DESIGN AND FABRICATION OF A CENTRIFUGAL SUNFLOWER DEHULLER FOR IMPROVED SUNFLOWER OIL AND CAKE QUALITY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
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ABSTRACT

A study was conducted to examine the effect of dehulling sunflower seeds on oil extraction efficiency and cake quality. Specifically the study involved; design, fabrication and performance evaluation of a motorized centrifugal sunflower dehuller. Two sunflower seed varieties (*Record* and *Kenya Fedha*) were used in this study. The seed physical properties, machine design factors and operation conditions related to the dehulling process were studied and incorporated in the design, fabrication and performance evaluation phases of the developed centrifugal dehuller. The performance evaluation parameters of the designed dehuller included; throughput capacity, dehulling efficiency, kernel breakage and product yield. The dehuller was able to achieve a throughput capacity of 427 kg/h for *Record* variety and 513 kg/h for *Kenya Fedha* variety. Dehulling efficiency was 80 % and 79.3 %, kernel breakage was 5.6 % and 2.5 %, while product yield was 70.3 % and 66.7 % for *Record* and *Kenya Fedha* varieties respectively. Dehulling improved oil quality and increased oil yield by 15.4 % for *Record* variety and by 14.6 % for *Kenya Fedha* variety. Dehulling significantly ($p<0.05$) increased crude protein content of the cake from 29.62 % to 44.49 % for *Record* variety and from 29.31 % to 44.94 % for *Kenya Fedha* variety. Also, dehulling significantly ($p<0.05$) reduced cake crude fiber from 33.41 % to 17.71 % and ether extracts from 16.62 % to 13.86 % for *Record* variety. The corresponding reductions of crude fiber and ether extracts for *Kenya Fedha* variety were 23.93 % to 17.35 % and 11.65 % to 10.56 %, respectively. Based on these results it is concluded that the use of the improved centrifugal dehuller can successfully improve oil extraction efficiency and cake quality produced by small and medium scale oil enterprises.

DECLARATION

I, MSAFIRI ROBERT, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
AOCS	American Oil Chemists' Society
ARI	Agriculture Research Institute
ASAE	American Society of Agricultural Engineers
ASME	American Society of Mechanical Engineers
ATI	Appropriate Technology International
AWS	American Welding Association
F	Force
FAOSTAT	Food and Agriculture Organization Statistics
GenStat	General Statistics Program
IPI	Institute of Production and Innovation
ISO	International Standard Organization
LTD	Limited
MAFC	Ministry of Agriculture Food Security and Cooperatives
M	Bending moment
M10	Ten millimeter diameter bolt
M12	Twelve millimeter diameter bolt
M8	Eight millimeter diameter bolt
meq	Milliequivalent
Mt	Torsion moment
NBS	National Bureau of Statistics
NRI	Natural Research Institute

RLDC	Rural Livelihood Development Company
RUCODIA	Ruvuma Commercial and Diversification of Agriculture
STHEP	Science, Technology and Higher Education Project
SUA	Sokoine University of Agriculture
TBS	Tanzania Bureau of Standards
TCCIA	Tanzania Chamber of Commerce, Industry and Agriculture
TDTC	Technology Development and Transfer Centre
TFDA	Tanzania Food and Drugs Authority
TZS	Tanzania Standards
USDA	United State Department of Agriculture
W1000	One thousand seed weight
$\sum$	Summation symbol
α	Alpha
π	Pi
σ_b	Combined shear stress for bending and torsion moments
%	Percent
°C	Centigrade Celsius
g	Gram(s)
hp	Horsepower
kg	Kilogram(s)
kg/h	Kilogram per hour
kg/m^3	Kilogram per meter cubed
kW	Kilowatt(s)
Ltrs	Litre(s)
m/s	Meter per second

meq	Milliequivalent
mg	Milligram(s)
mm	Millimeter
mm^2	Millimeter squared
N	Newton
N/mm2	Newton per millimeter squared
N/mol	Normality per moles
N-mm	Newton - millimeter
rad/s	Radian per second
rpm	Revolution per minute
s	Second(s)
t	Ton(s)

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Sunflower (*Helianthus annuus L.)* is an annual plant native to the Americas. It possesses a large inflorescence (flowering head). Its tolerance to draught and different soil types accounts for its suitability to most areas of the world. The crop is grown on over 21 million hectares worldwide (Škoric *et al.,* 2007). In 2008-2009, world sunflower seed production was estimated at 33.3 million tons where European Union, Russia, Ukraine, Argentina, United States, China, India and Turkey were the major producers (USDA, 2010a). In the same period, Tanzania produced 8,021 tons of sunflower seeds (FAOSTAT, 2011). Sunflower varieties are separated into two major types; varieties for oil production and varieties for confectionary purposes. Oil-type sunflower varieties are black in colour with thin hulls; are rich in oil (about 40 – 50 % by weight); and are considered to be a good source of fat for human consumption due to their high ratio of polyunsaturated and saturated fatty acids and high content in linoleic acid (Ohlson, 1992; Isobe *et al.*, 1992). The oil-type sunflower varieties grow well in central and southern regions of Tanzania; where Singida and Rukwa are the leading producers with an average annual production of 45.7 and 27.1tons, respectively MAFC (2008), cited by Mpagalile *et al.* (2008).

Several methods are used for sunflower oil extraction, however, the continuous screw expeller method is the most widely used method in the world (Mrema and McNulty, 1985). According to USDA (2010b), the continuous screw expeller method is among the two major oil extraction technologies used to process sunflower in the United States. However, most extraction plants use the continuous screw expeller method followed by solvent extraction with hexane as a solvent to extract the remaining oil in the pressed cake. In Sub-Saharan Africa, the continuous screw expeller method followed by solvent extraction was first introduced and operated in Zambia, Gambia and Sudan (Panigrahi, 1995). The same oil extraction technique was found dominant in Zimbabwe for extracting oil from Soybean and sunflower (Schmidt, 1999).

In Tanzania, the continuous screw expeller method was introduced in 1990's (RUCODIA, 2007). So far this is the only method used by Small and Medium Oil Enterprises for the extraction of oil from oilseeds while the residual oil in the cake is never recovered (Kibazohi, 2004). Oilseed productions in Tanzania mainly focus on Groundnuts (40 %), Sunflower (36 %), Sesame (15 %), Cotton (8 %) and Palm (1 %). The main oilseeds used for edible vegetable oil production are sunflower seeds, cotton and palm fruit. Production of edible vegetable oil from locally grown oilseeds is estimated at 50,000 metric tons Wangwe (2002), cited by Kibazohi (2004). A research conducted in 2008 revealed that, local production of both factory and home extracted sunflower oil contributed about 40 % of the national cooking oil requirements with the remaining 60% being imported ARI Ilonga (2008), cited by EPINAV (2012). Food and Agriculture Organization (FAO) recommends a minimum annual per capita consumption of 5kg of vegetable oil (RLDC, 2008). Based on this, and with a population of 44.9 million people, Tanzanian's minimum national cooking oil requirement is estimated at 224,500 tons (NBS, 2012). Therefore, more than 50 % of edible oil used in Tanzania is imported and out of this Palm oil accounts for more than 70 % (TCCIA, 2006).

The sunflower cake produced by continuous screw expeller is considered to be of relatively poor quality due to high residual oil and crude fiber content (Ngowi, 2010). Crude fiber is a heterogeneous chemical entity that includes those carbohydrates that can not be digested by the animal and therefore do not contribute energy when consumed. High crude fiber content in the cake therefore reduces its nutritive value and digestibility. Crude fiber is predominantly associated with the seed coat or hull. The percentage of hull content in sunflower seed varies according to the cultivar, seed size and oil content. In most of the varieties the hull content varies between 22 and 28 % (Carre, 2009). Dehulling or removal of the hull is a common practice necessary to reduce the cake crude fiber content and therefore produce a cake with adequate quality for animal feed (Bell, 1989).

1.2 Justification

Among different methods used for sunflower oil extraction, continuous screw expeller method is the most commonly used by small and medium oil enterprises. Sunflower oil produced using this method is of relatively poor quality due to presence of undesirable characteristics in the oil which includes; bad odour, dark yellowish colour and high wax content which shortens the shelf life of the oil. Also, the use of sunflower cake produced by this method in livestock feeds has been limited due the high crude fiber content (Swick, 1999). Another problem related to oil extraction from undehulled seeds using continuous screw expeller method is that, high crude fiber content of the whole seeds result in increased wear and tear of the expeller cage and worm screw leading to low extraction efficiency after a short period of use; Also about 8 - 14 % of the available oil is left un-extracted in the pressed cake (Srikantha, 1980). Bamgboye and Adejumo (2007) estimated that, US$57 million worth of sunflower oil is left in the screw expeller pressed cake annually.

One method of reducing the undesirable characteristics of sunflower oil, increasing oil extraction efficiency and improve the quality of cake produced by screw expeller method is to remove the hull from the sunflower seeds before oil extraction by dehulling process. Dehulling is a process of removing hulls or seed coat from seeds to obtain hull free kernels. For sunflower seeds, the process increases oil extraction efficiency, throughput capacity and also reduces wear and tear of the extraction equipment. Literature shows that up to 93.6 % of the sunflower seed oil can be recovered on mechanical expression of dehulled sunflower seed compared to 33 % of undehulled seed (Isobe *et al.*, 1992 and Shukla *et al.*, 1992). The process also reduces the crude fiber content of the cake by 13 %, there by increasing its nutrient value and marketability as livestock feed (Swick, 1999; Ngowi, 2010).

Dehulling of sunflower seed can be accomplished either traditionally using mortar and pestle or mechanically using abrasive, compressive or centrifugal dehullers. The traditional method is laborious and time-consuming. On the other hand, abrasive dehulling is faster and less tedious compared to traditional dehulling, but it causes excessive losses of cotyledon in the hull fraction due to excessive kernel breakage. Compressive dehullers have high dehulling efficiency on confectionary sunflower seed but inefficient in dehulling of the oil-type sunflower seed. The current centrifugal dehullers are the most efficient and are extensively used in large scale oil production. However they are highly expensive and need highly skilled labour to operate. These factors make them unsuitable for small and medium scale oil enterprises here in Tanzania. Hence the need to design and develop a simple and affordable centrifugal dehuller that can lead to improved dehulling of the sunflower seed and reduce the hardship and problems involved in the traditional dehulling and other mechanical methods.

The need for a simple dehulling technology for sunflower seeds in Tanzania was recognized earlier by the Institute of Production Innovation (IPI) of the University of Dar es Salaam. In 1982, they produced a combined hand operated sunflower seed dehuller and winnower (GTZ, 1989). However, this dehuller was very inefficient, labour intensive and susceptible to frequent break downs. These problems resulted in low adoption of the dehuller and eventually it was abandoned in the late 1980s. The current project therefore is a continuation of the effort started by the IPI to improve the sunflower seed dehuller which will be more efficient and less labour intensive for the use by small and medium scale sunflower oil enterprises in Tanzania.

1.3 Objectives of the Study

1.3.1 Main objective

The main objective of this study was to design, fabricate and evaluate the performance of an improved centrifugal sunflower seed dehuller for improved oil extraction efficiency and cake quality.

1.3.2 Specific objectives

(i) To design and fabricate an improved motorized centrifugal sunflower dehuller

(ii) To evaluate the performance of the improved centrifugal sunflower dehuller

(iii) To determine the quality of the crude sunflower oil produced from dehulled sunflower seed and compare with the oil quality from undehulled sunflower seeds

(iv) To determine chemical composition of cake produced from dehulled sunflower seeds and compare with cake from undehulled sunflower seeds

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General Overview

This chapter reviews the history of sunflower and its current production status in Tanzania, sunflower dehulling methods, design factors, operating conditions and seed characteristics related to design of centrifugal sunflower dehuller. This is followed by a review of the contribution of sunflower oil processing to national edible oil requirements and the parameters influencing quality of both sunflower crude oil and cake.

2.2 Sunflower Historical Review

Sunflower (*Helianthus annuus L*) is widely believed to have originated from America. It was reported to be present in Arizona and New Mexico 3,000 years Before Christ (B.C) (Schneiter, 1997). Some archeologists suggest that sunflower may have been domesticated before corn. The Spanish explorer Monardes brought the plant to Europe in 1569. However, it was not until the eighteenth century that sunflower seeds were used as oil source. In the years 1682-1725 Tsar Peter the Great brought the plant from Europe to Russia where the most important development took place in the use of sunflower as both food and oil source (Grompone, 2005).

In Tanzania, sunflower was introduced during colonial times and it was found to grow in almost all parts of the country. The crop grows in warm to moderate semi-arid climatic conditions and adapts to a wide variety of soils hence its popularity in the Eastern, Central, Northern and Southern Highlands of Tanzania. A study by Rural Livelihood Development Company (RLDC) in 2008 revealed that, sunflower was predominantly produced by small scale farmers with one to three acres; however, there were also medium and large scale farmers with more than a thousand acres of sunflower. It further revealed that, the ups and downs in the production figures in Fig.1 might have been atributed to the use of poor quality sunflower seeds, lack of improved agronomic practices and fungus diseases related to the use of recycled seeds. Fig.1 shows sunflower production in Tanzania during the cropping season from 2000/01 to 2004/05. Production of sunflower seeds increased from 80.87 tones in the year 2000/01 to 134.36 tones in the year 2004/05.

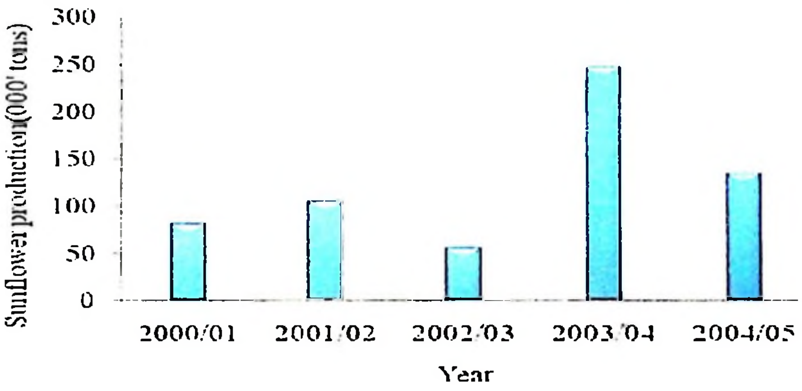

Figure 1: Annual sunflower production in Tanzania during 2000/01 - 2004/05 cropping season

Source: Ministry of Agriculture, Food and Cooperative (2008), cited by Mpagalile *et al.*, (2008).

2.3 Sunflower Dehulling Methods

There are several sunflower dehulling methods, which are practiced by small scale and large scale processors. These include traditional methods and mechanical methods.

2.3.1 Traditional dehulling methods

Shukla *et al.* (1992) reported that, traditionally sunflower seeds were dehulled manually using bare hands. Another method involved pounding of sunflower seeds in a mortar with pestle repetitively and then manually winnowed (NRI, 1995). According to Sanni (1993), one of the greatest challenges facing food scientists in Africa today is the upgrading of the traditional food processing and preservation technologies. In most cases, the traditional methods of food processing and preservation in Tanzania remain at the empirical level. These processes are often laborious and time consuming and invariably the quality of the products require substantial improvements.

2.3.2 Mechanical dehulling methods

Numerous methods of varying sophistication exist for mechanical dehulling of sunflower seeds. In some cases, the seed hulls are removed in small commercial or home-scale operations by abrasion and shearing using disk mill or bar mill and the hulls are then removed by winnowing (Shukla *et al.*, 1992). Commercial or power operated dehullers are more sophisticated, involving shaker separators with suitable mesh screens and cyclone separators. These dehullers operate on different working principles including compression/decompression, and impact (Carre, 2009; Hernandez and Belles, 2007; Dunford, 1993; Shukla *et al.*, 1992). Depending on configuration, efficiency can be optimized in these dehullers by adjusting factors such as impact force, impeller diameter, impact angle, texture and clearance between the dehulling surfaces. Seed moisture content, genotype, and size are also important factors affecting dehulling efficiency.

2.3.2.1 Compression and decompression dehullers

The principle of this dehuller is to place the sunflower seed in a tight chamber in which compressed air is introduced. Once the pressure is stable, a brutal decompression is provoked enabling the compresed air on meats and hulls to expand suddenly resulting in cracking and removal of the hulls. This dehuller has high dehulling efficiency on confectionary sunflower seeds but inefficient, in dehulling and energy consumption in oil-type sunflower seeds (Carre, 2009).

2.3.2.2 Abrasive dehullers

Abrasive dehullers employ horizontally or vertically mounted abrasive disks. Abrasive techniques are generally applied to mills in which the dehulling takes place between two emery discs rotating in a horizontal or vertical plane. The two emery disks, with one disk stationary and the other rotating, provide the dehulling action in the mill. The clearance between the two disks can be varied depending on the seed size and shape. The size variability and flattened shape of sunflower seed presents an inherent difficulty for complete dehulling of the seed using abrasive type dehullers as considerable proportion of seed escapes undehulled (Shukla *et al.,* 1992).

