DEVELOPMENT OF A BAMBARA GROUNDNUTS SHELLER

LITERATURE REVIEW AND PROJECT PROPOSAL

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PREFACE

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ABSTRACT

Bambara groundnut (*Vigna subterranean (L) Verdc*) is an indigenous African crop. It is classified as a drought resistant crop that produces yields even in low fertile soil conditions. This crop is currently grown by rural or subsistence farmers in South Africa. Current research on this crop is primarily focused on the agronomic and breading aspect. Information on the physical properties and availability of processing equipment of bambara groundnuts is limited. As a result, this challenge creates a stumbling block in terms of resources for rural farmers during the processing and preservation of bambara groundnuts. The main objective of this research project is to determine the physical properties of bambara groundnut pods, kernels, and nuts that are required for designing a bambara groundnut sheller. The physical properties determined in this study will include cracking force, weight, dimensions, porosity, bulk density, true density, angle of repose, and volume. The bambara groundnuts will be set at three different moisture content which are 6, 15, and 20%, using the Association of Official Agricultural Chemistry method (AOAC). Microsoft Excel will be used to analyse this quantitative data from the three different moisture contents to acquire the design parameters, such as maximum cracking force, static coefficient of friction and porosity. Then, the physical properties will be used to develop a portable bambara groundnut sheller that uses either a petrol engine or electrical motor. The bambara groundnut shelling machine will consist of a hopper, shelling chamber, blower, and power source.

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1. INTRODUCTION

In the past, a combination of fertiliser application, pest control, and irrigation systems resulted in an increase in yield production. However, due to water shortages and water pollution, crops that require less agricultural management such as application of fertiliser and irrigation are required to sustain food security (Aydin, 2002 ; Dordas, 2009). Introducing crops that are drought resistant will reduce water usage in the agricultural sector and reduce the level of poverty, especially in the African continent.

The bambara groundnut crop (*Vigna subterranean (L) Verdc*) is an indigenous crop that originated from West Africa, and it was widely distributed to the rest of Africa by indigenous people (Swanevelder, 1998 ; Department of Agriculture and Fisheries, 2011). This crop is primarily cultivated by small-scale and subsistence farmers for both human and animal consumption (Koné *et al.*, 2009). The groundnut crop can also be classified as a drought resistances plant, and it also has the an ability to produce good yields on poor soil conditions (Berchie *et al.*, 2012 ; Hillocks *et al.*, 2012).

Bambara groundnuts are legumes which have compact and well-developed tap roots. The leaves are approximately 15 cm long, stiff, and green in colour (DAFF, 2011). The pods of these groundnuts are grown below the soil, with a round shape, and wrinkled with one or two seeds, while the seed inside the pods are brown, yellow or purple when matured (DAFF, 2011). According to DAFF (2011), these types of plants take 7 to 15 days to germinate, the seeds should be stored for approximately 12 months before planting. The flowering takes place after 30 days from planting (Atiku *et al.*, 2004 ; DAFF, 2011). These groundnuts grow during the summer season (Swanevelder, 1998). The soil PH must range between 5 and 6.5, at the temperature between 20 to 28 ˚C, and these crops can be grown in poor soils (Swanevelder, 1998 ; DAFF, 2011). In rural farming, commercial fertilisers are not used. Instead, animal manure is used to provide nutrients for these plants (Nigam *et al.*, 2004).

Bambara groundnuts contribute to increased food production, especially in West African countries. This crop is also grown for its high protein (Massawe *et al.*, 2005). Primarily, this crop is grown for human consumption, the pods or seeds are usually consumed while they are still green, immature or when they are dry (DAFF, 2011 ; Hillocks *et al.*, 2012 ; Khan *et al.*, 2017). According to Massawe *et al.* (2005), these groundnuts can also be used to produce milk similar to soya bean milk which is rich in proteins. In other African countries, such as Nigeria and Burkina Faso, bambara groundnuts are used in production of cosmetics, pharmaceutical products. Farmers also use groundnut kernels, leaves, and stalks in animal feed (DAFF, 2011 ; Hillocks *et al.*, 2012). In Botswana and Ghana, people use these groundnuts to produce flour for baking. Studies have also shown that bambara groundnuts have potential to produce oil (Brough *et al.*, 1993 ; Mkandawire, 2007 ; Mpotokwane *et al.*, 2008). According to Massawe *et al.* (2005), bambara groundnuts are consumed in Asia during special occasions, and usually this nuts are served as snacks.

