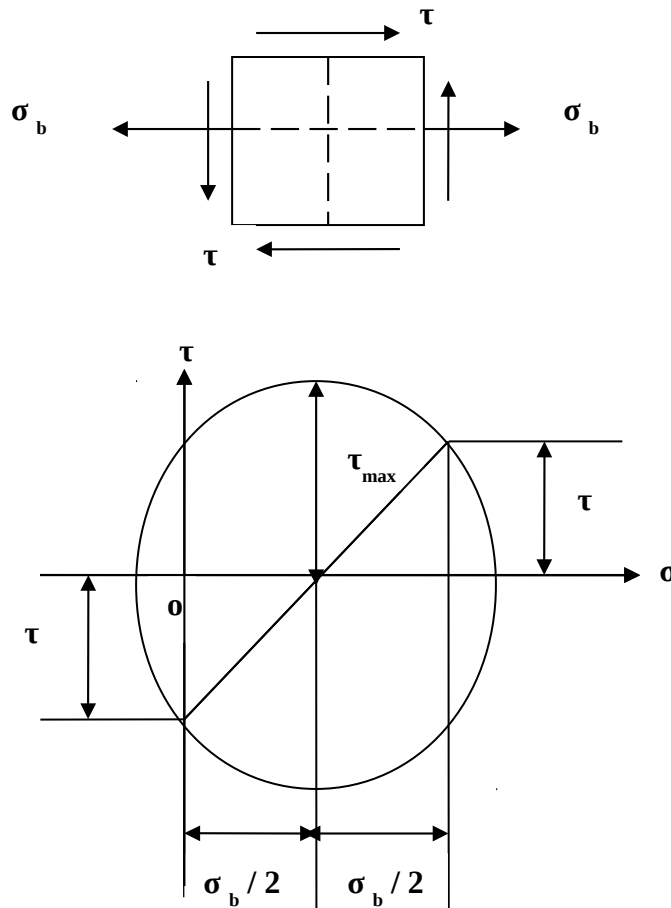


Figure 5: Mohr's circle for shaft element

The maximum shear stress in the shaft was determined using the following equation (Bhandari, 1983).

.....(11)

Substituting (9) and (10) in the above expression (11) we have;

$$\tau_{max} = \frac{16}{\pi d^3} \sqrt{(M_b)^2 + (M_t)^2} \dots\dots\dots(12)$$

According to the maximum shear-stress theory of failure (Bhandari, 1983):

$$S_{sy} = 0.5S_{yt} \dots\dots\dots(13)$$

Where:

S_{sy} = Yield strength of the material in shear, (N/mm²).

S_{yt} = Yield strength of the material in tension, (N/mm²)

Therefore,

$$\tau_{max} = \frac{S_{sy}}{f_s} \dots\dots\dots(14)$$

Where:

f_s = Factor of safety.

One important approach in designing a transmission shaft was to use the ASME Code. According to this code, the permissible shear stress (τ_d) for shaft without key ways is taken as 30% of the yield strength in tension or 18% of the ultimate tensile strength of material, whichever is minimum.

Therefore,

$$\tau_d = 0.30S_{yt} \quad \text{Or} \quad \tau_d = 0.18S_{ut} \dots\dots\dots(15)$$

If the keyways were present, these values were to be reduced by 25%. According to ASME code, the bending and torsional moments have to be multiplied by factors (k_b) and (k_t) respectively, to account for shock and fatigue in operating conditions.

Equation (12) was therefore modified and rewritten as:

$$\tau_{max} = \frac{16}{\pi d^3} \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \dots\dots\dots(16)$$

Where:

- d = Shaft diameter (mm)
- M_b = Bending moment (N–mm)
- M_t = Torsional moment (N- mm)
- k_b = Combined shock and fatigue factor applied to bending moment; and
- k_t = Combined shock and fatigue factor for torsional moment.

Equations (15) and (16) were used to determine the shaft diameter.

The values of (k_b) and (k_t) for rotating shafts are presented in Table 3.

Table 3: Combined Shock and Fatigue Factor for Bending and Torsional Moment for Determining Shaft Diameter

Parameter	k _b	k _t
Load gradually applied	1.5	1.0
Load suddenly applied (minor shock)	1.5 – 2.0	1.0 - 1.5
Load suddenly applied (heavy shock)	2.0 – 3.0	1.5 - 3.0

Source: ASME Code (1982)

The diameter of the shaft was obtained from the following equation (Bhandari, 1988);

$$d^3 = \frac{16}{\pi \tau_{max}} \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \dots\dots\dots(17)$$

$$d = \left(\frac{16}{\pi \tau_{max}} \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \right)^{1/3} \dots\dots\dots(18)$$

where:

- τ_{max} = Allowable combined shear stress for bending and torsion for steel shaft with keyway and is 87.75 N/mm² as obtained from Data book for

Mechanical Engineering for $S_{yt} = 390 \text{ N/mm}^2$ and $S_{ut} = 740 \text{ N/mm}^2$ for steel grade St. 50-2k.

kb = Combined shock and fatigue factor applied to bending moment is 1.5 - 2.0 for minor shock.

kt = Combined shock and fatigue factor applied to torsional moment is 1.0 - 1.5 for minor shock.

The resultant bending and torsional moments were calculated and found to be 115 000 N-mm and 69 000 N-mm respectively as shown in Appendix 6. The diameter was calculated and found to be 24.46 mm and a shaft of 25 mm was used in order to have a higher factor of safety.

3.2.2.2 Sizing the dehuller

The improved dehuller consists of four principal parts, which are the concave, the drum, the power transmission shaft and the discharge chute. The transmission shaft was the only component requiring critical design consideration hence dimensions of other components were estimated depending on availability and cost of materials, ease of machining and ease of operation. The improved dehuller conformed to the configurations shown in Fig. 6 – 9, with overall dimensions as shown and summarized in Table 4.

Table 4: Specifications and Working Features of the Improved Dehuller

Overall dimensions (mm)			Weight (kg)	Cylinder diameter (mm)	Cylinder inclination to the hopper (degree)
L	W	H		Drum	Concave

660	570	1130	35	140	147	15
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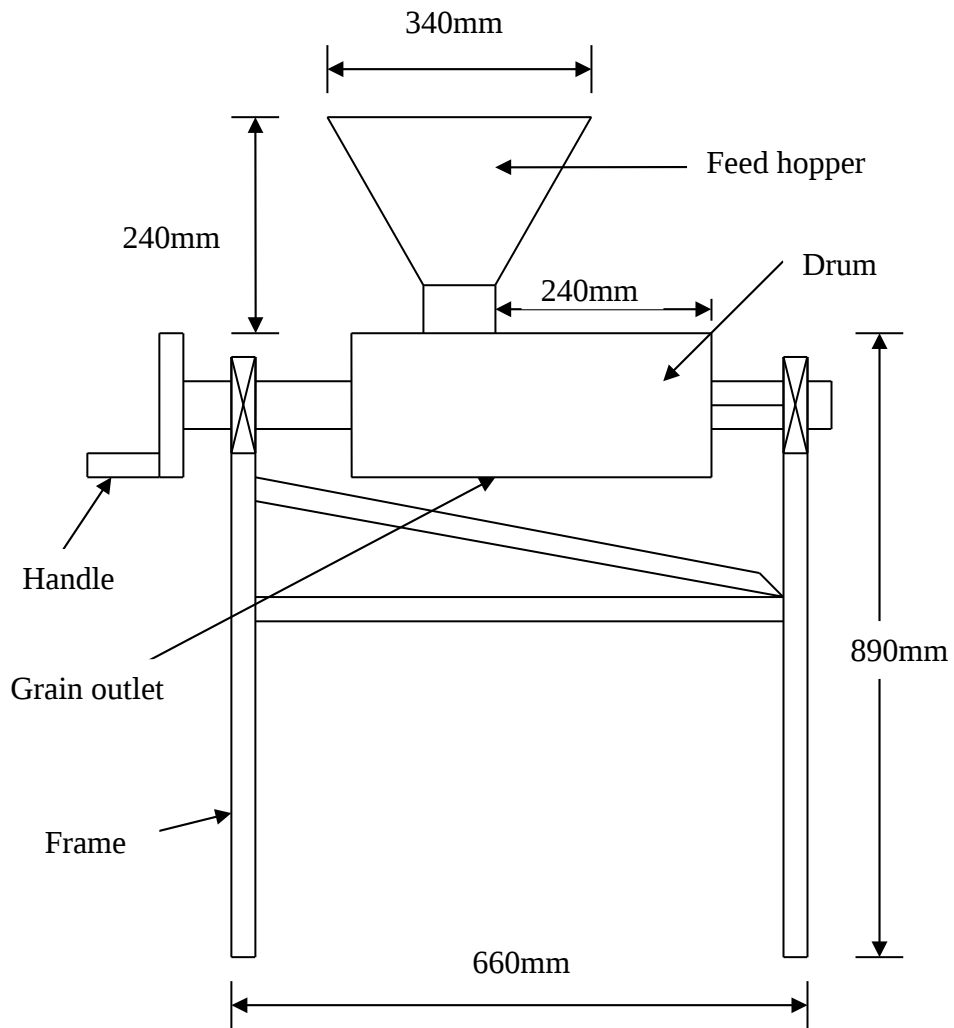