2.3.2.2.1 The IPI dehuller

The IPI dehuller (Fig. 2), which was operated by a single person, consisted of ten main parts. These included the decorticator hopper and winnower hopper, winnowing attachment which is removable, chaff (hulls) and kernels outlets, feed gate, impeller casing for hulling (with two emery disks), the gear box, a handle mounted on large gear and the main frame (metal stand).

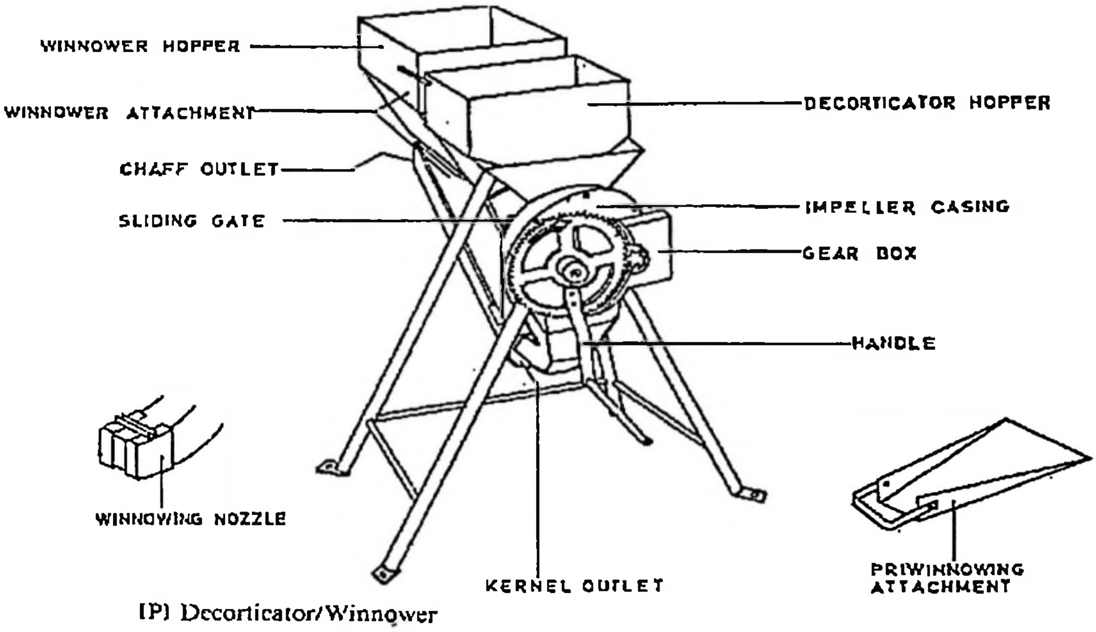

Figure 2: IPI dehuller/winnower

Source: GTZ (1989)

During operation, specific quantity of sunflower seeds are poured into the dehuller hopper manually after which the operator rotates the emery disk about its horizontal axis through shaft connected to the handle with the aid of gear box. The seeds are hulled due to abrasive and shearing action as they pass through a small clearance provided between the two emery disks; one rotating and one stationary. The kernels, hulls, non-dehulled and broken seeds are discharged through the outlet chute. The collected mixture is then fed into the winnower hopper manually for the separation operation. The major problems with this dehuller were; it was very laborious to operate, very inefficient and susceptible to frequent break downs these problems resulted in its low adoption and eventually died a natural death in the late 1985 (Hyman, 1991).

As a result of the problems with the IPI technology, Carl Bielenberg, an engineer with Appropriate Technology International (ATI), invented a manual operated ram press that does not require use of any auxiliary equipment in the late 1985. By mid-1986 there was a switch from IPI technology to ram press which seems appropriate for village oil extraction (Hyman, 1991).

2.3.2.3 Impact dehullers / Centrifugal dehullers

The centrifugal type dehullers dehull sunflower seeds on the principle of centrifugal action. The seeds move outward along a groove on the spinning disk due to centrifugal force and are discharged at high velocity and strike against a concentric stationary ring at a certain angle and then slide along the ring. The resulting impact causes the seed coat to open and the shearing action on the stationary outer ring strips off the seed coat; in this process, the cotyledons get freed (Nag *et al.*, 1983; Subramanian *et al.*, 1990). The seed motion depends on its shape, coefficient of friction between the seed and the groove/vanes material of construction, and the shape of the impeller (Das and Gupta, 2005).

2.4 Design Factors Related to Centrifugal Dehuller

Effect of construction material, impact angle, impeller diameter, number of vanes and angulations are among several design factors which influence the centrifugal dehulling process and therefore need to be considered during design phase of a centrifugal dehuller.

2.4.1 Effect of construction materials for the centrifugal dehuller

The most important component of the centrifugal dehuller is the impeller. Various construction materials can be used for impeller design which includes wood, plastics and sheet metals. All these construction materials have different coefficient of dynamic friction. Lower coefficient of dynamic friction was found to be associated with high impact force leading to higher hulling efficiency (Joshi *et al.*, 1993). Therefore, construction materials for the impeller should have as low coefficient of dynamic friction as possible.

2.4.2 Impact angle

Impact angle refers to the degree of inclination of the surface of the impact ring to the impeller groove seed exit point. Small impact angle has higher shearing action leading to high removal of the seed hull with minimum seed breakage. More seed breakage was found to be associated with large impact angle and high discharge velocity of the seed resulting into rebounce on the impact ring thus leading to further fragmentation (Khodabakhshian and Bayati, 2011).

2.4.3 Impeller diameter

Egbuta and Uyah (2003) in a 2^3 factorial experiment found that, with a high speed and small diameter impeller, the number of shelled but broken seeds was five times greater than with a low speed and large impeller diameter. Also, the force of impact between the seed and the impact ring was found to be affected by the impeller radius (Okokon *et al.*, 2007).

2.4.4 Vanes number and angulations

Vanes (slots) refers to a hollow section or groove channels on the impeller, which are used to guide the seeds during dehulling process. Number of vanes on the impeller may range from two to eight and take different angulations such as 30° or 45° or 90° from the center to edge of the impeller (Makanjuola, 1975; Odigboh, 1979; Oluwole *et al.*, 2004). Oluwole *et al.* (2007) found that, radial vane impellers have higher dehulling efficiency compared to other vanes / impeller angulations. It was further observed that low vane number on the impeller was associated with low dehulling efficiency and high kernel breakage. High vane number on the impeller was associated with high dehulling efficiency and low kernels breakage due to more seed exit points hence well distributed impact force that allows higher number of seeds to hit the impact ring with the required impact energy.

2.5 Machine Operation Condition Related to Centrifugal Dehuller

Impeller speed and feed rate are among the operating conditions that have significant effect on the performance of the centrifugal dehuller (Mieszkalski *et al.*, 1994). Seeds vary in their morphological and physical features, and therefore the design of hulling machines and their principal of operation also vary accordingly (Laskowski *et al.*, 1994 and Mieszkalski *et al.*, 1994).

2.5.1 Impeller speed, feed rate and seed moisture content

Subramanian *et al.* (1990) and Gupta and Das (1999) found that the performance of centrifugal dehuller for sunflower seeds was influenced by moisture content, impeller speed and feed rate. Also dehulling efficiency and non-recoverable kernel fraction were found to increase with increase in impeller speed, decrease in feed rate and decrease in the seed moisture content.

2.6 Sunflower Seed Characteristics Related to Centrifugal Dehulling

Seed size, genotype, moisture content, and oil content are among the sunflower seeds physical properties that are important in designing centrifugal dehuller.

2.6.1 Seed moisture content

Seed moisture content is the amount of water in the seed and is usually expressed as a percentage on wet basis. Seed moisture content influences physical properties of a seed such as weight, density, refractive index, electrical conductivity and many more. At low moisture levels sunflower seed tissues within the pericarps are not flexible. This makes them susceptible to mechanical damage (Mieszkalski, 1997). Low moisture levels give almost complete dehulling but high kernel breakage while high moisture levels give low kernel breakage and lower levels of dehulling (Sallans and Sinclair, 1945).

2.6.2 Seed size

Sunflower seeds vary in their morphological and physical features and this affect the dehulling process. Therefore, the knowledge of the physical properties of seeds before processing is necessary in the rational design of dehuller (Mieszkalski, 1997). This was also supported by Subramanian *et al.* (1990) and Das and Gupta (2005) when they observed that, dehulling efficiency increases as the size of the sunflower seed increases, which attribute to the higher magnitude centrifugal impact on the sunflower seeds.

2.6.3 Seed variety

According to Baldini *et al.* (1996), seed variety is the main source of the variation in seed physical characteristics and hence dehulling ability. In their investigation on the dehulling efficiency of different seed varieties, they found that some variety traits, such as the length of the period from emergence to flowering and from flowering to physiological maturity, correlate with seed physical characteristics and dehulling ability.

2.6.4 Seed oil content

The general finding of several researchers shows that high seed oil content was associated with lower dehulling efficiency (Dedio and Dorrell, 1989; Beauguillaume and Cadeac, 1992; Dedio, 1993; Denis *et al.*, 1994; Denis and Vear, 1996). However, Baldini and Vannozzi (1996) found that this negative relationship is not universal since the cultivar Euroflor, in contrast with other cultivars, has high oil content and a high dehulling efficiency.

2.7 Sunflower Oil Processing

Since the ancient times people have made use of the oils obtained from oilseeds. Various small-scale techniques such as powered expellers, manual or animal-powered mechanical presses, and simple procedures using water have been used to extract oil from oil bearing seeds (NRI, 1995). The oilseeds available in Tanzania include groundnuts, cotton, sesame, sunflower, palm fruits and palm kernel, and castor. Oilseeds production focuses mainly on groundnuts 40 %, sunflower 36 %, sesame 15 %, cotton 8 % and palm 1 % (RLDC, 2008). However, while there is a large production of oilseeds such as groundnuts, sesame and palm oil, there has been no substantial oil production from these seeds, thus making sunflower oil the most important vegetable oil produced in Tanzania. Also a fall of cotton production and hence cotton oil, has led to increase in oil demand from other sources such as sunflower (TCCIA, 2006). Fig. 3 shows sunflower oil production during the 1999/2000-2006/2007 cropping seasons. Oil production increased from 11 560 tons in the year 1999/2000 to 88 753 tons in the year 2006/2007.

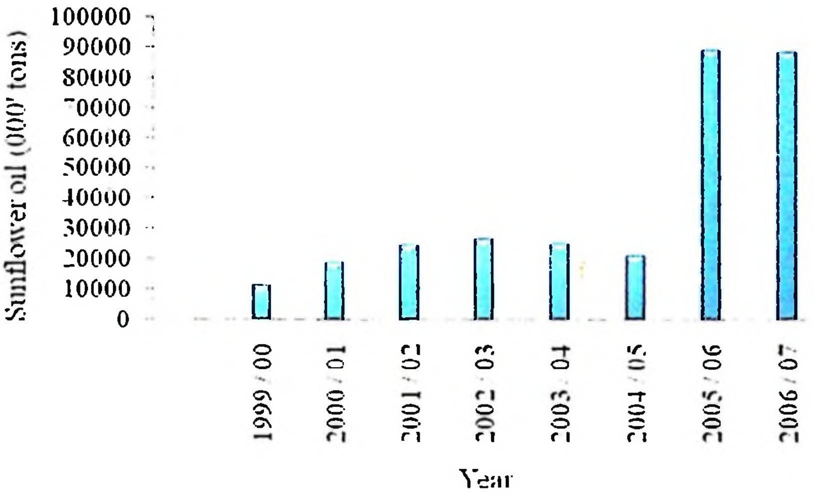

Figure 3: Annual sunflower oil production during the 1999/00-2006/07 cropping season

Source: RLDC (2008)

2.8 Parameters Influencing Sunflower Oil Quality

Initially oil quality was measured primarily based on free fatty acid composition (Knowles, 1983; Rondanini *et al.*, 2003). However, more recently other quality indicators of vegetable oils that influence their nutritional and technological properties are being emphasized by oil chemists and nutritionists (Fernandez-Martinez *et al.*, 2007). These include refractive index, relative density, saponification value, iodine value, peroxide value, acid value, colour and unsaponifiable matter (TBS, 2011).

2.8.1 Refractive index

The refractive index is among characteristic property of oil commonly used as quality indicator for edible oils. Refractive index measures the change in unsaturation as the fat or oil is hydrogenated. The refractive index of oils depends on their molecular weight, (Nichols and Sanderson, 2002). The determination of the refractive index can be done using Abbe Refractometer following the procedure of Cocks and van Rede (1997).

2.8.2 Relative density

The term relative density means oil density in comparison to that of water. Relative density plays major role during oil transportation because at high temperature, density decreases and volume increases (thermal dilatation), which may lead to bursting of the oil containers. Relative density can be determined following reference method according to TZS 1328: 2010 (TBS, 2011).

2.8.3 Saponification value

Saponification value is an important indicator that determines whether the oil can be used for soap making or not (Abitogun *et al.*, 2009). Saponification value measures the alkali-reactive groups in oil and is defined as the milligram of potassium hydroxide (mg of KOH) needed to saponify 1 gram of oil. Saponification value can be determined according to procedure of Jayaraman (1985).

2.8.4 Iodine value

Iodine value refers to a simple chemical constant for oil. Iodine value is defined as the number of grams of iodine that could be added to 100 gram of oil for measuring unsaturation or the average number of double bonds in oil which in turn determines the degree of flow of oil. The iodine value can be determined using Wijs method (Bockisch, 1998).

2.8.5 Peroxide value

Peroxide value (PV) is the measurement of lipid oxidation. Hydro peroxides have no flavour or odour of their own, but they are unstable and break down rapidly to other products such as aldehydes that have a strong, disagreeable flavour and odour. Peroxide value as a measure of the weight (mg) of active oxygen contained in gram of oil can be determined using the AOAC method as described by Horwitz (1975).

2.8.6 Acid value

Acid value is another common parameter in the identification of the oil. It denotes the content of free fatty acids in the oil, which causes the oil to turn rancid. Oil that is low in acidity is suitable for consumption (Alabi, 1993). Acid value (AV) is a measure of the content of free fatty acids in the oil and can be determined titrimetrically (ISO, 1996).

2.8.7 Free fatty acids

Free fatty acid is among the characteristic that are important for confirmation of the identity and edibility of the oil. Hydrolytic processes cause formation of free fatty acids, which split acylglycerols that affect flavour of the oil. Free fatty acids are normally calculated as free oleic acids on a percentage bases (AOCS, 1990).

2.8.8 Colour

The colour of the oil is an important quality factor for the processors as well as for end users. The color of the oil depends on several factors such as presence of fat soluble pigments such as carotenoids and chlorophyll or due to oxidation and polymerization products of the fatty acids (Shukla *et al.*, 1992). Oil colour can be determined using Lovibond tintometer (Hamilton and Cast, 1999).

2.8.9 Unsaponifiable matter

A small fraction of phospholipids, tocopherols and sterols are commonly referred to as the unsaponifiable matter. Unsaponifiable matter is responsible in lowering cholesterol levels therefore the higher the level of this fraction the better the oil (Dutta, 2004). The level of unsaponifiable matter in the oil can be determined using method of diethyl ether extraction (TBS, 2011).

2.8.10 Odour and Flavour

Flavour and odour of oil are the most important indicators of quality and acceptability of oil. Oil with poor taste and odour will be quickly rejected by consumers. Oxidative stability of edible oils depends primarily on their free fatty acid composition and to a lesser extent, on the stereospecific distribution of free fatty acids in the triacylglycerol molecules. Oxidation process in the oil may be due to autoxidation, photo-oxidation, thermal oxidation, and hydrolytic processes, all of which lead to production of undesirable flavour, odour and products harmful to human health. The flavour and odour defects in the oil may be detected by sensory analysis or chemical and instrumental methods (Perkins, 1992).

2.9 Sunflower Oil Quality

Sunflower crude oil produced by small and medium oil enterprise do not meet Tanzania Bureau of Standards (TBS) quality standard for raw sunflower oil because it is just filtered to remove particles, sediments and foreign matters, while retaining high wax, odour and colour compounds. According to TBS and Tanzania Food and Drugs Authority (TFDA), physico-chemical characteristics of edible sunflower oil suitable for human consumption should have specifications shown in Table 1:

Table 1: TBS Standards/TFDA (TZS 50:2011) for sunflower seed oil

RI At 40 °C	RD 20 °C	SV mg KOH /g oil	IV (Wijs)	Peroxide meqO_2/kg	Acid value (mg OH)/ g oil	Colour	UV %
1.464-1.480	0.918-0.923	188-194	110-143	≤ 10	≤ 3	≤ 20	≤ 1.5

RI = refractive index, RD = relative density, SV = saponification value, IV = iodine value, UV = unsaponifiable matter value and KOH = Potassium Hydroxide.