Recent research on bambara groundnut has focused on agronomic and breeding aspects (Khan *et al.*, 2017). Bambara groundnuts are shelled manually. However, the shells are hard to break, which makes shelling tedious (Atiku *et al.*, 2004 ; Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b). Thus, it is clear that the development of a sheller for bambara groundnuts is required to assist in the promotion of bambara as a potential industrial crop (Mkandawire, 2007).

There is limited information on the physical properties of unshelled bambara groundnuts. The only literature encounter was of the physical properties of seed of bambara groundnuts nuts (Mpotokwane *et al.*, 2008)**.** However, during the design process of bambara groundnuts processing equipment, such as a sheller, dusking equipment and harvesters, the physical properties the whole unshelled nut are required. Pliestic *et al.* (2006) used the universal testing machine to determine the cracking force required to crack filbert nut and kernel. This method can also be adopted to find the maximum cracking force required to break the kernels and nuts of bambara groundnuts. The cracking force can be used to find the maximum power required to shell these types of groundnuts.

The available bambara shelling machine consists of several main components including a hopper, blower, cracking chamber, and power transmission system (Atiku *et al.*, 2004 ; Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b). The available machine uses huge electrical motors to operate, whereas in rural areas most people do not have access to electricity on their farms. Therefore, these machines cannot be adopted to be used in rural farms. A low power consumption machine is required to suit rural farms. To commercilase the production of bambara groundnuts, a portable sheller that will use low energy during operating is required to accommodate rural farmers. In rural farms, the separation of the kernels and nuts during shelling is done manually, which is labour intensive and time consuming (Mkandawire, 2007 ; DAFF, 2011). Development of a bambara groundnut sheller that has a pneumatic cleaner still needs to be designed.

In this project, the physical properties of the bambara groundnut pods, nuts, and kernels will be determined. The physical properties will then be used during the design process of a shelling machine that can be used in rural farmers. The main objectives of this research are to investigate the physical properties of Bambara groundnuts and then develop a portable sheller. The sheller should use less power consumption to accommodate rural farmers.

This document is divided into several chapters. Chapter 2 is the literature review of bambara groundnuts. In this chapter, the bambara groundnuts production will be outlined from planting up until the shelling process. The available processing techniques will also be reviewed in this chapter. Chapter 3 is a project proposal. In this chapter methods and material that will be used during the determination physical properties of bambara groundnuts will be outlined. Also, the conceptual design of the sheller will be detailed explained.

2. LITERATURE REVIEW

In this chapter, a summary of relevant literature review will be outlined.

2.1 Global Production of Bambara Groundnut

The world's production of bambara groundnuts is approximately 330 000 tons per year. However, West Africa's production is about 45 to 50 % of the world's production (Koné *et al.*, 2009; Ibrahin and Ogunwusi, 2016). Global demand for bambara groundnuts is higher than current rates of production. That means there is potential for bambara groundnut production to be industrialised (Brough *et al.*, 1993 ; Swanevelder, 1998 ; Hillocks *et al.*, 2012). In semi-arid zones, bambara groundnuts can produce a yield between 450 to 850 kg ha^{-1} (Koné *et al.*, 2009 ; Ibrahin and Ogunwusi, 2016).

2.2 Bambara Groundnuts Production in Africa

The Food and Agriculture Organisation has statistical information about three African countries that grow bambara groundnuts for human and animal consumption. However, six or more countries also grows bambara groundnuts for human and animal consumption. (Swanevelder, 1998 ; Hillocks *et al.*, 2012 ; STATS, 2014). Production yields of bambara groundnuts have declined since 2012, due to limited research focus on these crops (Ibrahin and Ogunwusi, 2016). There are no post-harvest technologies available for processing this crop. As a result, production yields and consumption tends to decline over time. This trend is illustrated by **Error! Reference source not found.** (STATS, 2014).