Figure 6: Front view of the dehuller

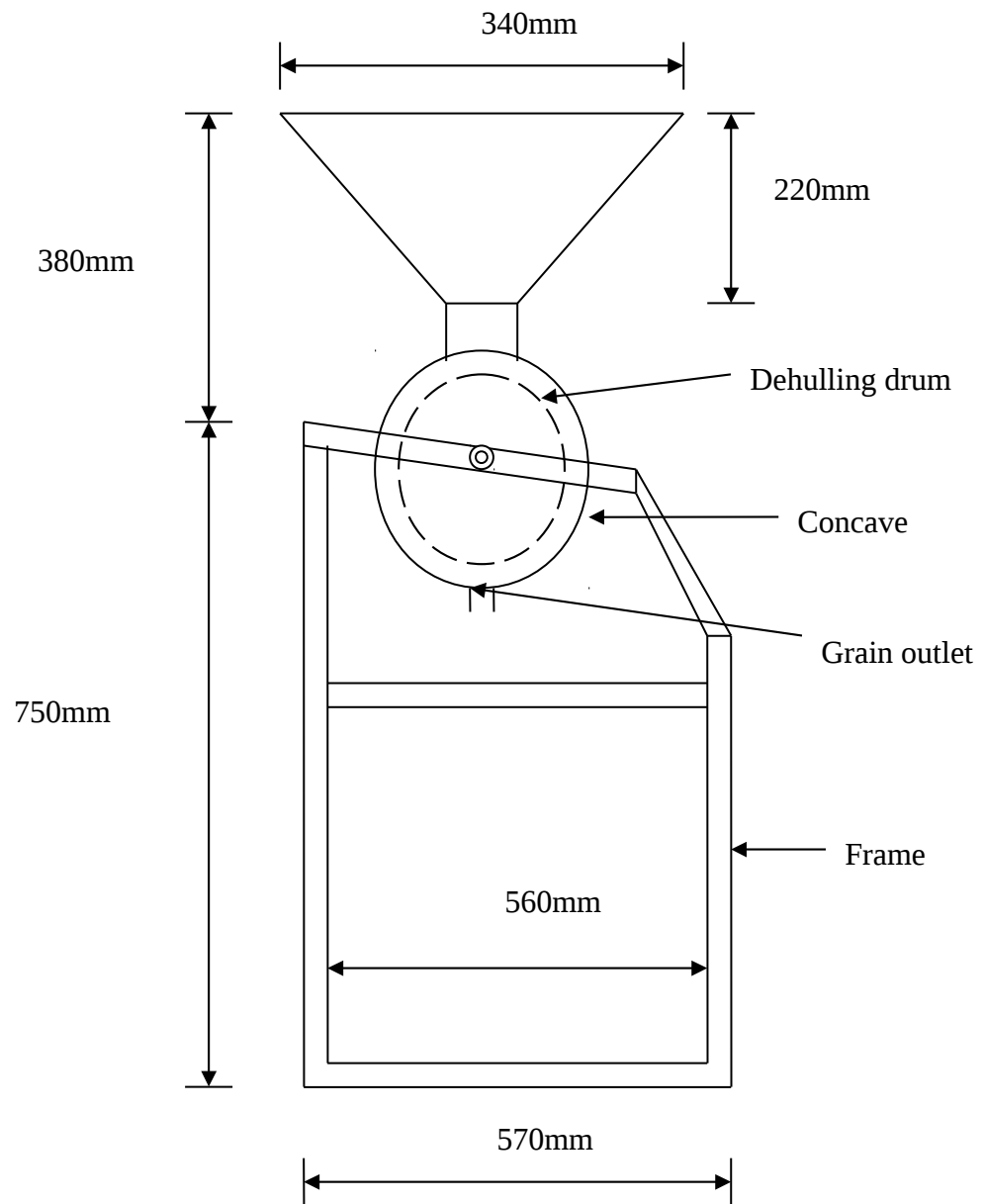


Figure 7: Side view of the dehuller

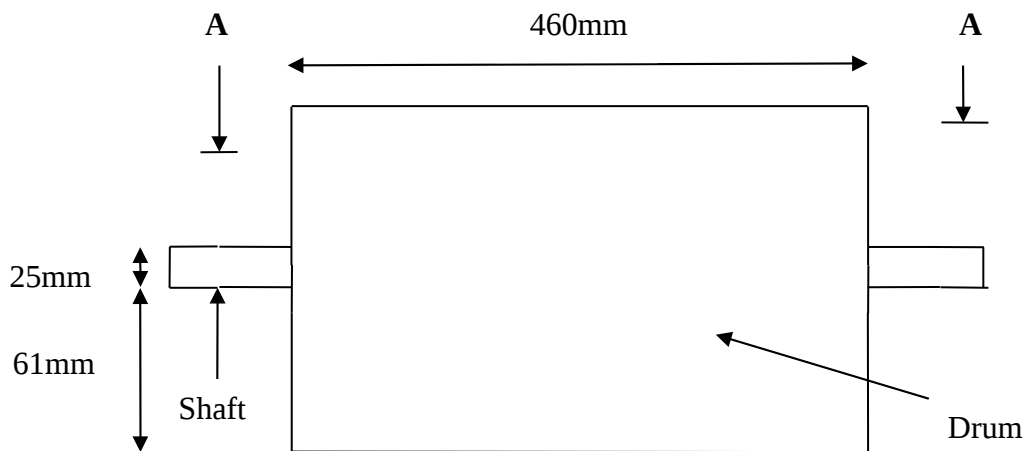


Figure 8: Dehulling drum

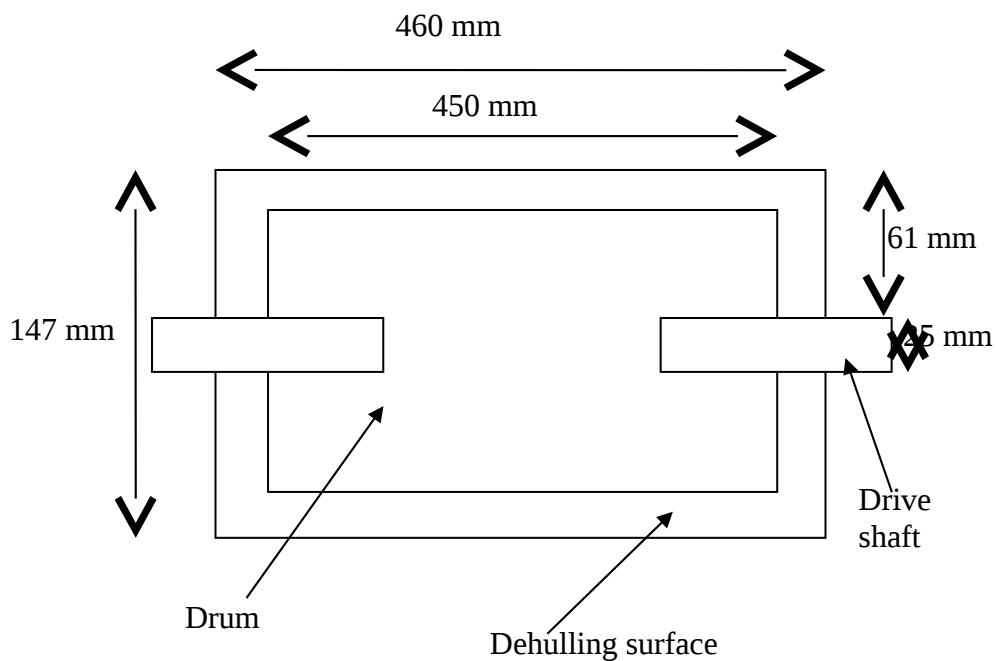


Figure 9: Section A- A of the dehulling drum

3.3 Manufacturing and Assembly

The concave was made of cast iron 460 mm long and 147 mm in diameter. An outlet on one end was provided at the lower surface and the inlet at the upper surface to which the

hopper is fixed 30 mm from the other end. The inner surface of the concave was lined with aluminium sheet so that the soybean will not come in contact with the cast iron. The hopper was made of wood lined with aluminium sheet gauge 20 in the inner side with four sides all slanting towards the inlet at an angle of 55° to the horizontal. The drum was made of hard wood 140 mm in diameter and 450 mm long with the power transmission shaft in two pieces fixed to it tightly at both ends, so that both the wood and the shaft appear as a single unit and rotate together. The whole 450 mm length of the wood accommodated a dehulling surface, which was made from aluminium sheet rolled into the drum and had 2 mm protrusions on its outer surface with drilled holes to allow fastening to the drum with aluminium pop rivets. To develop these protrusions, a grid of 5 mm x 5 mm was drawn on the aluminium sheet then it was punched using a punch at a regular spacing following the grid pattern. The dehulling surface could be replaced whenever the roughened surface was worn out. The drum unit was assembled to rotate freely against the stationary concave when the handle was turned by hand. The gap between the drum and concave was 5 mm which was enough to dehull the boiled or soaked soybeans whose average thickness was about 6 mm as revealed from measurements in section 3.1.