2.10 Sunflower Cake Quality

Sunflower cake is the residual solid matter left after oil extraction from dehulled or undehulled sunflower seeds. The nutritive composition of sunflower cake varies according to the quality of the seed and the pre-treatment it under goes prior to oil extraction (Swick, 1999). The amount of hulls or fibers in the sunflower cake is the major sources of variation in nutrient content (Hesley, 1994). Research conducted by Jagadi *et al.* (1987) found that sunflower cake from Small and Medium Oil Enterprises has proximate composition as shown in Table 2. Utilization of this cake as feed or feed blend for non-ruminant animals, poultry and fish is limited due low crude protein content and high crude fiber content (Swick, 1999). According to Food and Agriculture Organization (FAO), proximate composition of good quality sunflower cake suitable for non ruminant animals and poultry should have specification as shown in Table 3.

Table 2: Proximate composition of sunflower whole seed cake

Crude protein (%)	Crude fiber (%)	Ether extract (%)	Dry matter (%)	Ash (%)	Nitrogen (%)
27.6	35.2	9.4	93.3	3.7	24.1

Source: Jagadi *et al.* (1987)

Table 3: Recommended proximate composition of sunflower cake for monogastric

Crude protein (%)	Crude fiber (%)	Ether extract (%)	Dry matter (%)	Ash (%)	Nitrogen (%)
34.1	13.2	14.3	91.0	6.6	31.8

Source: FAO (2012)

CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 Materials

3.1.1 Determination of Physical Properties of Sunflower

Two sunflower seed varieties, *Record* and *Kenya Fedha* were used in this study. The varieties were procured from Ilonga Agricultural Research Institute-Kilosa. Before performing any test, the samples were cleaned to remove foreign materials, dust, broken seeds and chaff. Also the initial seed moisture content was determined by oven drying of representative samples at 130 °C for 3hours (ASAE, 1999).

3.1.2 Equipment

The following equipments were used: Hot air oven (Model Shenstone, Philip Harris LTD England) for determining moisture content, electronic balance (Model AC 211S Sartorius) for determining the weight of the seeds and a micrometer screw gauge for seed dimension determination.

3.2 Methods

3.2.1 Moisture content determination

Oven drying method was used to determine the moisture content of sunflower seeds. Empty moisture content containers along with their covers were weighed. The sunflower seeds were thoroughly mixed and 10 gram sample from each seed variety was weighed directly into the moisture content containers. After weighing, the covers of the containers were removed and the open containers put in the oven at 130°C for 3 hrs (ASAE, 1999). At the end of the drying period, the containers were closed while still hot and then kept in a desiccator to allow the samples to cool. After cooling samples were weighed again and the moisture contents of both varieties were calculated using the following formula:

$$M_c = \left(\frac{W_2 - W_3}{W_2 - W_1}\right) \times 100 \qquad (1)$$

Where:

M_c = seed moisture content (%)

W_1 = weight of the empty container with its cover (g)

W_2 = weight of the container with its cover and seeds before drying (g)

W_3 = weight of the container with its cover and seeds after drying (g)

3.2.2 Angle of repose

Sunflower seeds were freely poured on a level surface to form a conical shaped pile. The height (H) and diameter (D) of the pile were then measured using a straight edge and a tape measure. From the values of H and D obtained, the angle of repose was calculated using the following formula (Ozarslan, 2002).

$$A_r = \tan^{-1}\left(\frac{H}{D}\right) \qquad (2)$$

Where:

A_r = angle of repose

H = height of sunflower seed pile (cm)

D = diameter of sunflower seeds pile (cm)

The procedure was replicated five times and the average value was taken as the angle of repose for the sunflower seed.

3.2.3 Seed dimensions

The seed dimensions were obtained by determining the seeds three principal dimensions, length (L), width (W) and thickness (T). To determine these seed dimensions, twenty sunflower seed kernels were picked at random from the main sample. For each seed kernel, the three principal dimensions (L, W, and T) were measured as accurate as possible using a micrometer screw gauge (reading to 0.01 mm). All the measurements for the twenty seeds were added together and the average length, width and thickness of the sunflower seeds was determined by dividing each dimension total by 20. The principal dimensions were then used to calculate the arithmetic mean diameter, geometrical mean diameter, spherecity and surface area of the sunflower seeds; parameters which are necessary for the design of the sunflower dehuller.

3.2.4 Average seed diameter

The average diameter of the seeds was calculated by using the arithmetic mean diameter (D_a) and the geometric mean diameter (D_g) of the seed. The arithmetic mean diameter D_a of the seeds was calculated by using the following relationship (Mohsenin, 1986).

$$D_a = \left(\frac{L \times W \times T}{3}\right) \dots\dots\dots\dots \tag{3}$$

Where:

D_a = arithmetic mean diameter (mm)

L = length (mm)

W = width (mm)

T = thickness (mm)

The geometric mean diameter (D_g) of the individual seed kernel was calculated using the following equation (Gupta and Das, 1997):

$D_g = (L \times W \times T)^{1/3}$ .... (4)

Where:

D_g = geometric mean diameter (mm)

L = length of the seed (mm)

W = width of seed (mm)

L = thickness of the seed (mm)

3.2.5 Sphericity (Φ)

Sphericity, which refers to how close the seed kernels shape approaches a sphere was calculated using the following equation (Gupta and Das, 1997):

$\Phi = \left(\frac{(L\times W\times T)^{1/3}}{3}\right) \times 100$ ....(5)

Where:

Φ = sphericity (%)

$(LWT)^{1/3}$ = geometric mean diameter (mm)

3.2.6 Surface area (S)

The surface area of sunflower seed was calculated using the following equation (Sacilik *et al.*, 2003; Altuntas *et al.*, 2005):

$S = (\pi \times D_g^2)$ .... (6)

Where:

S = surface area in $(mm)^2$

D_g = geometric mean diameter (mm)

3.2.7 True density (ρ_t)

The true density of the seed which is the ratio between the mass and the true volume of the seeds was determined using the toluene (C_7H_8) displacement method as described by Baryeh (2001). One 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 0.001 g. 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):

$$\rho_t = \left(\frac{M_a}{V_s}\right) \qquad (7)$$

Where:

ρ_t = true density (kg/m^3)

M_a = mass of air dry sample (kg)

V_s = volume of sample (m^3)

3.2.8 Bulk density (ρ_b)

The bulk density was determined using the mass to volume relationship as described by Ghasemi *et al.* (2008). An empty plastic container of predetermined volume was filled by pouring the seeds from a constant height until the container overflowed. Excess seeds were removed by striking off using a straight edge. The container was then weighed using a precision electronic balance (reading to 0.01 g accuracy). The procedure was replicated three times and the bulk density was calculated using the following equation:

$$\rho_b = \left(\frac{M_2 - M_1}{V_C}\right) \quad (8)$$

Where:

ρ_b = bulk density (kg/m^3)

M_1 = mass of empty container (kg)

M_2 = mass of container with sunflower seeds (kg)

V_C = volume of container (m^3)

3.2.9 Porosity (ε)

Porosity refers to the percentage of volume of voids in the seed sample at given moisture content. This was calculated from the following relationship (Mohsenin, 1970).

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad (9)$$

Where:

ε = porosity in (%)

ρ_b = bulk density in (kg/m^3)

ρ_t = true density in (kg/m^3)

3.2.10 One thousand seed weight (W_{1000})

The one thousand seed weight was determined by counting 100 seeds and weighing them using a precision electronic balance and then multiplying the figure obtained by 10 to give the weight of 1000 seeds of each sunflower variety. This was replicated 10 times.

CHAPTER FOUR

4.0 DESIGN OF THE CENTRIFUGAL SUNFLOWER DEHULLER

4.1 Design Considerations

The criteria for material selection for the various structural components of the dehuller was based on the type of forces that would be acting on these components; the work they were expected to perform, the environmental condition in which they will be functioning, their cost, chemical nature of the materials and their availability in the local market.

4.2 Selection of the V-belt from Gates Rubber Company Design Manual

Among the flexible machine elements, v-belt drives have widest industrial application due to their ability in overcoming slippage and misalignment during operation. The v-belts for dehuller were selected according to the design manual published by the Gates Rubber Company (GRC) (1976).

4.2.1 Dehuller power requirement

The power requirement for running the dehuller is divided into two parts; (1) power required for dehulling and (2) design power (power required for driving pulleys).

Power required for dehulling was obtained from the following equation:

$$P_d = \left(\frac{F \times 2\pi r \times N}{60 \times 60}\right) \quad \ldots\ldots (10)$$

Where:

P_d = dehulling power (W)

F = weight of impeller, shaft and driven pulley (N)

r = impeller radius (m)

N = impeller speed (rpm)

Using the above equation and the total weight of impeller, shaft and driven pulley (580 N), impeller radius (0.3 m) and impeller speed of 2890 rpm selected from a range of (477 – 4600 rpm) for dehulling sunflower seeds (Hernandez and Bells, 2007; Das and Gupta, 2005; IDRC, 1998) the dehulling power was found to be 2930 W.

The design power was calculated by multiply the dehulling power by service factor. Service factor refer to a multiplier that is applied to the dehulling power required to determine a conservative minimum design power for v-belts selection. A service factor of 1.4 for the dehulling power was obtained from the GRC design manual and the design power was evaluated follows:

$$\begin{aligned}\text{Design power} &= \text{dehulling power} \times \text{service factor}\\ &= 2930\ \text{W} \times 1.4\\ &= 4.102\ \text{kW}\end{aligned}$$

4.2.2 Selection of the proper v-belt

Two pulleys were required to transmit power between the motor and the driven shaft. V-belt drives are recommended for power trains that operate at high speeds and drives that have shock loads. Therefore, by using GRC design manual, V-belt (B) section was selected for a 4.102 kW motor running at 2890 rpm.

4.2.3 Determination of speed ratio

The dehuller was designed to run in three different speeds of 2890, 1445 and 963 rpm in order to determine the most appropriate impeller speed that will produce enough impact force against the mild steel lined walls of the dehuller chamber to dehull the sunflower seeds. The speed ratio between the pulleys was therefore determined using the ratio of the motor shaft speed (rpm) to that of the driven shaft speed (rpm) of the dehuller.

Speed ratios for the three pulleys were then calculated as follows:

$$\text{Speed ratio} = \frac{\text{rpm of motor pulley}}{\text{rpm of dehuller pulley}}$$

$$\text{Speed ratio one} = \frac{2890}{2890} = 1$$

$$\text{Speed ratio two} = \frac{2890}{1445} = 2$$

$$\text{Speed ratio three} = \frac{2890}{963} = 3$$

4.2.4 Determination of driven shaft pulleys diameter

By using GRC design manual recommended sheave diameter, 78 mm diameter pulley was selected for the speed ratio one. The equivalent diameter for speed ratio one, speed ratio two and three were calculated using the following relation:

Speed ratio 1: pulley equivalent diameter = 78 mm × 1

= 78 mm

Speed ratio 2: pulley equivalent diameter = 78 mm × 2

= 156 mm

Speed ratio 3: pulley equivalent diameter = 78 mm × 3

= 234 mm

4.2.5 Determination of pulleys center distance

The center distance between drive pulley and driven pulley refer to a linear distance between centers of the two pulleys. The center distance was calculated using the following equation:

$$\mathbf{C} = \left(\frac{\mathbf{D+d}}{\mathbf{2}}\right) + \mathbf{d} \qquad \text{(11)}$$

Where:

C = center distance between pulleys (mm)

D = datum diameter of large pulley (mm)

d = datum diameter of small pulley (mm)

The center distance values calculated were 156 mm for the smallest driven pulley, 195 mm for medium driven pulley and 234 mm for largest driven pulley.

4.2.6 Determination of the v-belt length

V-belts have trapezoidal cross section and do not have any joints hence are manufactured only for certain standard lengths. The calculations of v-belt length are based on pitch diameter. Also, the v-belt lengths are designated using inside length. V-belt inside length was calculated using the following equation:

$$I_S = \left\{2C_1 + \left[\frac{(D+d)}{2}\right] + \frac{(D-d)^2}{4C_1}\right\} - X \quad \text{...(12)}$$

Where:

I_s = inside length (mm)

C_l = largest center distance (mm)

X = length difference (mm)

Length difference refers to the difference between belt pitch length position and belt inside length position and was 46 mm for B section v-belt (obtained from GRC design manual). However, the center distance for the largest driven pulley was used in the calculation of v-belt inside length for all driven pulleys because it allows space for adjustments during speed ratio selection. From the GRC design manual; v-belt number B26, B31and B36 were selected for speed ratio one, speed ratio two and speed ratio three, respectively.

4.3 Shaft Design

A shaft is a rotating member usually of circular cross section (solid or hollow), which supports elements such as pulleys (sheaves), gears, flywheels, clutches, and sprockets for transmitting power and rotational motion. The dehuller shaft transmits power through pulleys and belts. Therefore, it was considered to be subjected to torsional stress and bending stress. The dehuller shaft was designed using the expected torque to be transmitted and bending moments which will be experienced during operation.

4.3.1 Torque acting on the shaft

Torque (torsional moment) is the tendency of force to rotate the shaft about an axis. The power from motor is transmitted to the driven shaft through torque created by belts and pulley. The torque acting on the driven shaft was calculated using the following equation;

$$T_r = \left(\frac{P_t}{2\times\pi\times N}\right) \qquad (13)$$

Where:

T_r = torque acting on the shaft (N-mm)

P_t = power transmitted (4.102 kW)

N = pulley rotation for speed ratio three (963 rpm)

Pulley rotation for speed ratio three was used in the design calculation because it produces the largest torque on the driven shaft compared to other speed ratios. However, the torque acting on the shaft was calculated and found to be 40.68×10^{3} N-mm.

4.3.2 Forces exerted on the driven shaft

The mode of transmitting power from motor to driven shaft consisted of keyed pulleys and belts. Therefore, both sides of each belt were expected to experience tension as shown in Fig. 4 and 5:

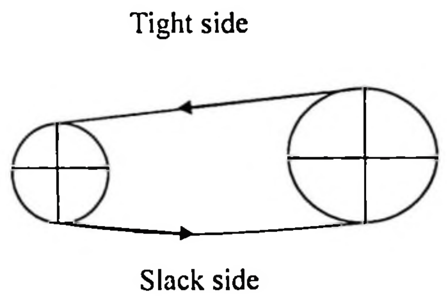

Figure 4: Tight side and slack side

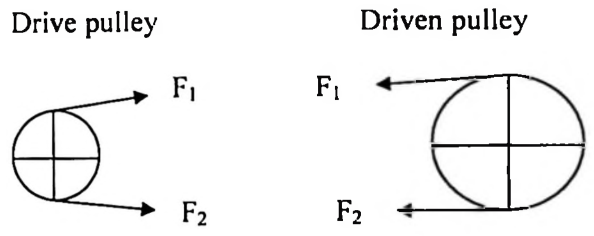

Figure 5: Forces exerted by the belt on pulleys

The net force, F_N exerted by belt on the shaft was determined using following equation:

$F_N = (F_1 - F_2)$ .... (14)

Where:

F_N = net force (N)

F_1 = tight side tension (N)

F_2 = slack side tension (N)

The magnitude of the net driving force was computed from the torque acting on the driven shaft using the following equation (Cornish, 1991).

$F_N = \left(\frac{M_t}{R}\right)$ .... (15)

Where:

F_N = net force (N)

M_t = torsional moment acting on the shaft (N-mm)

R = radius of driven shaft pulley (mm)

Then by combining equations (14) and (15) the equation for finding torsional moment acting on the shaft was obtained as shown below.

$M_t = R(F_1 - F_2)$ .... (16)

The values of tension on tight and slack sides were computed by equating the value of torque transmitted (40.68×10^3 N-mm) with equation (16).