In Africa, Nigeria has the highest yield production of bambara groundnuts and is approximately 10 000 tons per year, which is equivalent to the yield of 800 $kg \cdot ha^{-1}$ (Koné *et al.*, 2009 ; Adebowale *et al.*, 2011). In Zimbabwe, bambara groundnuts are inter-cropped with maize during the rainy season, since the growers believe that intercropping improves soil conditions and fertility (Hillocks *et al.*, 2012).

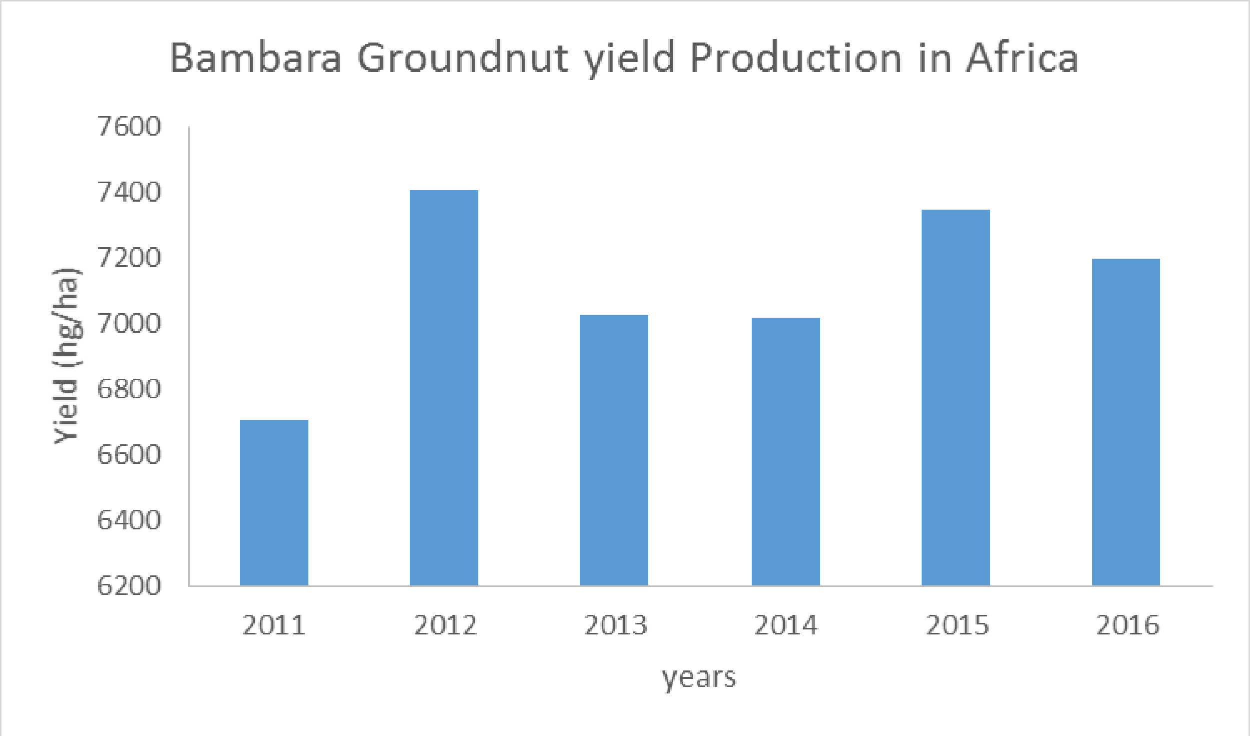

Figure 2.1 The summary of bambara groundnut yield production in Africa (STATS, 2014)

2.3 Bambara Groundnut Production in South Africa

In South Africa, bambara groundnut s are cultivated in the Mpumalanga, Limpopo, and KwaZulu-Natal provinces. The crop was migrated by indigenous people from West Africa to South Africa (Swanevelder, 1998 ; Department of Agriculture and Fisheries, 2011 ; Mabhaudhi and Modi, 2013). The groundnut is currently grown by small-scale farmers in an area that ranges in between 300 to 2500 m^2 per farmer. Yield production is approximately 300 $kg{\cdot}ha^{-1}$ (Swanevelder, 1998).