The mild steel solid shaft for power transmission which was 25 mm in diameter was cut in two pieces. One piece had a length of 300 mm and was fixed on one end while the other piece had a length of 200 mm fixed on the other end of the drum. Both pieces are supported at both ends on ball bearings, which were in turn bolted to the supporting frame. A photograph of the complete assembly of the improved dehuller is shown in Fig. 10.



Figure 10: Photograph of the improved dehuller

3.4 Operation of the Improved Dehuller

The soybeans to be dehulled were prepared by boiling for 30 minutes and then cooled before being introduced into the dehuller. In operation, the grains were loaded into the machine and the drum rotated about its horizontal axis by the handle coupled to the shaft. Water was added during dehulling to prevent the grain from sticking against the drum. As the drum rotated, the grains were squeezed through the gap between the drum and the concave. The abrasion between the grain and the rough surface of the drum resulted in shearing action which removes the seed coat from the grain. This dehuller produced a mixture of dehulled grains and hulls. The dehulled grains had to be separated from the hulls by water floatation where by the hulls float and could easily be skimmed off by hand.

3.5 Performance Evaluation of the Dehuller

3.5.1 Materials

Two varieties of soybean, Uyole soya -1, and TGX 1895-33F were used to evaluate the dehulling performance of the constructed dehuller. Other varieties were not used because Uyole soya-1 is commonly cultivated by most of the farmers and TGX 1895-33F is a newly promising variety to be released. The initial moisture content of the grain was 12.45% and 12.79 % (d.b) for TGX 1895-33F and Uyole soya-1 respectively.

3.5.2 Methods

3.5.2.1 Grain conditioning treatment

(a) Boiling treatment

Soybeans generally need pre-treatment before they are dehulled and splitting of the seed into individual cotyledons. The main purpose of boiling is to inactivate the anti-nutritional factors such as trypsin inhibitors that are present in soybeans, to deactivate the lipoxygenase enzyme and also to soften the seed coat. Boiling is also essential to produce an acceptable texture. Soybeans were first cleaned by removing damaged grains, dirt, and stones and then weighed. Five hundred grammes of soybean seeds were randomly selected from each variety. The samples were conditioned by boiling in distilled water for 10, 20 and 30 minutes. The boiling treatment procedure involved boiling the water in a cooking pot until it started to boil, then slowly pouring the whole soybeans into boiling water and simmers the soybeans for the prescribed period of 30 minutes. Firewood was used as heating medium. After boiling, the water was drained and the grains were spread on a tray and allowed to cool to room temperature. The moisture content of the boiled samples was then determined before dehulling. The samples were then poured into the dehuller and dehulled while adding water to the sample to flush out the grains in order to avoid clogging.

(b) Soaking treatment

The process of soaking soybeans in excess water is generally used as pre-treatment by the village level processors. Water absorption modifies the grain texture, which facilitates or simplifies the subsequent dehulling of soybean grains. Five hundred grammes of sorted grains of each variety were soaked in cold tap water at room temperature (25° C) for 6 and 12 hours. Twenty soybean grains were picked from the sample and rapidly transferred to polyethylene bags and the bags sealed tightly. The samples were then wiped to remove excess superficial water, then moved to a weighed moisture can and put in oven for moisture content determination at 105 ± 5 °C for 24 hours (Balasubramanian, 2001). The pre-treated or soaked samples were then poured into the dehuller and dehulled while adding water to flush out the dehulled grains and hulls in order to avoid clogging. The dehulled grain was then separated from the hulls by floatation method.

3.5.2.2 Dehulling tests

The pre-treated soybean samples were poured into the hopper at the top of the dehuller, as they passed between the abrasive drum and the concave; the seed coats were removed by abrasion between seed and abrasive surface, and between grain and grain. The dehulled mixture including unde-hulled grain, cotyledons, hulls and broken grain flowed out of the dehuller through the outlet chute at the base of the dehuller and was collected in a basin. The unde-hulled grains were sorted out manually from the mixture. The mixture of hulls and dehulled grains was then poured into a basin and sufficient amount of water was added to make the hulls float to facilitate separation. The dehulled cotyledon, whole grain and the hulls were then weighed separately for determination of throughput capacity and dehulling efficiency after drying to its initial moisture content.

3.5.3 Determination of the dehulling efficiency

In this study one method was used to evaluate the dehulling efficiency which is the extent to which the seed coat was removed from the cotyledon fraction. Five hundred grammes of grain samples were drawn from the dehulled grains and the seed coat remaining on partially dehulled grain kernels was hand sorted and weighed. The percentage seed coat removed from the dehulled grain was then determined as follows:_____

$$\% \text{ Seed coat removed} = 100 - \left(\frac{\% \text{ Seed coat in partially dehulled grain}}{\% \text{ Seed coat in unde-hulled grain}} \right) \times 100 \dots\dots\dots(19)$$

Kernel breakage was another important factor that needed to be considered when determining the dehulling efficiency because it shows the quality of the dehulled grain. The percentage of broken kernels was determined by sieving of the dehulled grain on 3 mm mesh screen because the mean geometric diameter for the samples in this study was 6 mm so any kernel passing through the mesh is taken as broken. The weight percentage of kernels passing through the screen gave the relative measure of the broken kernels in the sample. Dehulling efficiency (DE) was then determined as follows (Lazaro, 1999):

$$DE = 100 (C_h \times C_w \times C_y) \dots\dots\dots(20)$$

Where:

- C_h = Coefficient of dehulling which is defined as the extent of seed coat removal from the cotyledon during dehulling.
- C_w = Coefficient of wholeness of the dehulled kernels which defines the quality of dehulled grain recovered.

C_y = Yield factor which is defined as the proportion of dehulled grain recovered relative to the maximum expected yield.

The coefficients C_h , C_w and C_y were determined as follows:

$$C_h = \frac{M_h}{M_{uh}} \dots\dots\dots(21)$$

$$C_w = \frac{k}{b + k} \dots\dots\dots(22)$$

$$C_y = \frac{Y_a}{Y_e} \dots\dots\dots (23)$$

Where:

M_h = % of seed coat removed during dehulling (%)

M_{uh} = % of seed coat content of undehulled grain (%)

k = Mass of whole soybeans in the final product (g)

b = Mass of broken soybeans in the dehulled grain sample (g)

Y_a and Y_e are the actual and maximum expected yield of dehulled grain respectively and were determined as:

$$Y_a = \frac{x}{M} \times 100 \dots\dots\dots(24)$$

$$Y_e = (100 - u) \dots\dots\dots(25)$$

Where:

x = Mass of the dehulled grain recovered

M = Mass of grain sample before dehulling

u = Seed coat content of undehulled grain (%).

The maximum expected yield is the yield that would have been obtained if only the seed coat was removed from the grain without any loss of the cotyledon through breakage (i.e. 100% recovery of the cotyledon).

3.5.4 Throughput capacity (C)

Throughput capacity (kg/h) is one of the measures of quantitative performance of a machine which is defined as the quantity of grain processed by the machine per unit time. One kilogram of soybean was boiled for 30 minutes, cooled and then poured into the dehuller. The dehuller was operated for one minute while sufficient amount of water was added to flash out the samples. The throughput of the dehuller (C) was then evaluated using the following equation:

$$C = \frac{M_g}{t_d} \left(\frac{\text{kg}}{\text{h}} \right) \dots\dots\dots(26)$$

Where:

M_g = Mass of dehulled grain (kg)

t_d = Time used in dehulling (min.)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Effect of Moisture Content on the Physical Properties of Soybean

4.1.1 Grain dimensions

The average values of the three principal dimensions of soybean grain, namely length, width and thickness determined in this study at different moisture contents are presented in Appendix 1. Five varieties of soybean (Bossier, Uyole Soya-1, TGX 1954-1F, TGX 1889-12F, and TGX 1895-33F) were used to study the effects of moisture content on the physical properties of soybean grains. Each principal dimension appeared to be linearly dependent on the moisture content as shown in Fig. 11.