By taking the 117 mm radius of driven shaft pulley for speed ratio three, the values of the tensions were calculated as follows:

$$M_t = R(F_1 - F_2) = 40.68\times10^3 \text{ N-mm}$$

$$F_1 = 521.54 \text{ N and } F_2 = 173.84 \text{ N}$$

Then, belt tension experienced by the driven shaft was found by summing up both tensions of tight and slack side of the belt.

$$\text{Belt tension} = F_1 + F_2$$

$$= 173.84\ \text{N} + 521.54\ \text{N}$$

$$\text{Total belt tension on driven shaft} = 695.38\ \text{N}$$

The reactions of the belt tension on shaft due to loading are shown in Fig. 6:

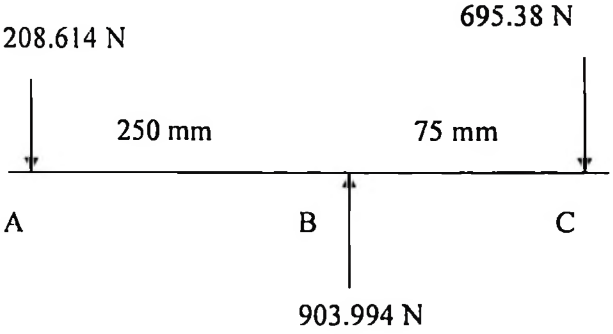

Figure 6: Loading diagram

By summing all the forces on the vertical y-axis such that and by taking moment at bearing A, both reaction forces at the bearing were found to be equal to 208.614 N and 903.994 N as shown in Fig.6.

$$\sum F_Y = 0; \quad F_B = F_A + 695.38\ \text{N}$$

4.3.3 Shear force acting on the shaft

Shear force refers to a strain produced when the layers of the shaft are subjected to opposing forces. Shear force can occur as a result of the applied loads on the shaft and belt tension. The shear force acting on the shaft was determined by drawing the shear force diagram while taking downward force to be negative (-) and the upward force to be positive (+).

For point F_A = - 208.614 N

For point F_B = -208.614 N + 903.994 N = 695.38 N

For point F_C = 695.38 N – 695.38 N = 0

The shear force diagram was then drawn as shown on Fig. 7:

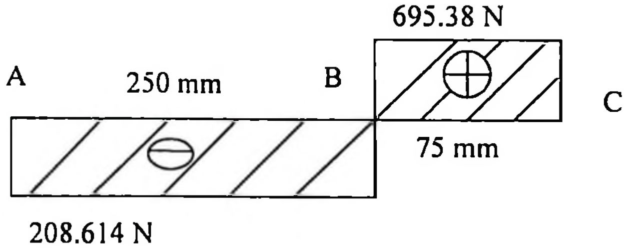

Figure 7: Shear force diagram

4.3.4 Bending moment acting on the shaft

Bending moment refers to the amount of bending occurs in the shaft when force is applied to shaft other than fixed end and its calculation was used to identify where the greatest amount of bending will take place. Bending moment on the driven shaft can occur as result of the applied loads and belt tension. The maximum bending moment acting on the shaft was calculated by taking moment from point A, B through C as follows:

Bending moment at point A

$$\sum M_A = 0$$

$$\sum M_A = 208.614N \times X$$

(X is equal to the distance of force from the point where moment is taken)

When X = 0mm

$$M_A = 0N\text{-}mm$$

Bending moment at point B

$$\sum M_B = 0$$

$$\sum M_B = 208.614N \times X$$

When X=250mm

$$\sum M_B = 208.614N \times 250mm$$

$$M_B = 52153.5N\text{-mm}$$

Bending moment at point C

$$\sum M_C = 0$$

$$\sum M_C = (208.614\ N \times X) - 903.994\ N\ (X - 250\ mm)$$

When X= 325 mm

$$\sum M_C = (208.61\ N \times 325\ mm) - 903.994\ N(325\ mm - 250\ mm)$$

$$M_C = 0\ N\text{-mm}$$

Then, maximum bending moment (M_{max}) which will be experienced by the shaft was found to act at B and its magnitude was 52.153×10^{3} N-mm as shown on Fig. 8:

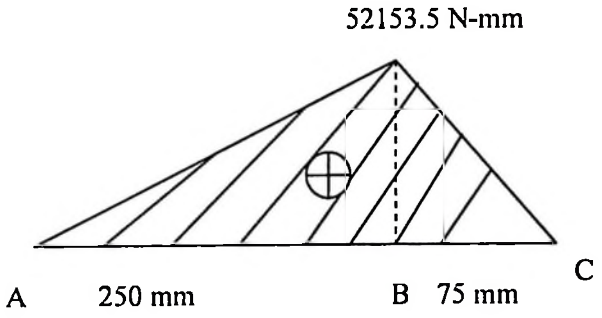

Figure 8: Bending moment diagram

4.3.5 Determination of shaft diameter

According to ASME code, the bending and torsional moments have to be multiplied by factors (K_m) and (K_t) respectively to account for shock and fatigue in operating conditions. The values of (K_m) and (K_t) for rotating shafts are presented in Table 4:

Where:

K_m = combined shock and fatigue factor for bending

K_t = combined shock and fatigue factor for torsion

Table 4: Combined shock and fatigue factor for bending and Torsional moment for determining shaft diameter

Parameter	**K_m**	**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 calculated using equivalent bending moment (E_{BM}) equation (17) (Khurmi and Gupta, 2005).

$$d = \left[\frac{16\left[(K_m \times M)+\left((K_m \times M)^2+(K_t \times M_t)^2\right)^{1/2}\right]}{\pi \times \sigma_b}\right]^{1/3} \qquad \text{...(17)}$$

Where:

d = shaft diameter (mm)

M = bending moment (N-mm)

M_t = torsional moment (N-mm)

σ_b = combined shear stress for bending and torsion (N/mm^2)

For steel shaft with key way, the allowable combined shear stress for bending and torsional moment was 40 N/mm^2 (Spotts, 1988).

$$d = \left[\frac{16\left[(1.5 \times 52.153 \times 10^3) + ((1.5 \times 52.153 \times 10^3)^2 + (1.0 \times 40.68 \times 10^3)^2)^{1/2}\right]}{\pi \times 40}\right]^{1/3}$$

Taking $K_m = 1.5$ and $K_t = 1.0$ and by plugging in the values, the shaft diameter was calculated and found to be 27.67 mm and a shaft of 37 mm was used for machining and standard purposes.

4.4 Fabrication Materials

The materials used for the dehuller fabrication were; Mild steel sheet (1, 2, 5, 8 and 12 mm gauge), angle iron L section (5 mm × 50 mm × 50 mm), bolts (8, 10, and M12), motor (5.5 hp), three phase direct online switch, three phase wire connector, three phase wire cable, vertical bearings (6308), flat channels section (5 mm × 15 mm and 10 mm × 40 mm), pulleys (Ø78 mm, 156 mm, and 234 mm), v-belts (B-26, B-31 and B-36), driven solid shaft (Ø37 mm × 420 mm), paints oil (red oxide and green grass) and welding electrodes (AWS) E6013(Ø2.5(3/32") × 300 mm and Ø3.2(1/8") × 350 mm).

4.4.1 Feeding hopper

The hopper of the dehuller was a square frustrum-shaped component with adjustable feed control gate at the bottom made from a mild steel plate 2 mm thick. The mild steel plate was sheared into five different pieces all with different dimensions. Piece no.1 dimensions were 400 mm at the top and 100 mm at the base, piece no.2:- dimensions were 300 mm at the top and 100 mm at the base, piece no.3:- dimensions were 400 mm at the top and 300 mm at the base and piece no.4 and 5 had similar dimensions of 400 mm at the top and 100 mm at the vertical side and 300 mm at the inclined side and 100 mm at the base. The pieces were welded together to form a square (shaped) frustum with side walls slanted at 45° to accommodate the angle of repose (28°) of sunflower seeds. The hopper diagram is shown in Fig. 9.

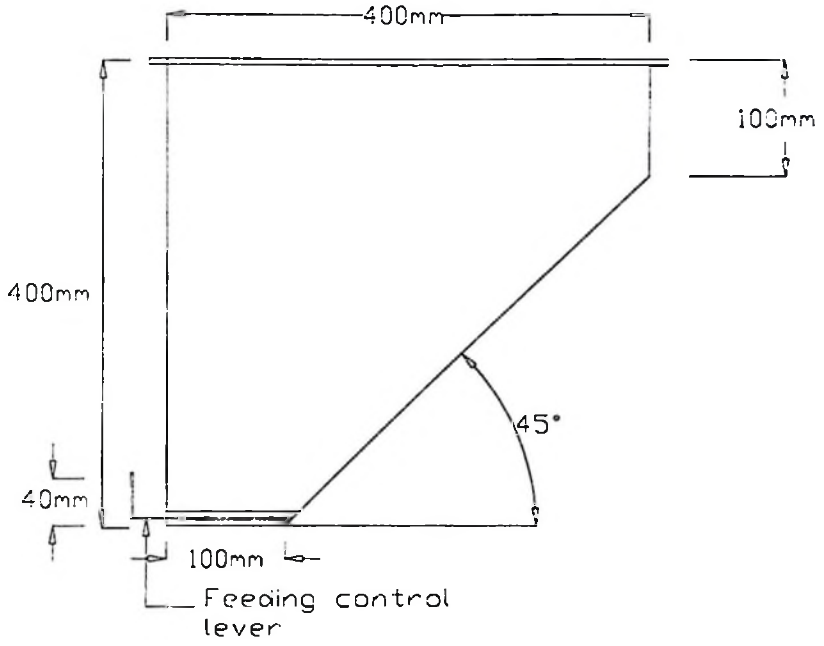

Figure 9: Feending hopper

4.4.2 Dehuller impeller

The impeller was made from mild steel plate 6 mm thick by cutting it into a round disk 300 mm radius with a 40 mm diameter hole at the center. Twenty four flat bars each with dimensions of 15 mm × 270 mm were fillet welded concentrically on top of the round disk to form a seed guide (vane/groove). The vane/groove size was chosen in accordance with average linear dimensions of the sunflower seed *Record* variety, which had higher average linear dimensions than *Kenya Fedha* variety. A keyed bush 40 mm diameter on inside and 50 mm diameter on outside was welded at the back of the round disk. A fan was made from four mild steel plates 2 mm thick, each measuring 37 mm × 150 mm and was welded concentrically on the bush. The diagram of the impeller is shown in Fig.10.

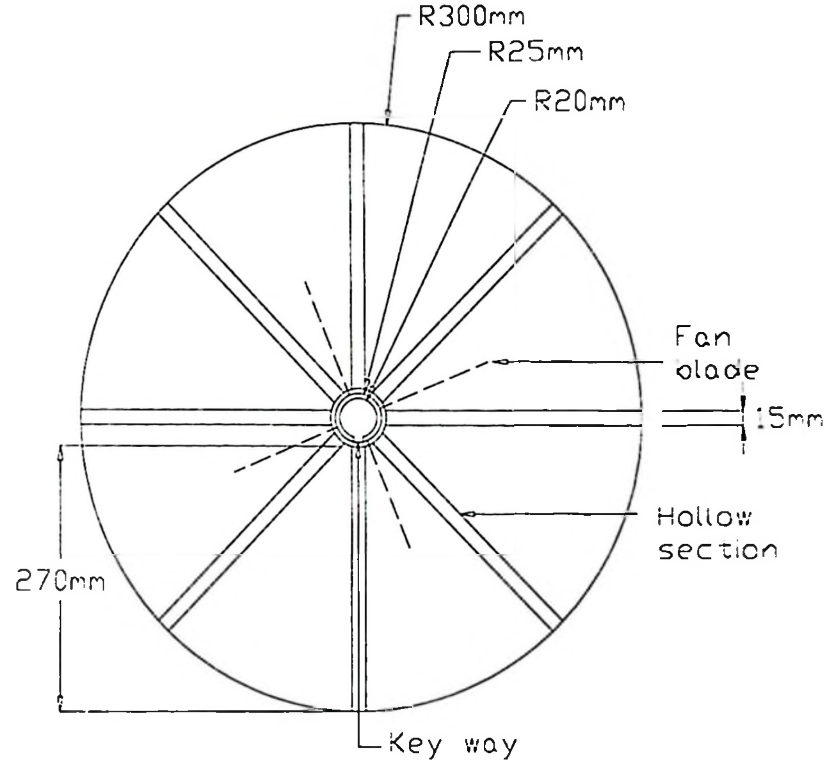

Figure 10: Dehuller impeller

4.4.3 Dehulling chamber

Dehulling chamber consisted of two parts; the first part also acting as the hopper seat was made of a mild steel plate 2 mm thick, which was cut into a disk 700 mm in diameter with a 40 mm diameter hole at the center. A rolled flat bar 5 mm width and 2000 mm long was welded around the disk edge. The disk had 20 mm width and 50 mm long protrusions with drilled holes to allow fastening to the bottom part using M10 bolts and nuts. These protrusions were positioned at 120° and welded around the disk edge as shown in Fig.11. The bottom part was made up by welding a rolled 2 mm thick mild steel plate 100 mm width and 2000 mm long with another disk 700 mm diameter. The entire casing was lined inside with a rolled mild steel plate.

8 mm width and 1950 mm long to act as the impact ring for the seeds ejected from the rotating impeller. The diagram of the dehulling chamber is shown in Fig.12:

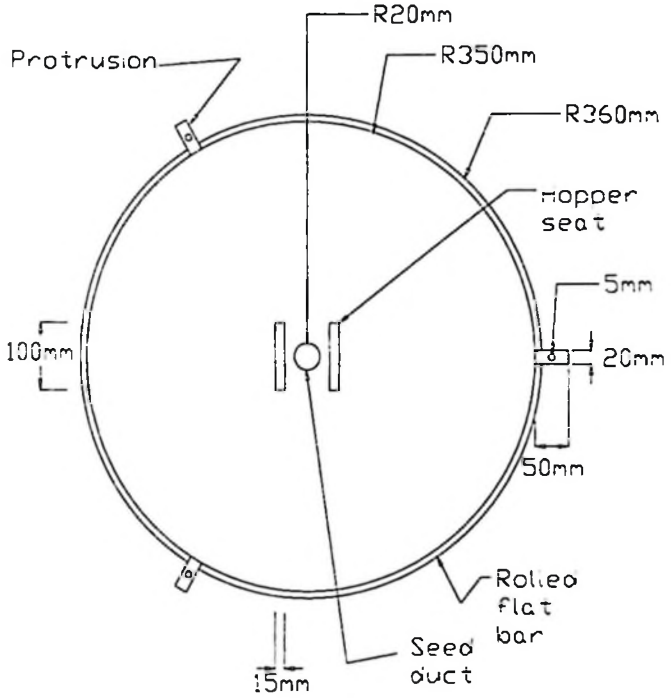

Figure 11: Dehuller chamber top part

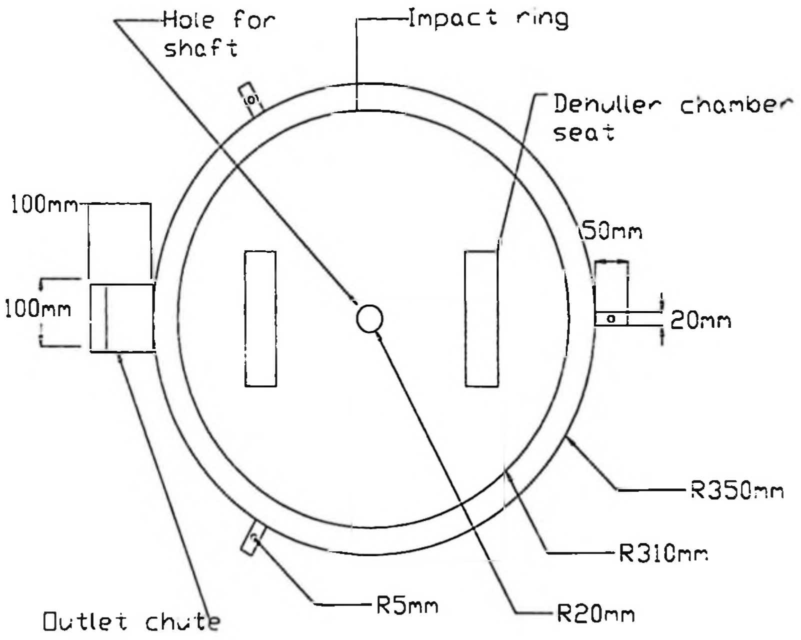

Figure 12: Dehuller chamber bottom part

4.4.4 The dehuller frame

This was a rigid body formed by welding 25 pieces of angle iron with dimensions 5 mm × 50 mm × 50 mm. A mild steel plate 12 mm thick, 180 mm width and 250 mm long was welded on the frame for mounting the electric motor. The frame was covered using eight different mild steel plates 1 mm thick. The diagram of the dehuller frame is shown in Fig. 13.