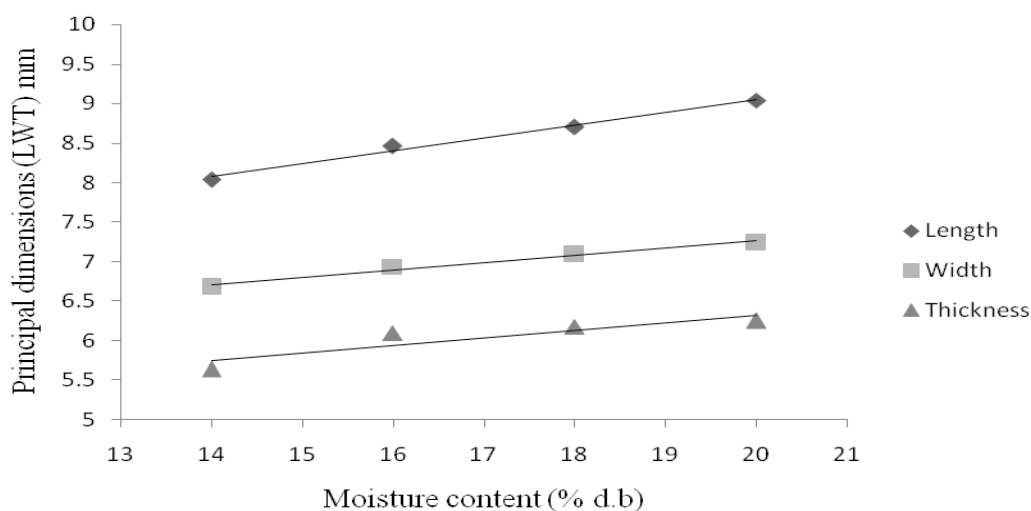


Figure 11: Variation of principal dimensions of soybean grains with moisture content for Bossier variety

Very high correlation observed between the three principal dimensions and moisture content indicate that upon moisture absorption, the soybean grain expanded in length, width and thickness within the moisture range of 14 to 20 % d.b. The relationship between

the grain dimensions (Y) and moisture content (M_c) could be expressed by the following linear equation:

$$Y = a + b M_c \dots\dots\dots(27)$$

Where:

- Y = Grain dimension (mm)
- M_c = Moisture content of the grain in (% d.b.)
- a, b = Constants

This means that each unit change in (M_c) produced a change of b on Y. The values of the constants (a) and (b) for each grain dimension along with the corresponding coefficient of determination (R²) are presented in Table 5.

4.1.2 Arithmetic and Geometric mean Diameters

The effect of moisture content on arithmetic mean diameter and geometric mean diameter are presented in Appendix 1. The mean diameters increased with increase in moisture content as shown in Fig. 12.

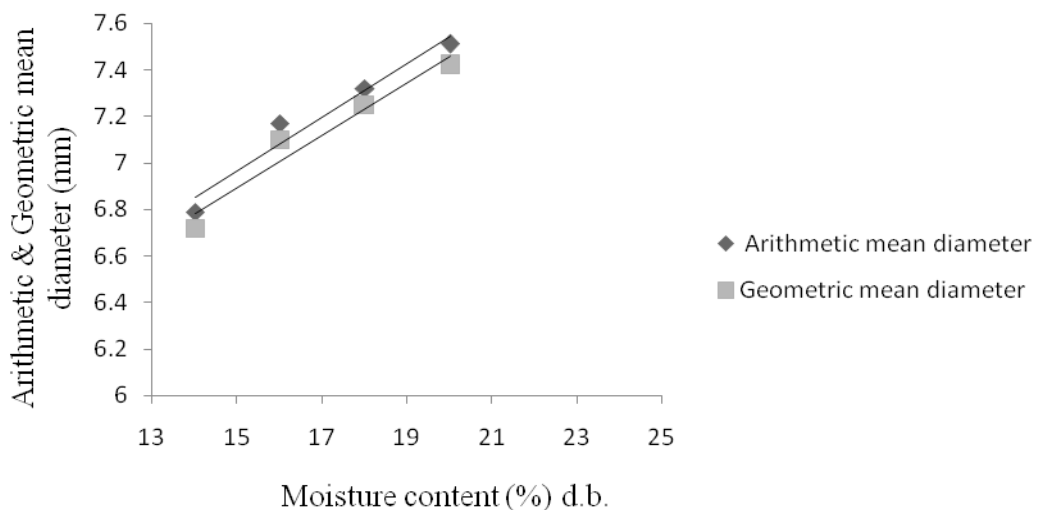


Figure 12: Effects of moisture content on the arithmetic and geometric mean diameters of Bossier grains.

Table 5: Fitted Constants for the Relationship between Grain Dimensions and Moisture Content

Grain variety	Dimension (mm)	a	b*10 ⁻²	R ²
Bossier	Length	5.806	16.2	0.99
	Width	5.404	9.33	0.96
	Thickness	4.417	9.57	0.93
Uyole soya-1	Length	7.360	6.28	0.99
	Width	5.754	7.30	0.99
	Thickness	5.384	2.80	0.92
TGX 1954-1F	Length	7.533	6.12	0.91
	Width	6.153	3.77	0.99
	Thickness	5.046	3.61	0.97
TGX 1887-12F	Length	6.570	6.12	0.99
	Width	5.621	8.65	0.99
	Thickness	4.123	10.1	0.99
TGX 1895-33F	Length	5.762	14.4	0.99
	Width	5.164	9.80	0.98
	Thickness	4.334	7.80	0.99

4.1.3 Sphericity

The values of sphericity were calculated by using equation (4) and the results obtained are presented in Appendix 1. The sphericity of the samples decreased from 83.94 to 82.12 % as the moisture content increases from 14 to 20 % d.b. Similar trends on the effect of moisture content on sphericity have been reported by Baryeh (2001) for groundnut, Nimkar and Chattopadhyay (2001) for green gram, Baryeh and Mangope (2002) for pigeon pea, Calisir *et al.* (2005) for rapeseed and Tekin *et al.* (2006) for Bombay bean.

The relationship between sphericity (Φ) and moisture content (M_c) of the Bossier variety is shown in Fig.13 and can be represented by the following equation:

$$\phi = -0.566M_c + 84.64 \quad R^2 = 0.872 \dots\dots\dots(28)$$

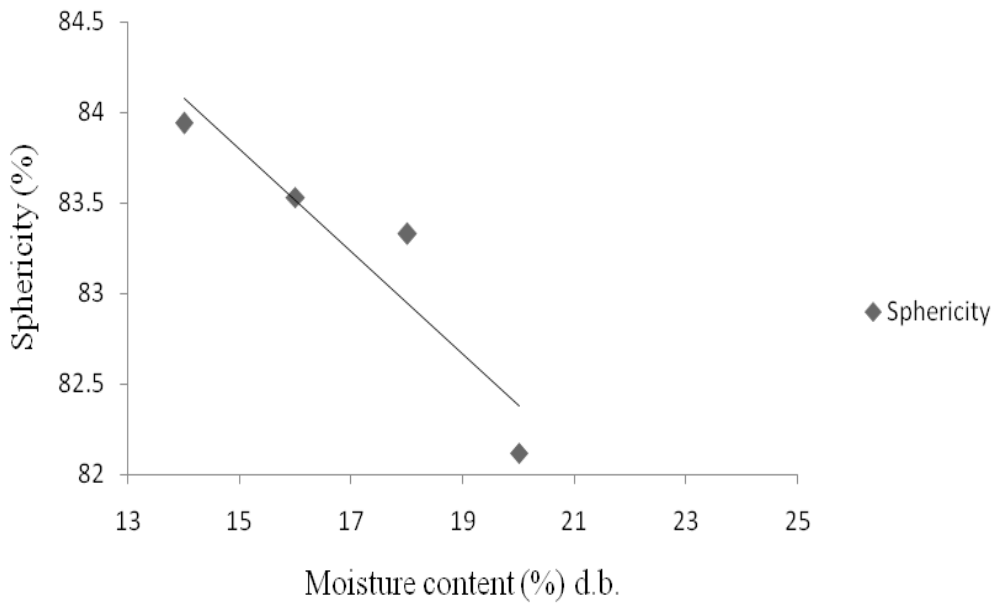


Figure 13: Variation of sphericity with moisture content of Bossier variety

4.1.4 Thousand grain weight (W_{1000})

The thousand grain weight of soybean increased linearly with moisture content for all varieties as indicated in Table 6. The relationship between 1000 grain weight (w_{1000}) and the moisture content (M_c) of Bossier variety is shown in Fig.14 and can be represented by the following linear equation:

$$W_{1000} = 13.20M_c + 152.3 \quad (R^2 = 0.971) \dots\dots\dots(29)$$

Similar trend was reported by Kasap and Altuntas (2006) for sugar beet seeds, Altuntas and Yildiz (2007) for faba bean grains, and Pradhan *et al.* (2008) for karanja kernel.

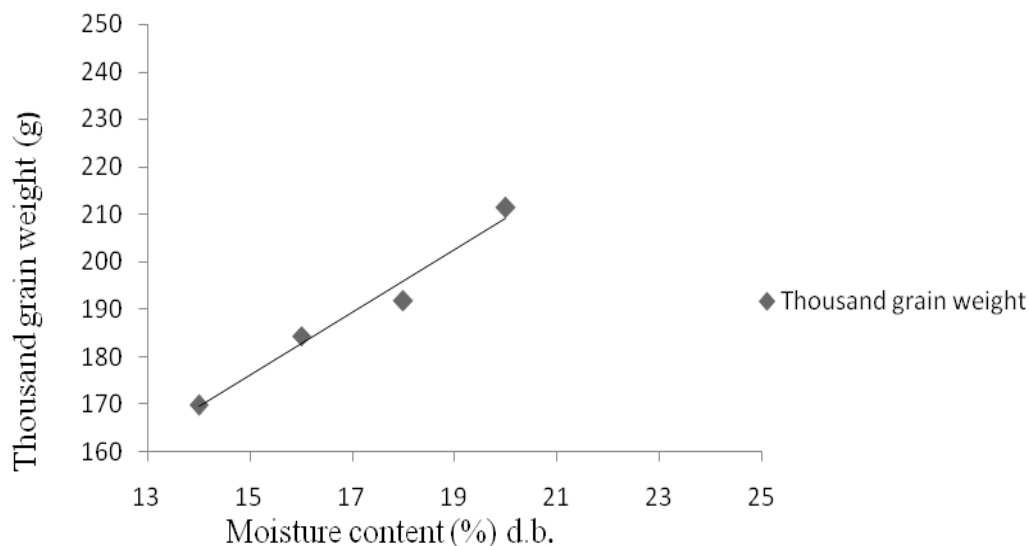


Figure 14: Effects of moisture content on W_{1000} of soybean grains (Bossier)

Table 6: Surface Area, Bulky Density, True Density and Porosity of Soybean Grains at Different Moisture Contents

Grain Variety	Moisture content (%)	Surface area (mm ²)	Bulky density (kg/m ³)	True density (kg/m ³)	Porosity (%)	1000 grain weight (g)	
Bossier	14	141.93	794	1129.35	29.69	169.85	
	16	158.44	784	1119.19	29.95	184.36	
	18	165.20	776	1112.56	30.25	191.76	
	20	173.04	771	1107.92	30.41	211.39	
Uyole	14	148.34	782	1127.75	30.66	157.71	
	Soya-1	16	154.89	772	1117.59	30.92	172.22
		18	162.03	764	1110.96	31.23	179.62
TGX 1954-1F	20	167.03	758	1106.32	31.48	199.25	
	14	144.48	780	1122.17	30.49	143.53	
	16	147.48	770	1112.01	30.76	158.04	
TGX 1889-12F	18	152.69	761	1105.38	31.15	165.44	
	20	155.77	755	1100.74	31.41	185.07	
	14	143.63	745	1125.85	33.83	151.07	
TGX 1895-33F	16	153.57	735	1115.69	34.12	165.58	
	18	164.29	726	1109.06	34.54	172.98	
	20	169.79	721	1104.42	34.72	192.61	
TGX 1895-33F	14	131.98	770	1088.73	29.28	162.47	
	16	142.36	761	1078.57	29.44	176.98	
	18	152.69	754	1071.94	29.66	184.38	
	20	158.44	750	1067.30	29.73	204.01	

4.1.5 Surface area

The surface area of soybean grain increased as the moisture content increased as shown in Fig. 15 and the relationship between the surface area and moisture content of Uyole soybean can be represented by the following linear equation:

$$A = 10.00M_c + 134.6 \quad (R^2= 0.953) \dots\dots\dots(30)$$

Similar trend was reported by Selvi *et al.* (2006) for linseed, Isik and Unal (2007) for red kidney bean grains, and Garnayak *et al.* (2008) for jatropha seed.

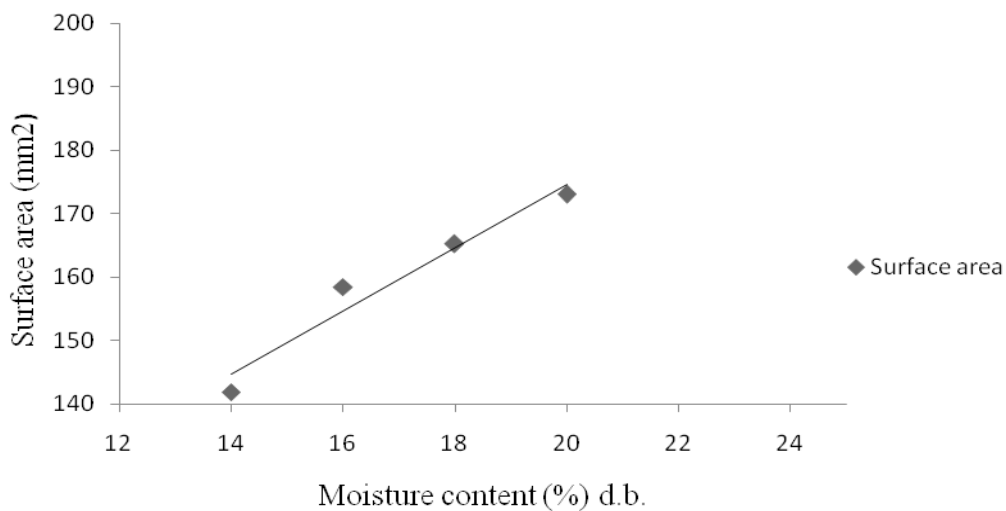


Figure 15: Effects of moisture content on surface area of Uyole soybean grains

4.1.6 Bulk density

The grains bulk density decreased with increasing moisture levels. This observation was due to the fact that an increase in mass owing to moisture gain in the sample was lower than corresponding volumetric expansion of the grain bulk (Pradhan *et al.*, 2008). The bulk density (ρ_b) of the grains had the following linear relationship with the moisture content (M_c) for Uyole soya-1:

$$\rho_b = -7.7M_c + 800.5 \quad (R^2= 0.979) \dots\dots\dots(31)$$

The regression equation indicated that the increase of moisture content caused a decrease in bulk density. It was also observed that the increase of moisture content of grain, depending on structure of fibre in grainy products, affected bulk density in studies made by Gupta and Das (1997), Baryeh (2001), Sahoo and Srivastava (2002), Aviara *et al.* (2005), Altuntas *et al.* (2005), Mwithiga and Sifuna (2005) and Yalcin (2006). Similar trend was reported by Yalcin *et al.* (2007) for pea seed, Altuntas and Demirtola (2007) for some legumes seeds, Garnayak *et al.* (2008) for jatropha seed and Pradhan *et al.* (2008) for karanja kernel. The relationship between the bulk density and moisture content of soybean is shown in Fig. 16.

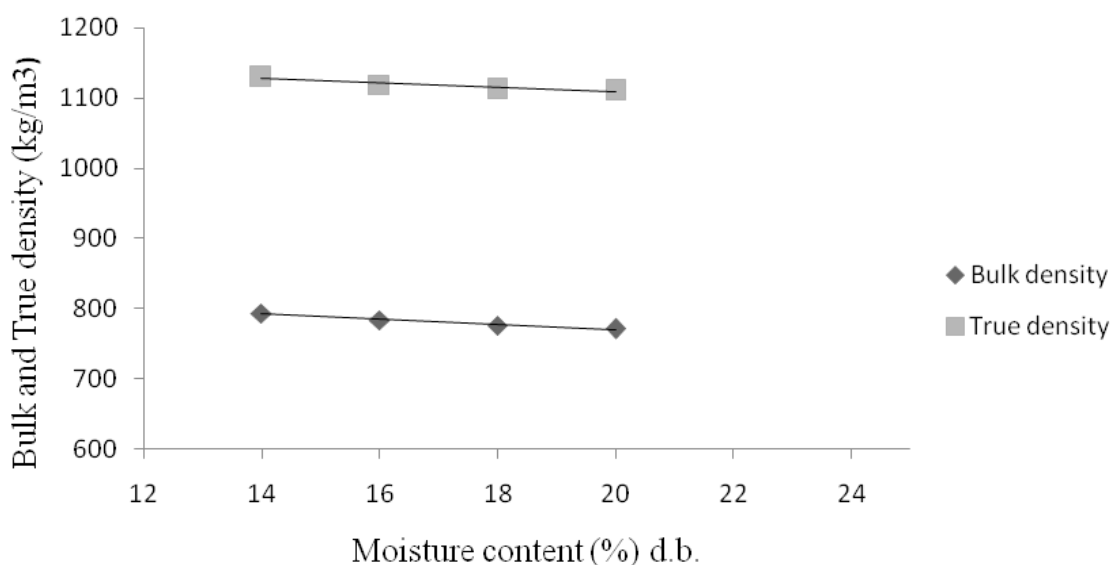


Figure 16: Effects of moisture content on bulk and true density of Bossier soybean grains