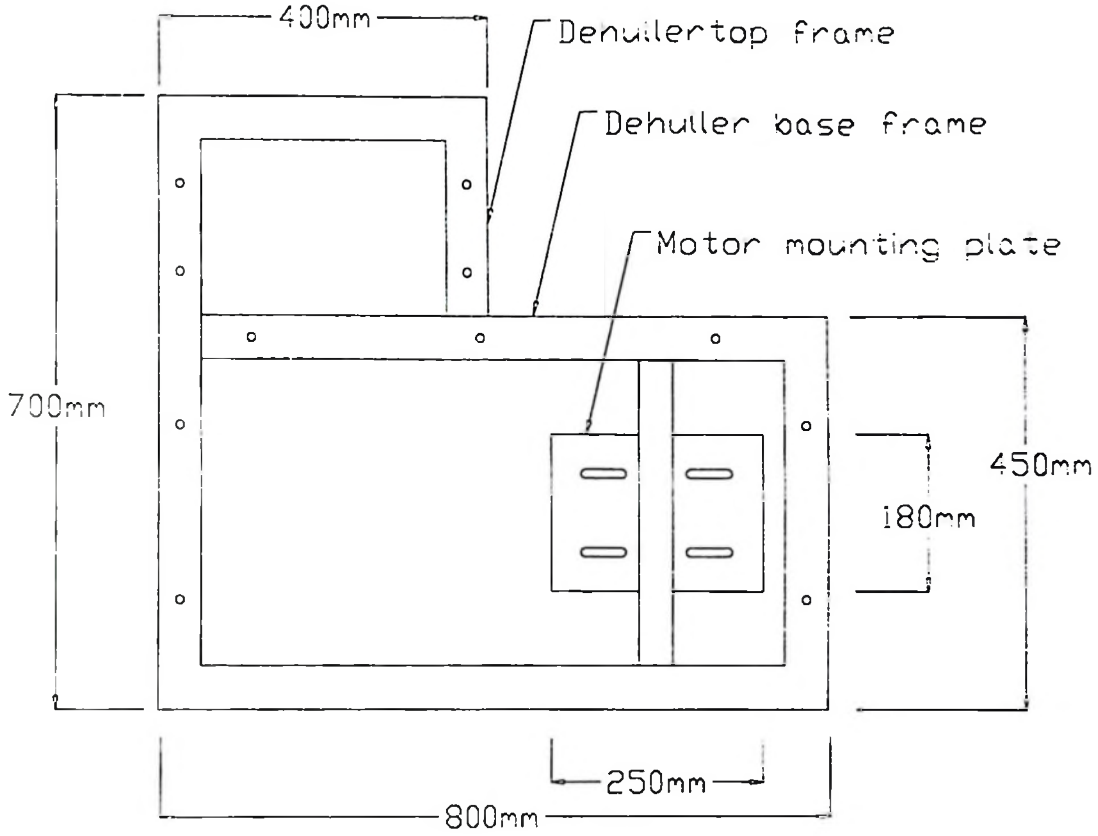

Figure 13: The dehuller frame

4.4.5 Painting of the dehuller components

For corrosion prevention and for aesthetic purposes, the dehuller components were painted with green grass oil paint after priming with red oxide oil paint.

4.5 Assembly of the Improved Centrifugal Dehuller

The shaft was fixed and positioned vertically in the machine frame with the bearings and bearing cups. Then the electric motor was mounted vertically with its base firmly bolted on a 12 mm thick mild steel plate welded on dehuller frame. Then drive pulley was keyed on the motor shaft using 8 mm width and 10 mm long square key and the driven pulley fastened on the driven shaft using 10 mm width and 10 mm long square key plus plain washer and M10 lock bolt to prevent the pulley from falling due to gravitational force. Three V-belts were fitted on both pulleys. The dehulling chamber was placed on top of the frame and fastened using 4-M12 bolts and nuts. The impeller was keyed on the driven shaft inside the dehulling chamber and fastened using a plain washer and M10 lock bolt. The top cover plate was then fastened to the dehulling chamber using 3-M10 bolts and nuts while the cover plates were fastened to the machine frame using 28-M8 bolts and nuts. Finally, the hopper was attached to the top cover plate using slide mesh fitting. The diagram of complete assembly of the improved centrifugal sunflower dehuller is shown in Fig.14.

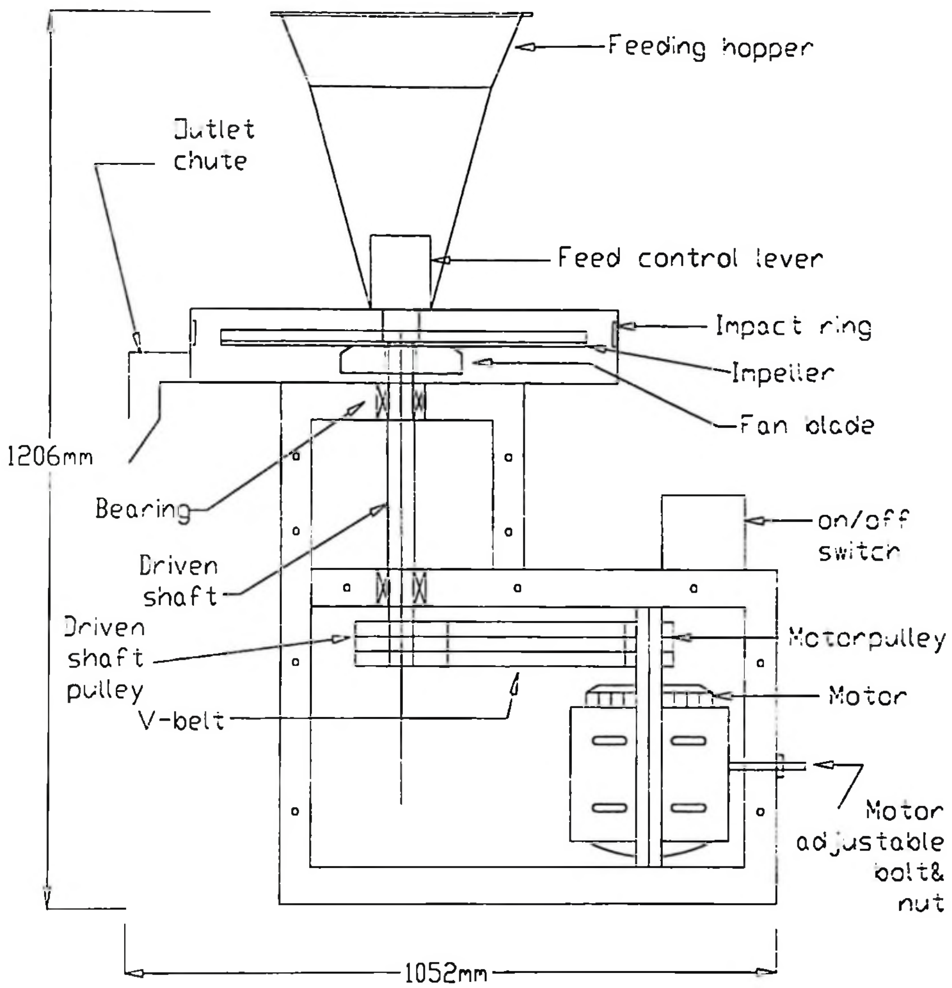

Figure 14: Assembled improved centrifugal sunflower dehuller

4.6 Principle of Operation of the Improved Centrifugal Sunflower Dehuller

Sunflower seeds are fed into the feeding hopper and flow by gravity through the feed duct beneath the hopper into a rotating impeller seed vanes. Due to centrifugal force acting on the seed, the seeds travel through the ducts and emerge from the impeller with a high velocity and impacting to a fixed impact ring. As a result of the impact, the seed hull breaks and releases the cotyledon. A schematic diagram of the motion of a seed in a rotating impeller vane is shown in Fig. 15.

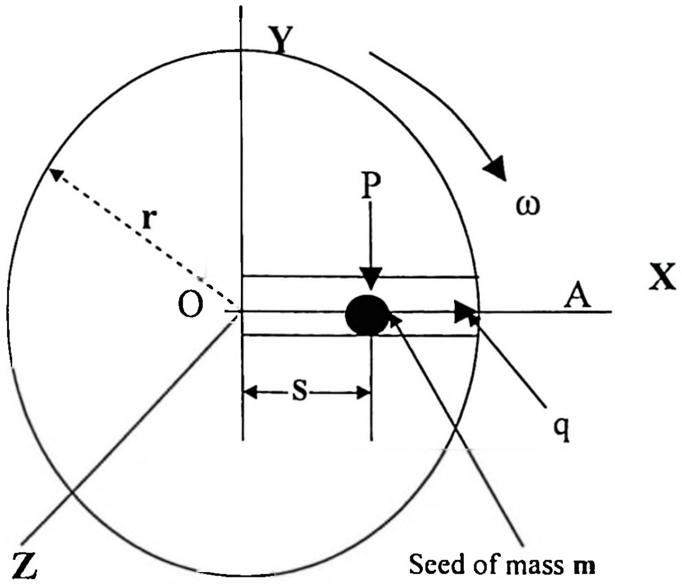

Figure 15: A schematic diagram of the seed motion in a rotating impeller

The velocity of the seed from the impeller was obtained by assuming a seed of mass (**m**) moving along the vane (**OA**) in a rotating impeller of radius (**r**) at angular velocity (**ω**) radians/sec (Fig.15). The main force acting on the seed as it travels through the vane is the centrifugal force (q). Let the seed be a distance (s) from the center of the impeller. The acceleration ($\bar{a}$) of the seed within the vane can be expressed as:

$$\vec{a} = \vec{a}_o + \vec{\omega} \times (\vec{\omega} + \vec{s}) + \vec{\dot{\omega}} \times \vec{s} + \vec{\ddot{s}} + 2\vec{\omega} \times \vec{s} \quad \text{..}(18)$$

Since the impeller is fixed,

$$\vec{a}_o = \vec{\dot{\omega}} = 0$$

By expressing in unit vectors, $\vec{\imath}, \vec{\jmath}, \vec{k}$

$$\vec{\omega} = -\omega\vec{k};\ \vec{\ddot{s}} = \ddot{s}\vec{\imath};\ \vec{\dot{s}} = \dot{s}\vec{\imath}$$

and noting that,

$$\vec{\omega} \times (\vec{\omega} \times \vec{s}) = -\omega\vec{k} \times \left(-\omega\vec{k} \times s\vec{\imath}\right) = -s\omega^2\vec{\imath}$$

and

$$2\vec{\omega} \times \vec{\dot{s}} = -2\omega\vec{k} \times \dot{s}\vec{\imath} = -2\omega\dot{s}\vec{\jmath}$$

then equation (18) becomes

$$\vec{a} = -s\omega^2\vec{\imath} + \ddot{s}\vec{\imath} - 2\omega\dot{s}\vec{\jmath} \tag{19}$$

Since force = m × $\vec{a}$

$$-q\vec{\jmath} = m[(\ddot{s} - s\omega^2)\vec{\imath} - 2\omega\dot{s}\vec{\jmath}] \tag{20}$$

equating forces on the system

$$\ddot{S} - S\omega^2 = 0 \tag{21}$$

But $\ddot{S} = \dot{S}\frac{d\dot{s}}{ds}$

Therefore $$\dot{S}\frac{d\dot{s}}{ds} = S\omega^2 \tag{22}$$

By integrating equation (22) and assuming that the seeds are released at a distance (f) from the center of the impeller with negligible initial velocity,

$$\int \dot{s}d\dot{s} = \omega^2 \int_f^r sds$$

$$\frac{1}{2}\dot{S} = \frac{\omega^2}{2}(r^2 - f^2)$$

$$\dot{S} = \omega(r^2 - f^2)^{1/2} \tag{23}$$

From equation (23), the exit velocity of the seed from the impeller was obtained from the following equation;

$$V = \omega(r^2 - f^2)^{1/2} \tag{24}$$

But f = 0 since seeds are released at the center of the impeller and therefore equation (24) becomes;

$$V = (\omega \times r) \qquad (25)$$

Where:

V = Exit velocity of seed (m/s)

ω = impeller angular velocity (rad/s)

r = impeller radius (m)

The centrifugal force required to break sunflower seed during dehulling was determined according to the equation given by Okokon *et al.* (2007).

$$F = (E \times \rho)^{1/2} \times \left(\frac{m}{M}\right) \omega r S \qquad (26)$$

Where:

F = sunflower seed breaking force (N)

E = young's modulus of elasticity of the seed (N/mm^2)

ρ = density of the seed (kg/mm^3)

m = mass of the seed (kg)

M = mass of the impeller (kg)

ω = angular velocity of the impeller (rad/s)

r = radius of the impeller (mm)

S = seed cross-section area (mm^2)

4.7 Performance Evaluation of Centrifugal Sunflower Dehuller

4.7.1 Materials

Sunflower seeds varieties *Record* and *Kenya Fedha* cultivated by most of the farmers and commonly used for oil extraction by small and medium enterprises were used to evaluate the performance of the developed dehuller. The initial moisture content of the seeds for both varieties was 6.0 % wet weight basis.

4.7.2 Equipment

The following equipment were used during performance test; Stop watch for determining dehulling time, tachometer (Model PLT- 5000 non-contact) for determining shaft speed.

4.7.3 Methods

4.7.3.1 Determination of the optimum dehulling speed

In determining the optimum dehulling speed, 15 kg from each sunflower seeds variety were dehulled using three pre-selected impeller speeds, which were selected based on speed ratios of the pulleys. The speeds were selected by using three different pulleys with dimensions 78 mm, 156 mm, and 234 mm and V-belt type B number: 26, 31, and 36 respectively. The three-pre-selected impeller speeds were 963 rpm, 1445 rpm and 2890 rpm. The performance evaluation of the dehuller at these pre-selected impeller speeds were based on throughput capacity, dehulling efficiency, kernels breakage and product yield. The values of these parameters were calculated as described in sections 4.7.3.3 to 4.7.3.6. The impeller speed capable of producing highest dehulling efficiency and product yield but low kernels breakage was considered the most efficient dehulling speed. The obtained optimum dehulling speed was then used as the impeller dehulling speed for the performance evaluation of the dehuller for *Record* and *Kenya Fedha* sunflower seeds varieties.

4.7.3.2 Performance of the dehuller at optimum dehulling speed

The performance of the dehuller was based on throughput capacity, dehulling efficiency, kernel breakage and product yield. Initially the dehuller was allowed to run idle for about 5 minutes to attain a steady state speed. Then 10 kg from each sunflower variety was dehulled separately and the dehuller performance was evaluated according to equations 27, 28, 29 and 30.

4.7.3.3 Determination of throughput capacity

Throughput capacity is a measure of a quantitative performance of a machine or the quantity of the product processed per unit time. A 10 kg sample of sunflower seed from each variety was poured into the hopper and dehulled separately while measuring the time taken. The throughput capacity of the dehuller was then calculated using the following equation:

$$T_C = \left(\frac{M_s}{D_t}\right) \qquad (27)$$

Where:

T_c = throughput capacity (kg/h)

M_s = weight of sample fed into the hopper (kg)

D_t = dehulling time (h)

4.7.3.4 Determination of dehulling efficiency

Dehulling efficiency is the measure of the effectiveness of the machine in the removal of the hulls from the seed. In measuring the dehuller efficiency, 10 kg sample from *Record* and *Kenya Fedha* was fed into the hopper and dehulled separately. The dehulled kernels, hulls and undehulled seeds were collected and manually separated into three fractions of dehulled seeds, partially dehulled seeds and undehulled seeds and each fraction was weighed separately. Dehulling efficiency was then calculated using the following equation (Ndukwu and Asoegwu, 2010):

$$D_e = \left(\frac{M_S - Y}{M_S}\right) \times 100 \qquad (28)$$

Where:

D_e = dehulling efficiency (%)

M_s = weight of seed sample before dehulling (kg)

Y = weight of partially dehulled and undehulled seed (kg)

4.7.3.5 Determination of percentage broken kernels

Kernels breakage defines the quality of the dehulled seed. The weight of broken kernels for each sunflower variety was determined by sieving of the dehulled seed on a 3 mm mesh screen. The mesh size was selected because the geometric mean diameter for the samples in this study was 6.3 mm for *Record* and 6.08 mm for *Kenya Fedha* so any kernel passing through the 3 mm mesh was considered as broken. The percentage of kernels broken for both varieties was determined using the following equation (Ndukwu and Asoegwu, 2010):

$$KBR = \left(\frac{M_b}{M_b+M_d}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(29)}$$

Where:

KBR = broken kernels (%)

M_b = weight of broken kernels (kg)

M_d = weight of dehulled kernels (kg)

4.7.3.6 Product yield

Product yield is the amount of the sunflower kernels collected after the dehulling process. It is therefore the cumulative sum of dehulled kernels, undehulled kernels and broken kernels collected after the dehulling process. The percentage product yield of each variety was calculated from the following formular:

$$P_y = \left(\frac{D_s+U_d+B_g}{W_s}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(30)}$$

Where:

P_y = product yield (%)

D_s = weight of dehulled seeds (kg)

U_d = weight of undehulled seeds (kg)

B_g = weight of broken kernels (kg)

W_s = weight of weight of initial sample (kg)

4.7.4 Determination of crude oil quality

4.7.4.1 Oil extraction

Seventy kilograms of dehulled and undehulled seeds each from both sunflower varieties was pressed using continuous screw expeller at Vyahumu Trust oil mill located at Kihonda industrial area.