4.1.7 True density

The true density of soybean grains also decreased with increasing moisture levels. The effect of moisture content on true density of soybean is also shown on Fig. 16. The relationship between moisture content (M_c) and true density (ρ_t) could be described by the following linear equation:

$$\rho_t = 1134 - 6.492M_c \quad (R^2 = 0.99) \dots\dots\dots (32)$$

The results were similar to those reported by Sacilik *et al.* (2003) for hemp seed, Yalcin *et al.* (2007) for pea seed, Cetin (2007) for barbunia bean seed and Altuntas and Demirtola (2007) for some legume seeds.

4.1.8 Porosity

Porosity was calculated by using the data on bulk and true densities of the soybean grain. The variation of porosity depended upon moisture content as shown in Fig. 17.

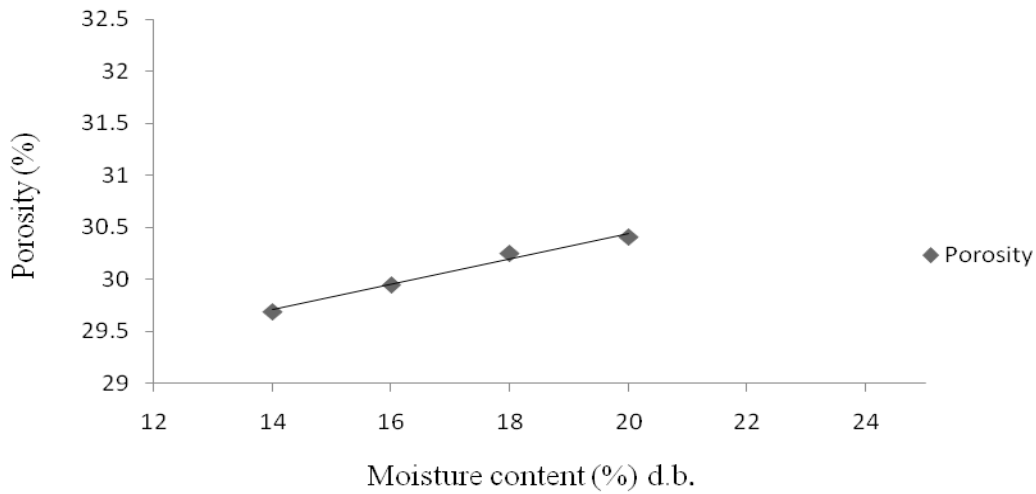


Figure 17: Effect of moisture contents on the porosity of Bossier soybean grain

Both bulk and true densities of soybean grains decreased with increase in moisture content, whereas the porosity increased. This was due to the fact that a decrease in the true density was lower than decrease in the bulk density. The relationship between porosity (ϵ) and the moisture content (M_c) of Bossier grains could be represented by equation 33:

$$\epsilon = 0.246M_c + 29.46 \quad (R^2 = 0.986) \dots\dots\dots(33)$$

Yalcin and Ozarslan (2004), Altuntas and Yildiz (2007), Garnayak *et al.* (2008) and Pradhan *et al.* (2008) reported similar trends for vetch seeds, faba bean grains, jatropha seed and karanja kernel, respectively. Similar results were also reported by Cetin (2007) for barbungia bean, and Isik and Unal (2007) for white speckled red kidney bean.

4.2 Evaluation of Dehulling Efficiency of Soybean

4.2.1 Effects of boiling pre-treatment on the moisture content and dehulling efficiency of soybean

Boiling for 10, 20 and 30 minutes resulted in an increase in moisture content of the soybean from the initial moisture content value of 12.45 % (db) to 22.21, 25.16 and 26.24 % (db) for Uyole soya-1, and from 12.79 % d.b to 19.77, 25.77 and 29.48 % (db) for TGX 1895-33F. Dehulling efficiency increased with increased boiling duration. Minimum and maximum efficiencies of 40.91 and 70.62 % were obtained at 10 and 30 minutes boiling respectively for Uyole soya-1 and 50.25 to 72.57 % at 10 and 30 minutes boiling respectively for TGX 1895-33F. The effect of boiling pre-treatment on dehulling efficiency for Uyole soya-1 and TGX 1895-33F are presented in Table 7 for the two selected varieties.

Table 7: Effect of Boiling Pre-Treatment on Moisture Content and Dehulling Efficiency of Soybean

Variety	Boiling duration (min.)	Moisture content % (db)	Dehulling efficiency (%)
Uyole Soya-1	10	22.21	40.91
	20	25.16	56.94
	30	26.24	70.62
TGX 1895-33F	10	19.77	50.25
	20	25.77	62.82
	30	29.48	72.57

4.2.2 Effects of soaking pre-treatment on moisture content and dehulling efficiency of soybean

Soaking of the grain resulted in absorption of moisture by the grain. The amount of absorbed water increases as soaking time increases. Soaking for 6 and 12 hours at room temperature (25°C) resulted in an increase in moisture content of the grain from the initial moisture content of 12.45 % (db) to 18.18 and 21.85 % for Uyole soya-1 and from 12.79 % (db) to 18.98 and 22.88 % for TGX 1895-33F respectively. Soaking followed by a rest period to allow surface moisture to be absorbed resulted in a dehulling efficiency of 57.24 and 63.58 % respectively for Uyole soya-1, and 54.61 and 65.69 % respectively for TGX 1895-33F as presented in Table 8.

Table 8: Effect of soaking pre-treatment on moisture content and dehulling efficiency of soybean

Variety	Soaking Duration (hours)	Moisture content % (db)	Dehulling efficiency (%)
Uyole Soya-1	6	18.18	57.24
	12	21.85	63.58
TGX 1895-33F	6	18.98	54.61
	12	22.88	65.69

The major factor used to evaluate dehulling efficiencies was the amount of seed coat removed from the dehulled grain. Kernel breakage and the product yield were also considered as important factors in the evaluation of dehulling efficiency. These two factors defined the quality and the quantity of the recovered grain. Boiling for 10, 20 and 30 minutes followed by cooling at ambient condition resulted in a dehulling efficiency of 40.91, 56.94 and 70.62 % respectively for Uyole soya-1 and 50.25, 62.82 and 72.57 % respectively for TGX 1895-33F. Soaking for 6 and 12 hours followed by a rest period to allow surface moisture to be absorbed resulted in a dehulling efficiency of 57.24 and 63.58 % respectively for Uyole soya-1 and 54.61 and 65.69 % respectively for TGX 1895-33F.

The dehulling efficiency for untreated grain was 20.21% for Uyole soya-1 and 33.99 % for TGX 1895-33F. This means that in terms of seed coat removal, boiling the grain for 30 minutes improved the dehulling efficiency by 50.41 % for Uyole soya-1 and 38.58 % for TGX 1895-33F over the untreated grain. Soaking for 12 hours resulted in an improvement in dehulling efficiency of 43.37 % over untreated grains for Uyole soya-1 and 31.70% for TGX 1895-33F. The results of dehulling efficiency of the two soybean varieties in terms of seed coat removal from the dehulled grain at different pre-treatments are presented in Appendices 4 and 5 and summarized in Table 9.

Table 9: Effect of Different Pre-Treatments on Dehulling Efficiency of Soybean in Terms of Seed Coat Removal

Grain variety	Treatment	Duration	Drying method	DE
Uyole soya-1	Control			20.21
	Boiling	10 min.	Ambient drying	40.91
	Boiling	20 min.	Ambient drying	56.94
	Boiling	30 min.	Ambient drying	70.62
	Soaking	6 hours	Ambient drying	57.24
	Soaking	12 hours	Ambient drying	63.58
TGX1895-33F	Control			33.99
	Boiling	10 min.	Ambient drying	50.25
	Boiling	20 min.	Ambient drying	62.82
	Boiling	30 min.	Ambient drying	72.57
	Soaking	6 hours	Ambient drying	54.61
	Soaking	12 hours	Ambient drying	65.69

4.2.3 Throughput (C) capacity of the dehuller

4.2.3.1 Effects of boiling pre-treatment on throughput capacity

Increase in boiling duration reduced the throughput capacity of the dehuller. Boiling for 10 minutes gives the throughput capacity of 50.76 kg/h and 55.50 kg/h for Uyole soya-1 and TGX 1895-33F respectively, while when boiled for 30 minutes, the throughput capacity obtained was 34.32 kg/h for Uyole soya-1 and 37.68 kg/h for TGX 1895-33F. The throughput decreased with boiling duration because at high temperatures the seeds were

softening in such a way that it was easier to stick on the walls of the drum and the concave. This made the flow of soybeans very difficult during dehulling and hence the rate of discharge was reduced. But at lower temperatures, the soybeans become less soft and therefore were able to flow much more freely. The variation of boiling duration with throughput capacity is shown in Table 10.

Table 10: Variation of Throughput Capacity with Boiling Duration of Soybean

Variety	Treatment	Duration (mm)	Moisture content (d.b) %	Throughput capacity (kg/h)
Uyole soya-1	Boiling	10	22.21	50.76
		20	25.16	45.54
		30	26.24	34.32
TGX 1895-33F		10	19.77	55.50
		20	25.77	43.80
		30	29.48	37.68

4.2.3.2 Effects of soaking pre-treatment on throughput capacity

The variation of throughput capacity with soaking duration is presented in Table 11.

Table 11: Variation of Throughput Capacity with Soaking Duration

Variety	Treatment	Duration (hours)	Moisture content (%)	Throughput(C) (kg/h)
Uyole soya-1	Soaking	6	18.18	54.72
		12	21.85	40.86
TGX 1895-33F		6	18.98	51.78
		12	22.88	39.12

The increase in soaking duration resulted in an increase in moisture content which led to decrease in throughput capacity. Soaking for 6 and 12 hours resulted in moisture contents of 18.18 and 21.86 % which led to reduction of throughput capacity from 54.72 to 40.86 kg/h respectively for Uyole soya-1. Also soaking for 6 and 12 hours resulted in moisture contents of 18.98 and 22.88 % which led to reduction of throughput capacity from 51.78 to 39.12 kg/h respectively for TGX 1895-33F. The throughput capacity decreased with

soaking duration because at high moisture content the seed coats became more sticky to the dehulling surface resulting in a reduction of friction between the soaked soybeans and the dehulling surface. This made the flow of soybeans very difficult during dehulling and hence the rate of discharge was also reduced. But at lower moisture content, the soybeans were less sticky and therefore were able to flow much more freely. However, when aided by using water to flush out the soybeans, the stickiness was reduced.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of the research presented in this dissertation was to determine the physical properties of soybean grains, for the sake of designing and fabrication of an improved manually operated soybean dehuller with improved dehulling efficiency and throughput capacity compared to the one previously designed at SUA. To achieve this objective it was necessary to study different grain physical properties related to dehulling and how these properties are influenced by different conditions likely to be encountered during the dehulling process. Pre-treatment methods which were found to be useful in the traditional dehulling systems such as boiling and soaking were also studied and incorporated in the improved dehuller.

Based on experimental results on grain physical properties and the use of different pre-treatments, an improved prototype dehuller for dehulling soybean grains was designed and fabricated. The boiling duration of 30 minutes followed by a rest period to allow the grain to cool down and surface moisture to be absorbed before the grain was introduced into the dehuller and the use of excess water to flush the grains in the hopper during dehulling eliminates clogging problems. Boiling pre-treatment for 30 minutes improved the dehulling efficiency of soybean by 50.41 % and 38.58 % for Uyole soya-1 and TGX 1895-33F respectively while soaking pre-treatment for 12 hours followed by a rest period improved the dehulling efficiency of soybean by 43.37 % and 31.70 % for Uyole soya-1 and TGX 1895-33F respectively.

The study has shown that boiling or soaking pre-treatments result in a significant improvement on the dehulling efficiency of soybeans. Soybean variety TGX 1895-33F showed higher dehulling efficiency percentage compared to Uyole soya-1 variety. Also the study indicates that dehulling soybeans without pre-treatment tended to account for the higher material loss.

The performance evaluation of the dehuller showed that it is possible to increase the dehulling efficiency and throughput capacity of soybean by the use of appropriate dehulling equipment in combination with controlled pre-treatment procedures. This therefore call for more efforts for developing dehulling equipment which can incorporate more of the pre-treatments currently used in the traditional dehulling system.

5.2 Recommendations

Since soybeans are produced in remote areas where electricity is a problem, there is need to develop and improve manually operated dehullers. This will eliminate shortcomings such as low efficiency and low throughput which are also influenced by the operator.

Modification of the prototype developed in this study so that it can be pedal - operated will be one step ahead. This dehuller can also be arranged to use a 0.25 hp petrol or diesel engine by replacing the hand cranking handle with a pulley of suitable size coupled to the shaft through a V- belt drive. More efforts are required for developing dehulling equipment which can incorporate more of the pre-treatments currently used in the traditional dehulling system in order to increase the dehulling efficiency and the throughput capacity of soybean.

In collaboration with agronomists, it may also be possible to investigate the possibility of developing soybean genotypes that are less prone to shattering during dehulling. More detailed research on factors that influence seed coat adherence to the cotyledon may also be warranted.

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APPENDICES

Appendix 1: Physical Dimensions and Shape of Soybean Grains at Different Moisture Contents

Grain Variety	Moisture content (%db.)	Axial dimensions (mm)			Average diameters (mm)		Sphericity (%)
		Length (L)	Width (W)	Thickness (T)	Geometric mean(D_g)	Arithmetic mean (D_a)	
Bossier	14	8.04	6.68	5.64	6.72	6.79	83.94
	16	8.46	6.94	6.10	7.10	7.17	83.53
	18	8.70	7.09	6.18	7.25	7.32	83.33
	20	9.04	7.24	6.25	7.42	7.51	82.12
Uyole Soya-1	14	8.23	6.79	5.79	6.87	6.94	84.63
	16	8.37	6.91	5.99	7.02	7.04	84.59
	18	8.49	7.05	6.19	7.18	7.24	83.91
	20	8.62	7.23	6.23	7.29	7.36	83.41
TGX 1954-1F	14	8.39	6.69	5.55	6.78	6.88	80.79
	16	8.51	6.73	5.61	6.85	6.95	80.60
	18	8.65	6.85	5.72	6.97	7.07	80.48
	20	8.75	6.91	5.76	7.04	7.14	80.41
TGX 1889-12F	14	8.25	6.78	5.53	6.76	6.85	82.81
	16	8.49	6.99	5.76	6.99	7.08	82.35
	18	8.73	7.19	6.02	7.23	7.31	81.98
	20	8.97	7.29	6.06	7.35	7.44	81.88
TGX 1895-33F	14	7.78	6.54	5.36	6.48	6.56	83.72
	16	8.08	6.75	5.59	6.73	6.81	83.35
	18	8.32	6.98	5.82	6.97	7.04	83.29
	20	8.66	7.06	5.86	7.10	7.19	82.01

Appendix 2: Determination of Moisture Content of boiled Samples

Sample variety	Boiling Time (min.)	Weight of empty dish (g)	Weight of wet sample + dish (g)	Weight of dry sample (g)	Weight of wet sample (g)	Moisture content (%)
Uyole soya-1	10	42.0778	46.1359	3.3206	4.0581	22.21
	20	26.8970	31.2443	3.4935	4.3473	25.16
	30	29.7896	34.7735	3.9480	4.9839	26.24
TGX 1895-33F	10	22.1084	26.8925	3.9943	4.7841	19.77
	20	42.4742	47.5254	4.0161	5.0512	25.77
	30	48.4245	53.9201	4.2446	5.4965	29.48

Appendix 3: Determination of Moisture Content of Soaked Samples

Sample variety	Soaking Time (Hours.)	Weight of empty dish (g)	Weight of wet sample + dish (g)	Weight of dry sample (g)	Weight of wet sample (g)	Moisture content (%)
Uyole soya-1	6	50.8783	53.4043	2.1375	2.5260	18.18
	12	56.6438	59.5048	2.3479	2.8610	21.85
TGX 1895-33F	6	48.2657	52.4375	3.50473	4.1718	18.98
	12	56.0874	59.9564	3.1485	3.8690	22.88