4.7.4.2 Extracted oil yield

The extracted oil samples were collected, labeled and transported to SUA Department of Agricultural Engineering and Land Planning where they were stored for three days to allow sediments to settle down. After three days of sedimentation process, each oil sample was decanted to obtain clear oil which was then weighed using a precision electronic balance. Percentage oil yield from each seed sample was calculated using the following equation:

$$P_{yo} = \left(\frac{W_O}{W_S}\right) \times 100 \qquad (31)$$

Where:

P_{yo} = oil yield (%)

W_o = weight of decanted oil (kg)

W_s = weight of sunflower seed sample (kg)

4.7.4.3 Chemical analysis of extracted oil

Samples from the decanted oil were sent to the Department of Food Sciences Laboratory SUA and Tanzania Food and Drugs Authority for physico-chemical analysis.

The following parameters were analyzed;

a) **Physical characteristics of the oil**

Refractive index of the oil

Refractive index of the oil was determined using abbey refractometer.

Oil colors

Oil color was determined using Lovibond scale in 2.54 cm cell, based on the expression (5R + Y) where R is the red pigment and Y is the yellow pigment.

Oil odour

Odour (smell) of the oil was done using sensory analysis panel of five people selected randomly from members of the Department of Food Science and Technology. Oil odour was rated for the overall smell intensity using numerical scale of 1 to 4 with 1 = no odour, 2 = weak odour, 3 = moderate odour, 4 = strong odour.

b) **Chemical properties of the oil**

The chemical properties of the oil investigated included; saponification value, peroxide value, iodine value and acid value these were determined using oil analysis methods as specified by TBS (2011).

4.7.5 Cake yield and quality evaluation

4.7.5.1 Cake yield

For each sunflower variety, cake from dehulled and undehulled seeds were collected and weighed. Then values of cake yield for dehulled and undehulled seeds for both varieties were determined using the following equation:

$$C_Y = \left(\frac{W_C}{W_S}\right) \times 100 \quad (32)$$

Where:

C_y = cake yield (%)
W_c = weight of collected cake (kg)
W_s = weight of sunflower seed sample before oil extraction (kg)

4.7.5.2 Quality analysis of the pressed cake

The quality of the pressed cakes from dehulled seeds and undehulled seeds was evaluated in terms of crude protein content, crude fiber content and ether extracts. After the oil extraction process the cake from both dehulled and undehulled seeds for both sunflower varieties were collected, packed, labeled and transported to the Department of Animal Science and Production Laboratory at SUA for proximate analysis, where the following parameters were analyzed:

Crude protein

Crude Protein was determined according to Kjeldah method using block digestion and steam distillationand was calculated using the following equation (AOAC, 1990):

$$CP = \left(\left(\frac{14.01 \times (T_t - B_v) \times C_B}{S_W \times 10}\right) \times F\right) \quad (33)$$

Where:

CP = crude protein (%)
T_t = titre (mls)
B_v = blank value (0.000)

C_a = concentration of HCL acid (0.1014 N/mol)

S_w = sample weight (g)

F = factor for sunflower cake (6.25)

Crude fiber

Crude Fiber was determined using Ankom technology and was obtained using the following equation:

$$\mathbf{CF} = \left(\frac{(D-G)\times 100}{A}\right) \qquad (34)$$

Where:

CF = crude fiber (%)

D = weight of residue (g)

G = weight of ash (g)

A = weight of sample (g)

Ether extract

Ether extract was determined using Soxtec technology and calculated from equation:

$$\mathbf{EE} = \left(\frac{C-B}{A}\right) \times 100 \qquad (35)$$

Where:

EE = ether extract (%)

C = weight of cup and residue ether extract (g)

B = weight of cup (g)

A = weight of sample (g)

4.7.5.3 Statistical analysis

All proximate analyses were performed in three replications and the results were statistically analyzed. The data were evaluated for significant differences ($p<0.05$) in their means using Analysis of Variance (ANOVA) in completely randomized block design using the GenStat version 13.3 software.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 Design and Fabrication of the Centrifugal Dehuller

The centrifugal sunflower dehuller was designed and fabricated at the Department of Mechanical Engineering, University of Dar es Salaam. The developed sunflower dehuller consisted of three main parts, which are: (i) feeding hopper, (ii) dehulling chamber and (iii) the frame and (iv) the power unit as shown in Fig.13.

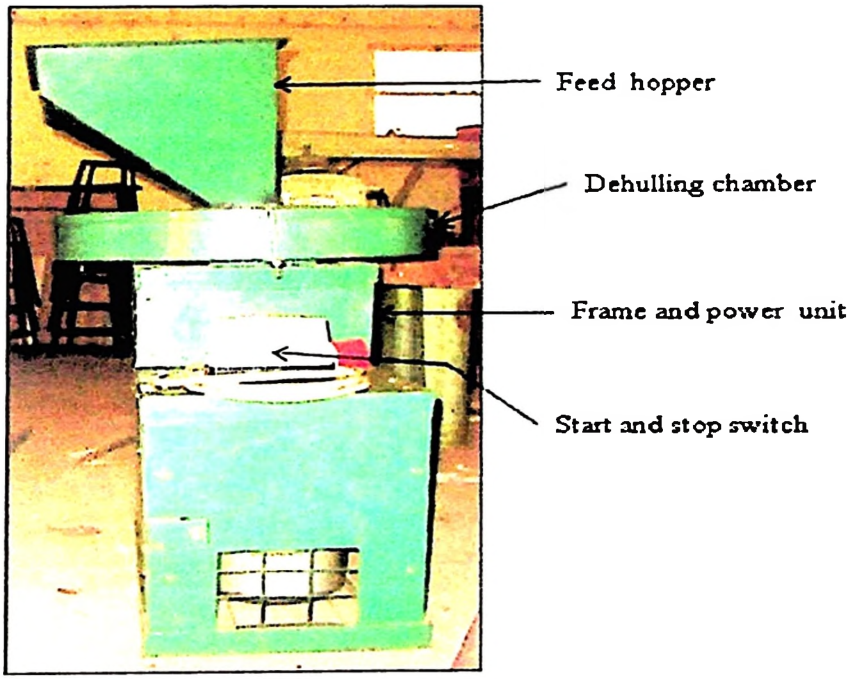

Plate 1: Side view photograph of the improved dehuller

5.2 Physical Properties of Sunflower Seed

5.2.1 Seed dimensions and shape

The average values of the three principal dimensions of the sunflower seed (length, width and thickness) determined in this study are summarized in Table 5 for both *Record* and *Kenya Fedha* varieties. The results showed that, the difference between seed width (W) and thickness (T) were smaller compared to the difference between these two dimensions and seed length (L), indicating that sunflower seeds used in this research were flattened, wedge shaped.

Seed shape was expressed in terms of sphericity which expressed how close the seed kernels shape, approaches a sphere. The results are also summarised in Table 5. Average sphericity for *Record* variety was 56.8 % while for *Kenya Fedha* variety was 54.5 %. This shows that, on average *Record* seeds were more spherical compared to *Kenya Fedha* seeds as indicated by their higher sphericity.

Table 5: Sunflower seed physical dimensions and shape

Sunflower variety	L (mm)	W (mm)	T (mm)	D_a (mm)	D_g (mm)	S (mm^2)	Φ (%)
Record	11.10	5.91	3.81	6.90	6.30	124.90	56.80
Kenya Fedha	11.16	5.59	3.59	6.80	6.10	116.10	54.50

L = seed length, W = seed width, T = seed thickness, D_a= arithmetic mean diameter, D_g = geometric mean diameter, S = surface area, Φ = sphericity (%).

5.2.2 Seed colour

The colour of the *Record* variety used in this investigation was black with grey strips, while *Kenya Fedha* colour was vivid black. Seed colour is an important factor in oil extraction because it influences the colour of the extracted oil. Most consumers prefer sunflower oil with light yellowish colour compared to dark yellowish colour.

5.2.3 Seed weight

Seed weight was expressed in terms of a thousand-grain weight. The one thousand-grain weight for *Record* variety was higher than *Kenya Fedha* variety. The results for both sunflower varieties are summarized in Table 6.

Table 6: Seedweight, bulk density, true density and porosity

Sunflower variety	W_{1000} (g)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)
Record	77.12	400	530.17	24.55
Kenya Fedha	62.6	350	452.47	22.65

5.2.4 Bulk density, true density and porosity

Bulk density, true density and porosity are important parameters in the design of the dehuller hopper. The values of bulk density, true density and porosity for both sunflower varieties are given in Table 6. The bulk density, true density and porosity of *Record* variety were higher compared to *Kenya Fedha* variety. Therefore, designing of the dehuller hopper was based on values of porosity, bulk and true density of the *Record* variety.

5.3 Optimum Dehulling Speed

Before determining the performance of the dehuller, it was necessary to determine the optimum dehulling speed for each sunflower variety used in this investigation. The results of optimum dehulling speed for both sunflower varieties are presented in Appendix 4 and summarized in Table 7. Dehulling at 1445 rpm and 2890 rpm impeller speed resulted in high throughput capacity, high kernel breakage and high dehulling efficiency but low product yield. On the other hand, impeller speed of 963 rpm resulted in lowest throughput capacity, broken kernels and dehulling efficiency but highest product yield.

The results indicated that, product yield and kernels breakage were inversely proportional to the impeller speed while dehulling efficiency and throughput capacity were directly proportional to impeller speed. Despite the low dehulling efficiency obtained using impeller speed of 963 rpm, this speed was selected as the optimum dehulling speed because it resulted into highest product yield indicating there was minimum breakage and hence minimum loss of sunflower kernels in the hull fraction which will eventually lead to more oil recovery.

Table 7: Effect of impeller speed on dehulling efficiency, kernels breakage, throughput capacity and product yield

Sunflower variety	Impeller speed (rpm)	Dehulling efficiency (%)	Throughput capacity (kg/h)	Kernels breakage (%)	Product yield (%)
Record	963	80.0	427.0	6.05	68.7
	1445	87.0	467.1	6.81	66.7
	2890	94.3	661.7	26.48	62.7
Kenya Fedha	963	79.3	513.0	2.66	62.2
	1445	89.1	502.6	10.79	51.8
	2890	93.1	707.7	18.07	53.7

5.4 Performance Evaluation of the Dehuller

Performance evaluation of the dehuller for both sunflower varieties was based on throughput capacity, dehulling efficiency, percentage kernels breakage and product yield.

5.4.1 Throughput capacity of the dehuller

Results for dehuller performance in terms of throughput capacity for both sunflower varieties are summarized in Table 8 and presented in Appendix 5. The throughput capacities for both varieties were calculated according to equation (27) in section 4.7.3.3.

Dehulling both sunflower varieties at the optimum dehulling speed (963 rpm) resulted in throughput capacity of 513 kg/h for *Kenya Fedha* variety and 427 kg/h for *Record* variety. The variation observed in throughput capacity for the two sunflower varieties may have been attributed to the lower true density of *Kenya Fedha* variety, which might have resulted into higher residence time associated with lower centrifugal force acting on the seeds and hence low seed momentum compared to *Record* variety, which had higher true density, hence higher centrifugal force acting on the seed and higher seed momentum (Shittu and Ndrika, 2012).

Table 8: Throughput capacity, dehulling efficiency and percentage broken kernels

Sunflower variety	Impeller speed (rpm)	Throughput capacity (kg/h)	Dehulling efficiency (%)	Broken kernels (%)	Product Yield (%)
Record	963	427	80	5.6	70.3
Kenya Fedha	963	513	79.3	2.5	66.7

5.4.2 Dehulling efficiency of the dehuller

The results for dehulling efficiency for both *Record* and *Kenya Fedha* sunflower varieties are summarized in Table 8 and in Appendix 5. The performance of the dehuller at optimum dehulling speed resulted in dehulling efficiency of 80.0 % for *Record* variety and 79.3 % for *Kenya Fedha* variety. The observed variation in dehulling efficiency might have been attributed to the differences in physical properties of the two seeds variety (Baldini *et al.*, 1996). Similar findings on the effect of seed variety on dehulling efficiency were reported by Dorrell and Vick (1997) for sunflower seeds.

5.4.3 Percentage broken kernels

The results of the evaluation of the dehuller in terms of percent broken kernels are shown in Table 8 and in Appendix 5. Equation (29) (section 4.7.3.5) was used to determine the percentage of broken kernels for both varieties. The percentage broken kernels at optimum dehulling speed was 5.6 % and 2.5 % for *Record* and *Kenya Fedha* varieties respectively. The result shows that *Record* variety had higher percentage broken kernels compared to *Kenya Fedha* variety. The variation in kernels breakage between the two varieties could be explained by the fact that, the higher values of seed mass and true density for *Record* variety influenced the centrifugal force acting on the seed resulting in high momentum thus leading into higher impact force and hence more broken kernels compared to *Kenya Fedha* variety, which had lower values of seed mass and true density (Shittu and Ndrika, 2012).

5.4.4 Product yield

The results of the dehuller performance in terms of product yield are presented in Table 8. Dehulling both sunflower varieties at optimum dehulling speed resulted in product yield of 70.3 % and 66.7 % for *Record* and *Kenya Fedha* varieties respectively. The results indicated that, *Record* variety had higher product yield than *Kenya Fedha* variety. The observed variation might have been attributed by the seed variety, which resulted into low arbsoption of excess energy hence low rebounce of the kernel between the impact ring and impeller which produced low non- recoverable fines for *Record* variety than *Kenya fedha* variety (Mohsenin, 1978).

5.5 Comparison of Performance of Centrifugal with Abrasive Dehuller

The obtained performance evaluation records for abrasive-IPI dehuller were throughput capacity and dehulling efficiency (GTZ, 1989). Therefore, comparison of performance of developed centrifugal with abrasive-IPI dehuller was based on throughput capacity and dehulling efficiency.

Table 9: Performance records of centrifugal and abrasive-IPI dehuller

Dehuller type	Sunflower variety	Throughput capacity (kg/h)	Dehulling efficiency (%)	Broken kernels (%)
Abrasive- IPI	*Record*	140	17.5	n.d
Centrifugal	*Record*	427	80	5.6
	Kenya Fedha	513	79.3	2.5

n.d = not done

Performance evaluation results of both the abrasive and the centrifugal dehuller for *Record* variety are sumarised in Table 9. Results indicated an increase in throughput capacity and dehulling efficiency in centrifugal dehuller after improvement. The throughput capacity of the developed centrifugal dehuller was 427 kg/h (140 kg/h before improvement), dehulling efficiency was 80 % (17.5 % before improvement), at 963 rpm optimum dehulling speed.

5.6 Oil Yield

The main interest in dehulling sunflower seed was to improve the oil extraction efficiency in terms of oil yield and quality. The results of the effect of dehulling on oil yield of the two sunflower varieties are presented in Table 10. The dehulling process resulted in an increase in oil yield of the dehulled seeds over undehulled seeds for both sunflower varieties from 19.7 % to 35.2 % for *Record* variety and from 16.4 % to 31.0 % for *Kenya Fedha* variety. The increase in oil yield may be due to relative increase in proportion of the seed kernels that are rich in oil caused by the removal of the hulls after dehulling. Another reason may be due to reduction of the oil loss due to absorption by the hulls. Similar results of increased oil yield of dehulled sunflower seed over undehulled sunflower seed were reported by Shukla *et al.* (1992).

Table 10: Oil yield from dehulled and undehulled sunflower seeds

Sunflower variety	Treatment	Seed weight (kg)	Oil yield (kg)	Oil yield (%)
	Dehulled	35	12.3	35.1
Record	Undehulled	35	6.9	19.7
	Dehulled	35	10.8	30.9
Kenya Fedha	Undehulled	35	5.7	16.3

5.7 Oil Quality

The oil quality from dehulled and undehulled seed was determined based on physico-chemical properties of the oil in comparison to the TBS recommended values.

5.7.1 Physico-chemical characteristic of extracted oils

Physico-chemical analyses of the extracted oil from dehulled and undehulled seeds are given in Table 11. Sensory analysis revealed that, dehulled seed oil had weak odour compared to strong odour rated for undehulled seed oil for both sunflower varieties. The variation in oil odour might be due to less wax content in the dehulled seed oil resulting from the removal of seed hulls which are rich in waxes. Colour of oil from dehulled seeds was bright yellowish while that from undehulled seeds was dark yellowish. This was expected due to the removal of significant amount of seed hulls which are rich in colour compounds.

Table 11: Physico-chemical composition of oil from *Record* and *Kenya Fedha* varities

Variety	Treatment	Odour	Colour	RI	RD	SV	IV	PV	AV
Record	D	2	19	1.465	0.918	179.59	141.05	1.05	2.78
	U	4	18	1.462	0.921	186.44	148.87	1.38	3.68
Kenya Fedha	D	2	19	1.466	0.919	176.94	141.54	1.84	1.92
	U	4	18	1.463	0.923	185.91	153.71	1.98	4.67
	TBS	-	≤ 20	(1.464-1.480)	0.918-0.923	188-194	110-143	≤ 10	≤ 3

D = dehulled seed, U = undehulled seed, 2 = weak odour, 4 = strongodour, RI = refractive index at 40°C, RD = relative density 20°C, SV = saponification values (mg KOH/g oil), IV = iodine values (g/g), PV = peroxide value (Meq/kg oil), AV = acid value (mg KOH/g), and finally the range of physico-chemical properties for sunflower seed oil from TBS (TZS 50:2011).