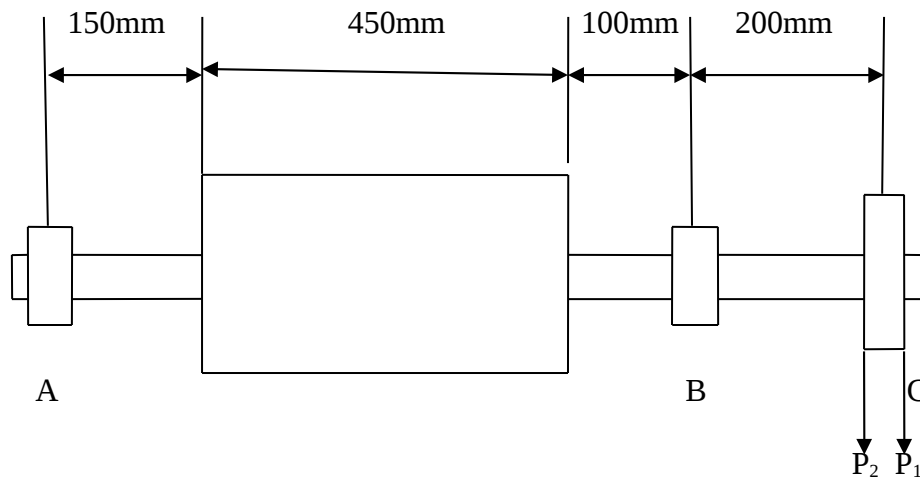
Appendix 4: Effect of Boiling Soybean Grain Samples on Dehulling

Grain variety	Boiling duration (min.)	Dehulled cotyledon (%)	Undehulled cotyledon (%)	Whole seeds (%)	Hulls (%)	Broken seeds (%)	Dehulling Efficiency (%)
Uyole	0	75.06	11.73	1.04	9.62	2.55	20.21
soya-1	10	76.40	9.05	0.95	11.97	1.63	40.91
	20	76.72	8.46	0.83	12.95	1.04	56.94
	30	80.21	5.02	0.45	13.34	0.98	70.62
TGX	0	70.34	14.95	1.27	12.19	1.25	33.99
1895-33F	10	74.75	9.87	0.93	13.31	1.14	50.25
	20	76.10	7.81	0.67	14.46	0.96	62.82
	30	77.77	5.87	0.35	15.32	0.69	72.57

Appendix 5: Effect of Soaking Duration of the Soybean Grain Samples on Dehulling

Grain variety	Soaking duration (hours)	Dehulled cotyledon (%)	Undehulled cotyledon (%)	Whole seeds (%)	Hulls (%)	Broken seeds (%)	Dehulling Efficiency (%)
Uyole	6	60.26	18.44	1.43	17.64	2.23	57.24
soya-1	12	63.25	16.33	1.18	18.14	1.10	63.58
TGX	6	60.22	17.92	1.74	18.56	1.56	54.61
1895-33F	12	61.11	16.96	1.28	19.67	0.98	65.69

Appendix 6: Determination of Shaft diameter by ASME Code



The shaft is mounted on two bearings A and B holding the dehulling drum in place.

Assume that an operator can operate the turning handle at a speed of 110 r.p.m and 0.8 kW power was used.

The tension on the shaft is assume to be $P_1 = 4P_2$

The shaft is made up of steel grade st. 50-2k. The turning handle is keyed to the shaft.

$$S_{ut} = 740 \text{ N/mm}^2 \quad S_{yt} = 390 \text{ N/mm}^2$$

$$k_t = 1.5 \quad k_b = 2$$

$$\text{Solution: } 0.30S_{yt} = 0.30 \times 390 = 117 \text{ N/mm}^2$$

$$0.18S_{sy} = 0.18 \times 740 = 133.2 \text{ N/mm}^2$$

Since there is keyways on the shaft, therefore $\tau_{\max} = 0.75 \times 117 = 87.75 \text{ N/mm}^2$

The torque transmitted by the shaft is given by:

$$M_t = \frac{60 \times 10^6 (\text{kW})}{2\pi n}$$

$$M_t = \frac{60 \times 10^6 (0.8)}{2\pi(110)} = 69,484.65 \text{ N} - \text{mm}$$

$$\text{Now, } P_1 - P_2(200) = 69,484.65$$

$$P_1 - P_2 = \frac{69,484.65}{200} = 347.4232$$

But $P_1 = 4P_2$

$$4P_2 - P_2 = 347.4232$$

$$P_2 = 347.4232/3 = 115.81\text{N}$$

$$P_1 = 4P_2$$

$$= 115.81 \times 4 = 463.24$$

$$P_1 + P_2 = 463.24 + 115.81 = 579.041\text{ N}$$

$$M_b = 579.041 \times 200 = 115,808.21\text{ N-mm}$$

The shaft diameter was calculated by:

$$d^3 = \frac{16}{\pi \tau_{max} \sqrt{(k_b M_b)^2}} + (k_t M_t)^2$$

$$d^3 = \frac{16}{\pi(87.75)\sqrt{(2 \times 115,808.21)^2}} + (1.5 \times 69,484.65)^2$$

$$d = 24.46\text{ mm}$$

Appendix 7: Physical Properties of Soybean Grains at Different Moisture Contents

Grain variety	Moisture content (% d.b.)	Axial Dimensions (mm)			Average diameters (mm)		Sphericity (%)	Surface Area (mm ²)	Bulk Density (Kg/m)	TRUE Density (Kg/m)	Porosity (%)	1000 grain weight (g)
		Length L	Width W	Thickness T	Geometric Mean (D _g)	Arithmetic Mean (D _a)						
Bossier	14	8.04 a	6.68a	5.64a	6.72	6.79	83.53	141.93	794	1129.35	26.69	169.85
		-0.55	-0.31	-0.29								
	16	8.46 b	6.94b	6.10 b	7.1	7.17	83.94	158.44	784	1119.19	29.95	184.36
		-0.51	-0.49	-0.4								
18	8.70 c	7.09 c	6.18 c	7.25	7.32	83.33	165.2	776	1112.56	30.25	191.76	
		-0.48	-0.57	-0.51								
20	9.04 d	7.24d	6.25 c	7.42	7.51	82.12	173.04	771	1107.92	30.41	211.39	
		-0.39	-0.37	-0.51								
Uyole Soya-1	14	8.23 a	6.71 a	5.79 a	6.87	6.94	83.41	148.34	782	1127.75	30.66	157.71
		-0.35	-0.3	-0.12								
	16	8.37 b	6.92b	5.99 b	7.02	7.04	83.91	154.89	772	1117.59	30.92	172.22
		-0.34	-0.09	-0.12								
18	8.49 c	7.05 c	6.19 c	7.18	7.24	84.59	162.03	764	1110.96	31.23	176.62	
		-0.31	-0.25	-0.14								
20	8.62 d	7.23d	6.23 c	7.29	7.36	84.63	167.03	758	1106.32	31.48	199.25	
		-0.33	-0.45	-0.3								

TGX 1954-1F	14	8.39 a	6.69 a	5.55 a	6.78	6.88	80.79	144.48	780	1122.17	30.49	143.53
		-0.45	-0.27	-0.42								
	16	8.51 b	6.73b	5.61 a	6.85	6.95	80.48	147.48	770	1112.01	30.76	158.04
		-0.4	-0.26	-0.26								
	18	8.65 c	6.85 a	5.72 b	6.97	7.07	80.6	152.69	761	1105.38	31.15	165.44
	-0.36	-0.26	-0.31									
	20	8.75 c	6.91 a	5.76 b	7.04	7.14	80.41	155.77	755	1100.74	31.41	185.07
		-0.33	-0.21	-0.21								
TGX 1887- 12F	14	8.25 a	6.78 a	5.53 a	6.76	6.85	81.98	143.63	745	1125.85	33.83	151.07
		-0.41	-0.18	-0.4								
	16	8.49 b	6.99b	5.76 b	6.99	7.08	82.35	153.57	735	1115.69	34.12	165.58
		-0.38	-0.14	-0.31								
	18	8.73 c	7.19 c	6.02 c	7.23	7.31	82.81	164.29	726	1109.06	34.54	172.98
	-0.4	-0.15	-0.07									
	20	8.97 d	7.29 c	6.06 c	7.35	7.44	81.88	169.79	721	1104.42	34.74	192.61
		-0.28	-0.41	-0.13								
TGX 1895- 33F	14	7.78 a	6.54 a	5.36 a	6.48	6.56	83.35	131.98	770	1088.73	29.28	162.47
		-0.31	-0.26	-0.35								
	16	8.08 b	6.75b	5.59 b	6.73	6.81	83.29	142.36	761	1078.57	29.44	176.98
		-0.35	-0.2	-0.18								
	18	8.32 c	6.98 c	5.82 c	6.97	7.04	83.72	152.69	754	1071.94	29.66	184.38
	-0.15	-0.17	-0.09									
	20	8.66 d	7.06 c	5.86 c	7.1	7.19	82.01	158.44	750	1067.3	29.73	204.01
		-0.23	-0.14	-0.09								