The refractive index of oil from dehulled seeds was 1.465 for *Record* variety and 1.466 for *Kenya Fedha* variety while refractive index of oil from undehulled seeds was 1.462 and 1.463 for both sunflower varieties respectively. Results indicated that oil from dehulled seeds had high refractive indices than oil from undehulled seeds for both sunflower varieties; this difference could be due to removal of significant amount of seed hulls which reduces relative amount fine hulls particles transferred to oil from dehulled seeds during oil extraction. However, all values obtained for the dehulled seeds were within the 1.464 to 1.480 refractive index range as specified by TBS (2011) while those for undehulled were below the specified standard.

The value of relative density for oil from dehulled seeds was 0.918 and 0.921 for oil from undehulled seeds for *Record* variety and the corresponding values of oil from dehulled seeds and undehulled seeds for *Kenya Fedha* variety were 0.919 and 0.923 respectively. These findings indicated that oil from dehulled seeds had low relative density compared to oil from undehulled seeds for both sunflower varieties. This variation might have been attributed by the removal of seed hulls, which resulted in low wax contents and low fine hull particles content in the oil from dehulled seeds. However, all values of relative densities for both sunflower varieties were within the specified range of 0.918 to 0.923 for sunflower seed oil (TBS, 2011).

Peroxide values of the oil from dehulled seeds and undehulled seeds for *Record* variety were 1.05 and 1.38 respectively while corresponding values of dehulled seeds and undehulled seeds for *Kenya Fedha* variety were 1.84 and 1.98 respectively. Results showed that oil from dehulled seeds had low peroxide value compared to oil from undehulled seeds. The observed difference in peroxide value might have been attributed by the removal of the hulls, which are rich in unsaturated fatty acids. All peroxide values for both varieties were in conformity with recommended TBS value (≤ 10).

The iodine values for oil from dehulled seeds and undehulled seeds were 141.05 and 148.87 for *Record* variety and the corresponding iodine values for *Kenya Fedha* variety were 141.54 and 153.71 respectively. Results indicated that oil from dehulled seeds had lower iodine value compared to oil from undehulled seeds. The low iodine value in dehulled seeds oil might be attributed by the removal of seed hulls, which are rich in unsaturated fatty acids. For both sunflower varieties the iodine values for oil from dehulled seeds were within the range (110 – 143) recommended by TBS while those for oil from undehulled seeds were higher than the recommended TBS values.

The saponification value was 179.59 for oil from dehulled seeds and 186.44 for oil from undehulled seeds for *Record* variety and the corresponding saponification values for *Kenya Fedha* variety were 176.94 and 185.91 respectively. The saponification values of oil from dehulled seeds were low compared to oil from undehulled seeds for both sunflower varieties. The observed variation may have also been caused by the removal of seed hulls, which are rich in triglycerides that increases mean molecular weight of the fatty acids in the oil. However, all saponification values were within the range (188 – 194) specified by TBS.

Acid values are among the characteristics that are necessary for the confirmation of the identity and edibility of oil. For *Record* variety the acid values of oil from dehulled seeds and undehulled seeds were 2.78 and 3.68 and the corresponding acid values for *Kenya Fedha* variety were 1.92 and 4.67, respectively. Results indicated that oil from dehulled seeds had low acidity than oil from undehulled seeds. The observed difference in acidity might have been due to removal of seed hulls, which are rich in triglycerides which release free fatty acids during the extraction process that increase oil acidity. The acid values for oil from dehulled seeds were in conformity with the TBS recommended value

(≤ 3) while the corresponding acid value for oil from undehulled seeds were higher than the TBS recommended values.

5.8 Cake Yield

Cake yield from dehulled and undehulled seed are given in Table 12. The weight of pressed cake collected after oil extraction was higher for undehulled seed compared to dehulled seed for both sunflower varieties. The lower cake yield from dehulled seed was due to the removal of hulls by dehulling process.

Table 12: Cake yield

Sunflower seed variety	Treatment	Seed sample weight before extraction (kg)	Cake weight after extraction (kg)	Cake Yield (%)
Record	Dehulled	35	19.03	54.4
	Undehulled	35	20.67	59.1
Kenya Fedha	Dehulled	35	25.08	71.7
	Undehulled	35	26.53	75.8

5.9 Quality Analysis of the Pressed Cake

The quality of the pressed cake from dehulled and undehulled seed was evaluated in terms of crude protein, crude fiber and ether extract content. Table 13 summarizes the results of nutrients composition of pressed cakes from dehulled and undehulled seeds.

Table 13: Nutrient composition of the pressed sunflower cake

Sunflower variety	Treatment	DM (%)	ASH (%)	CP (%)	CF (%)	EE (%)
Record	Dehulled	96.83	5.53	44.49	17.71	13.86
	Undehulled	97.20	7.05	29.62	33.41	16.62
Kenya Fedha	Dehulled	96.97	5.47	44.94	17.35	10.56
	Undehulled	97.50	6.93	29.31	23.93	11.65

DM = dry matter, ASH = ash content, CP = crude protein, CF = crude fiber, EE = ether extract.

5.9.1 Crude protein

For both sunflower varieties, the percentage crude protein of dehulled seed cake was higher than that of undehulled seed (Table 13). This was due to relative increase in the proportion of the seed kernels that are rich in protein caused by the removal of the hulls, which are very low in crude protein. Dehulling of seed prior to oil extraction resulted in an increase of crude protein in the cake from 29.62 % to 44.49 % for *Record* variety and from 29.31 % to 44.94 % for *Kenya Fedha* variety. The increase in cake crude protein content for dehulled seeds over undehulled seeds was statistically significant in both sunflower varieties at ($P<0.05$).

5.9.2 Crude fiber

Dehulling of the seeds resulted in decrease in crude fiber content from 33.41 % to 17.71 % for *Record* variety and from 23.93 % to 17.35 % for *Kenya Fedha* variety. The decrease in crude fiber in the dehulled seeds compared to the undehulled seeds was due to the removal of the hulls, which are rich in crude fiber. Statistical analysis of the crude fiber reduction data showed that there was a significant reduction of crude fiber in dehulled seeds compared to undehulled seeds for both sunflower varieties ($P<0.05$).

5.9.3 Ether extract

The results indicated that dehulling process reduced ether extracts of dehulled seeds compared to undehulled seeds from 16.62 % to 13.86 % for *Record* variety and from 11.65 % to 10.56 % for *Kenya Fedha* respectively. The observed variation could be explained by the fact that the removal of hulls, affected more the efficiency of ether extraction of dehulled than undehulled seeds (Nell *et al.*, 1993). Statistically dehulling process had significant effect on reducing ether extract of dehulled seeds compared to undehulled seeds for both sunflower varieties ($P<0.05$).

5.10 Comparison of Nutritive Values of Dehulled Sunflower Cake With FAO Recommended Values

Comparison of nutrients values of dehulled sunflower cake with those in the literature by FAO (2012) for monogastric was based on; dry matter, ash, crude protein, crude fiber and ether extract.

Table 14: Nutrient composition of dehulled sunflower cake and FAO recommended values

Sunflower variety	DM (%)	ASH (%)	CP (%)	CF (%)	EE (%)
Record	96.83	5.53	44.49	17.71	13.86
Kenya Fedha	96.97	5.47	44.94	17.35	10.56
FAO(2012)	91.0	6.6	34.1	13.2	14.3

Proximate composition of centrifugal dehulled sunflower cake and those recommended by FAO (2012) are sumarised in Table 14. Results indicated that for both sunflower varieties four parameters concur with the nutrients values as recommended by FAO (2012), however, only crude fiber content was relatively high. This slight variation in increase in crude fiber might have been attribute by the 10 % hulls added to facilitate oil extraction efficiency (Kibazohi, 2004).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The general objective of this study was to design, fabricate and evaluate the performance of an improved centrifugal sunflower dehuller for improved oil quality, extraction efficiency and cake quality produced by continuous screw expeller in small and medium scale oil expression enterprises in Tanzania. To achieve this objective, two sunflower varieties namely *Record* and *Kenya Fedha* were used. The seed physical properties, machine design factors and operation conditions related to the dehulling process were studied. These properties were then incorporated in designing and fabrication of an improved centrifugal dehuller. Based on the results obtained the following conclusions were drawn:

(i) *Record* sunflower variety showed higher dehulling efficiency and product yield compared to *Kenya Fedha* variety.

(ii) Oil extraction efficiency from dehulled seeds was highly influenced by the dehulling process. Dehulling resulted in increase in oil yield by up to 15.4 % for *Record* variety and 14.6 % for *Kenya Fedha* variety.

(iii) Dehulling resulted in improved oil quality for both sunflower varieties. The physico-chemical properties of oil from dehulled seeds were in conformity with TBS recommended values while those for oil from undehulled seeds were not.

(iv) Dehulling of sunflower seeds improved the pressed cake quality for both sunflower varieties. Dehulling increased crude protein content by 14.78 % and 15.63 %, reduce crude fibre content by 15.7 % and 6.58 %, ether extracts by 2.76 % and 1.06 % for *Record* and *Kenya Fedha* respectively in the dehulled seeds cake compared to undehulled seeds cake.

6.2 Recommendations

Based on the results of this study, the following recommendations are made:

(i) Dehulling of sunflower seed prior to oil extraction is a good idea in increasing sunflower oil yield and improving oil and cake qualities. Therefore, there is need for further studies to determine the optimum amount of hulls that should be left with dehulled seed for facilitating oil extraction without impairing the quality of pressed cake by crude fiber content and residual oil content.

(ii) There is need to design and fabricate a winnower that can be incorporated in the improved centrifugal dehuller so that dehulling and cleaning of the dehulled seeds can be done simultaneausly.

(iii) There is need to modify the developed centrifugal dehuller so as to allow other sources of power such as petrol and diesel engines to be used, especially when the dehuller is to be used in remote areas where electricity is a problem.

(iv) There is a need for further studies on the effect of the various machine design features with a view to find out optimum values for:

  a) Impact angle
  b) Impeller diameter
  c) Impeller speed – where a variable speed inverter should be used instead of varying impeller shaft pulley which cannot be varied in a continous manner.

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APPENDICES

Appendix 1: Annual sunflower production ('000tons) from 2000/2001-2004/2005

REGION	2000/01	2001/02	2002/03	2003/04	2004/05
Arusha	-	7.40	0.44	0.06	0.11
Dodoma	-	0.6	6.58	34.64	16.66
Iringa	-	16.30	7.30	63.48	12.21
Kagera	-	-	0.10	0.02	0.02
Kilimanjaro	-	-	3.72	2.80	0.29
Manyara	-	-	6.37	12.11	5.01
Mara	10.50	-	0.01	0.35	0.19
Mbeya	4.69	1.42	1.81	1.71	2.75
Mwanza	-	-	0.03	0.07	0.02
Morogoro	0.56	0.60	0.13	5.15	2.04
Rukwa	32.12	26.18	6.10	49.96	21.01
Ruvuma	-	0.01	0.40	1.54	1.45
Shinyanga	7.80	8.80	0.46	2.57	2.84
Singida	25.20	42.50	21.34	72.64	67.00
Tabora	-	0.63	0.15	0.74	0.89
Tanga	-	0.01	0.03	0.00	1.87
TOTAL	80.87	104.40	55.04	247.84	134.36

Source: Source: Ministry of Agriculture, Food and Cooperative (2008), cited by Mpagalile *et al.* (2008).

Appendix 2: Oil processing during 1999/2000-2006/2007 cropping season

Year	Sunflower oil (tons)
1999 / 2000	11 560
2000 / 2001	19 409
2001 / 2002	25 056
2002 / 2003	26 986
2003 / 2004	25 515
2004 / 2005	21 325
2005 / 2006	89 614
2006 / 2007	88 753

Source: RLDC (2008)

Appendix 3: Determination of moisture content of sunflower seeds

Sunflower variety	Lid weight (g)	Lid+ sample before drying (g)	Lid+ sample after drying (g)	Moisture content (%)
Record	36.70	46.70	46.10	6.0%
Kenya Fedha	39.77	49.77	49.10	6.0%

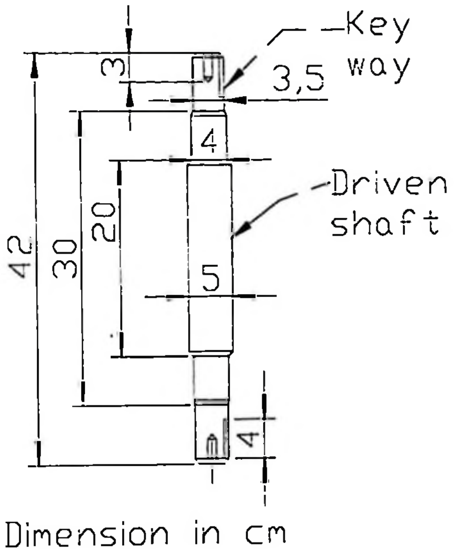
Appendix 4: Determination of optimum dehulling speed

Impeller Speed (rpm)	Sunflower variety	Dehulling time (s)	Dehulled kernels (kg)	Partially and undehulled seeds(kg)	Kernels breakage (kg)	Throughput capacity (kg/h)	Dehulling efficiency (%)	Product yield (%)
963	*Record*	47.29	2.342	0.950	0.142	380.55	80	68.7
	Kenya Fedha	42.43	2.242	1.033	0.058	424.19	79.3	66.7
1445	*Record*	38.53	2.325	0.650	0.158	467.12	87	62.7
	Kenya Fedha	35.82	2.317	0.542	0.250	502.55	89.1	62.2
2890	*Record*	27.20	1.825	0.283	0.483	661.76	94.3	51.8
	Kenya Fedha	25.43	1.983	0.342	0.358	707.73	93.1	53.7

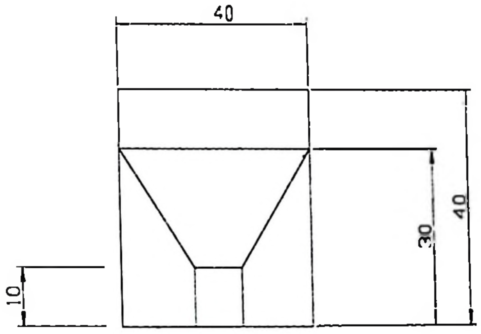
Appendix 5: Evaluation of the dehuller performance

Impeller speed(rpm)	Sunflower variety	Dehulled (kg)	Undehulled (kg)	Broken kernels (kg)	Hulls (kg)
963	*Record*	4.72	2.03	0.283	2.960
963	*Kenya Fedha*	4.48	2.07	0.116	3.330

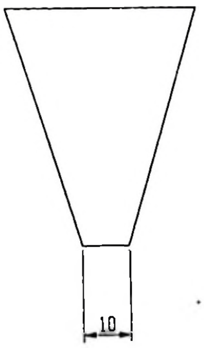
Appendix 6: Dehuller shaft



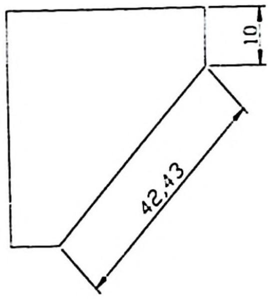
Appendix 7: Dehuller hopper different views



Top View



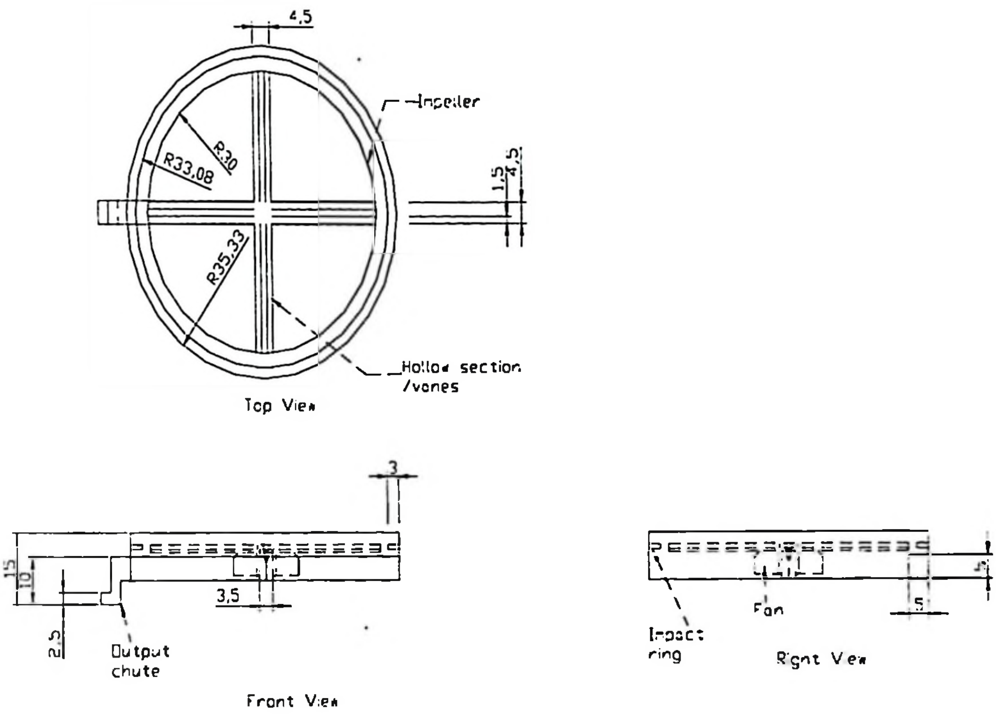
Front
View



Right
View

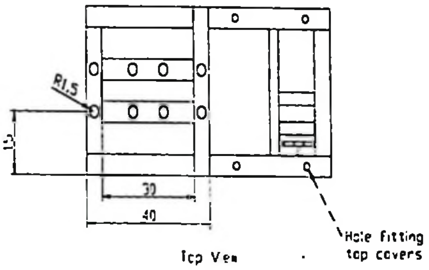
Dimension in cm

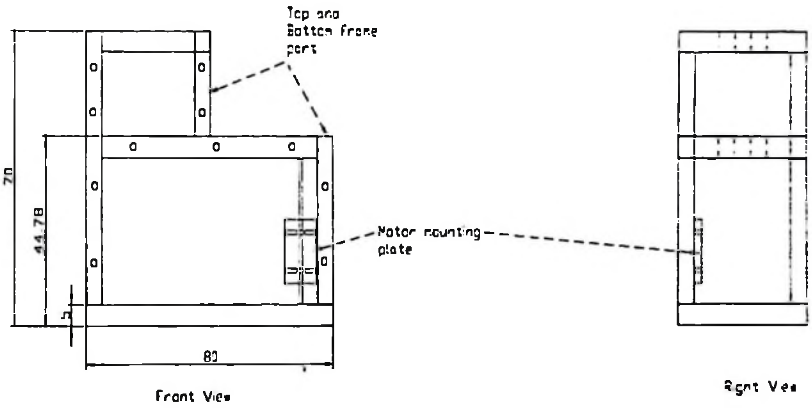
Appendix 8: Impeller and dehuller bottom part different views



Dimension in cm

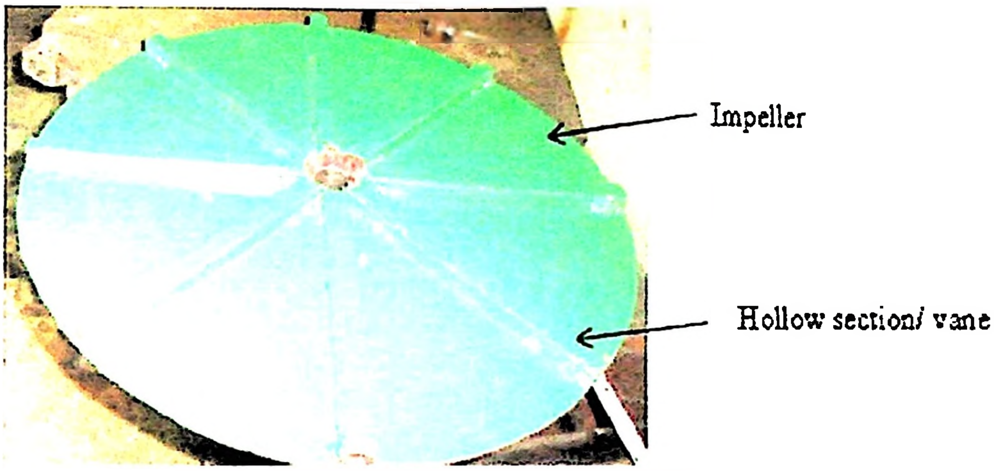
Appendix 9: Machine frame different views



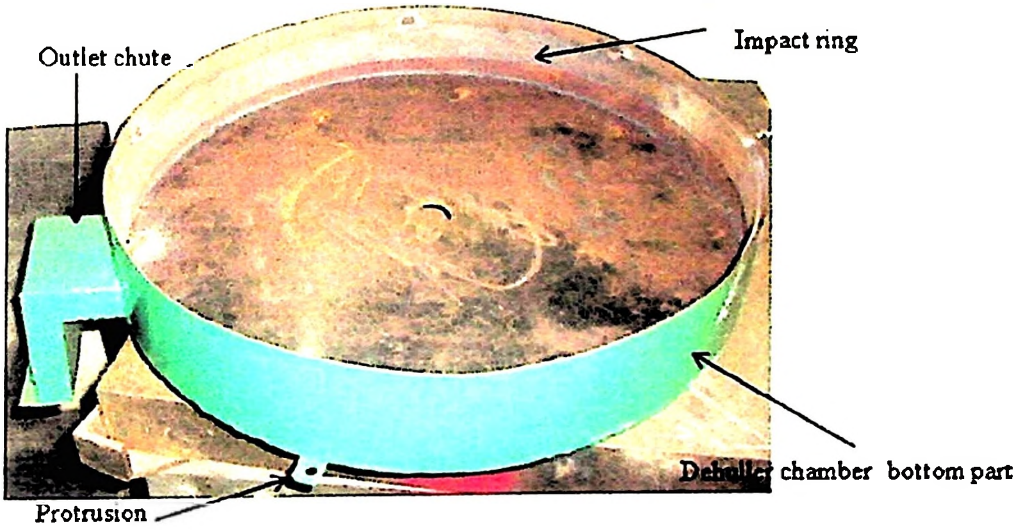


Dimension in cm

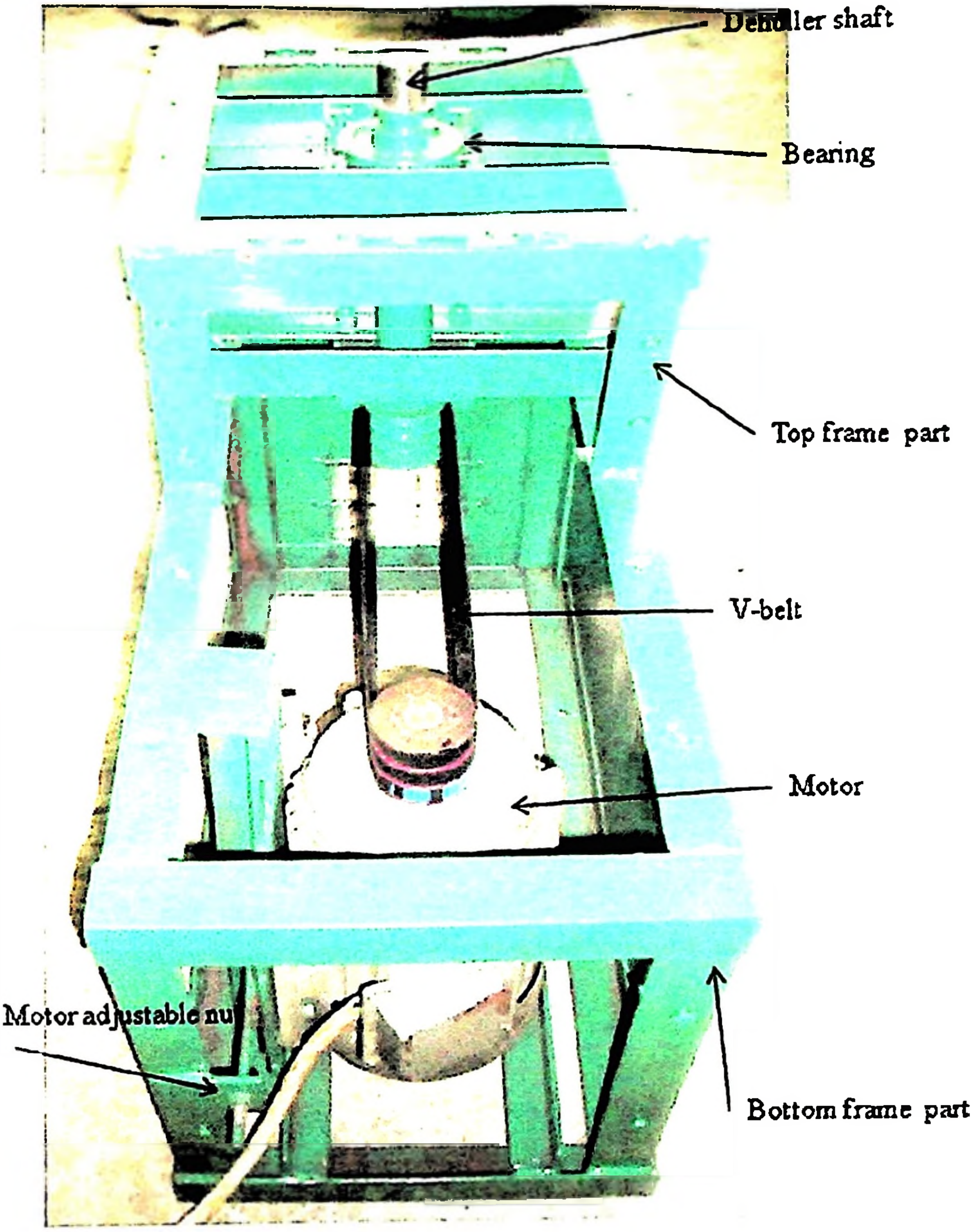
Appendix 10: Photographs of different components of the dehuller



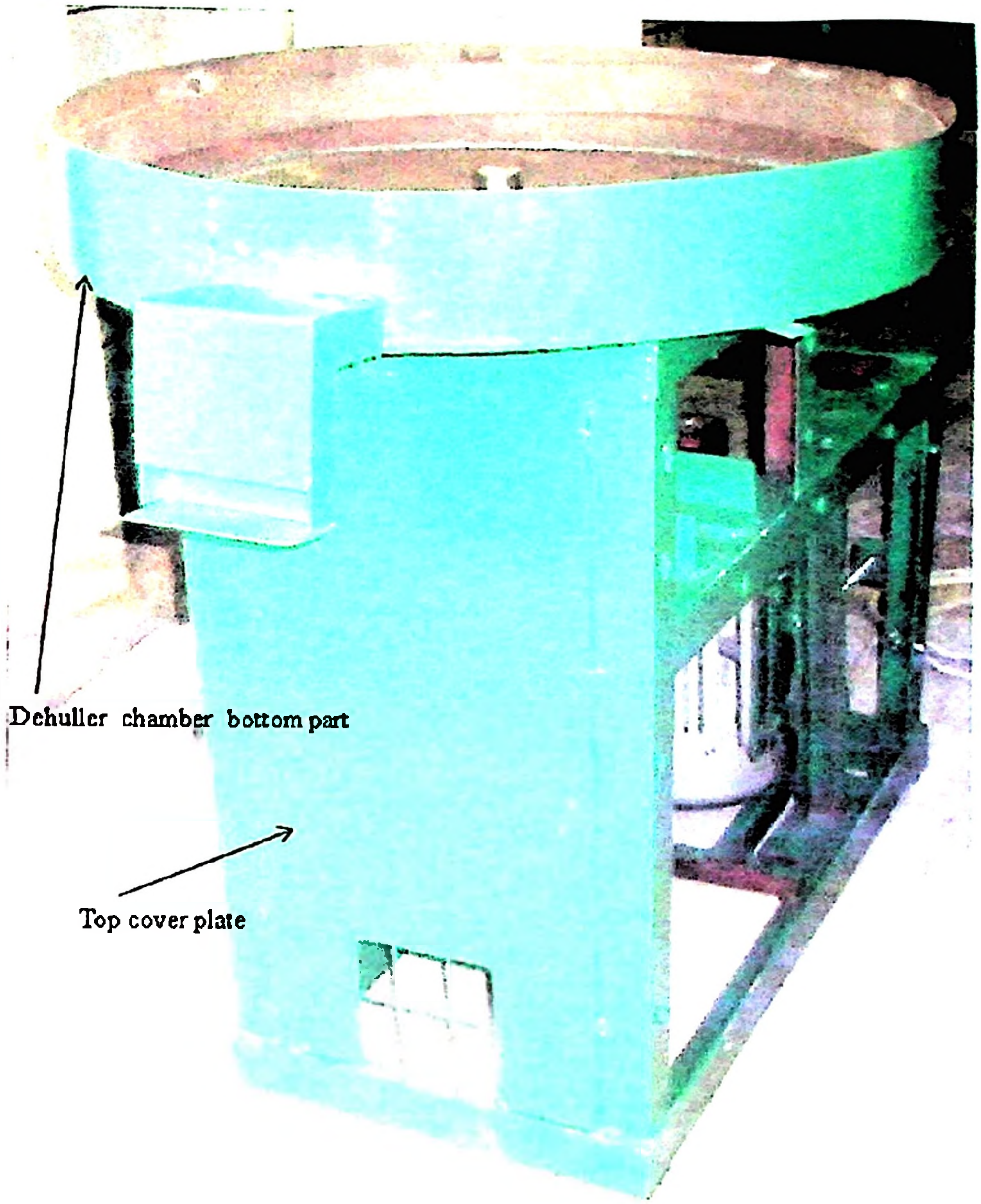
Photograph of the impeller



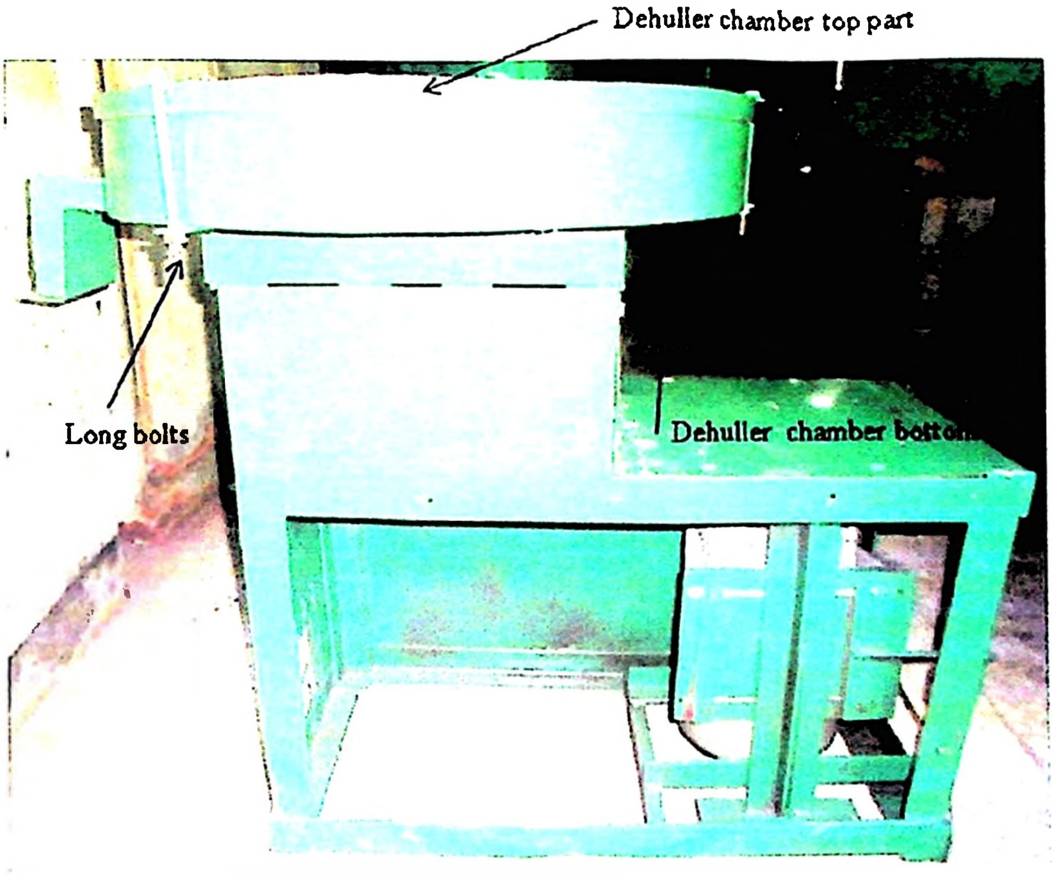
Photograph of the dehuller chamber bottom part



Photograph of the dehuller frame



Photograph of the dehuller chamber bottom part on the frame



Photograph of the dehuller chamber on the frame