2.4 Bambara Groundnut Consumption in Africa

Bambara groundnuts are consumed while they are still immature or when they are dry. Fresh seeds are boiled with or without shells and mixed with boiled maize (Swanevelder, 1998 ; Department of Agriculture and Fisheries, 2011 ; Abdualrahman *et al.*, 2016). In some countries, such as Ghana and Nigeria, a bambara groundnut gravy is produced and sold to supermarkets (Abdualrahman *et al.*, 2016). In Burkina Faso, Botswana, and Nigeria, these groundnut are crushed to produce flour for making porridge and cakes (Hillocks *et al.*, 2012).

2.5 Physical Properties of Bambara Groundnuts

Physical properties are important for the design of planting, harvesting, sorting, processing, and transporting equipment (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007 ; Mpotokwane *et al.*, 2008). During the design and fabrication of a shelling machine, physical properties are required for sizing the machine components including a hopper, cleaning system, shelling unit, transmission and power system (Mpotokwane *et al.*, 2008). Physical properties are required during the design of a specific component in the shelling machine. For example, when sizing the hopper, the designer needs to know the static coefficient, and volume of the bambara groundnuts.

2.5.1 Dimensions

According to Oluwole *et al.* (2007b), the effective moisture for the shelling process is 8 %. Therefore, it is important to measure the physical properties at this moisture content to obtain accurate results. To find the dimensions of the bambara groundnut pods and nuts, a caliper is used to measure the length, width, and thickness (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007 ; Kibar and Ozturk, 2008). According to Mpotokwane *et al.* (2008), the average length, width, and thickness of bambara groundnut nuts were found to be 11.01 mm, 9.96 mm, and 9.48 mm at 5 % moisture content (Mpotokwane *et al.*, 2008). However, there is no available literature where the dimensions of the pods and kernels were measured. During the design of the hopper and storage equipment, the size of the whole seeds are required. This is so that an effective hopper and storage can be sized to accommodate a certain number of groundnuts based on the design specifications (Kibar and Ozturk, 2008 ; Mpotokwane *et al.*, 2008).

2.5.2 Weight

The weight of the groundnuts requires important consideration during the design of the harvesting, planting, and shelling equipment (Pliestic *et al.*, 2006 ; Oluwole *et al.*, 2007b ; Yalcin and Ersan, 2007). The weight is measured using the digital weighing scale, and based on literature, the average weight of the bambara groundnut nuts was found to be 0.60 kg (Mpotokwane *et al.*, 2008). From the review of literature, only the average mass of the nuts without the kernel is recorded. However, in the design of the shelling machine, the mass of the pods is also required to determine the required feed rate (Ogunlade *et al.*, 2014). The weight of the seed with the kernel still needs to be determined from experiments.

2.5.3 Volume

During the design of the hopper of the shelling machine, or any processing machine for seeds, the volume of the pods is required to size the holding capacity of the hopper. The volume of the seeds depends on their dimensions (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007 ; Mpotokwane *et al.*, 2008).

Sphericity, surface area, and porosity are related to volume and dimension, which are also required as design parameters. In addition, these parameters are also used for classifying the shape of the groundnuts (Yalcin and Ersan, 2007 ; Kibar and Ozturk, 2008 ; Mpotokwane *et al.*, 2008). The method of Asoegwu *et al.* (2006) is commonly used to measure the dimensions of the seeds. In this method, 100 seeds at different moisture contents are collected randomly from the bowl. The dimensions (length, width, and thickness) of the seeds are then measured using a Vernier caliper (Mpotokwane *et al.*, 2008).

Equation 2.1 is used to calculate the volume of a groundnut from the dimensions results (Bart-Plange and Baryeh, 2003 ; Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007 ; Mpotokwane *et al.*, 2008).

$$V=\frac{\pi B^2 L^2}{6(2L-B)} \tag{2.1}$$

Where:

V=volume of the seeds,

L=length of the seed, and

B= parameter that relate to the width (W) and thickness (T).

$B=(WT)^{0.5}$

2.5.4 Sphericity

Sphericity measures how closely the shape of the seed approaches the perfect sphere (Jain and Bal, 1997 ; Bart-Plange and Baryeh, 2003 ; Yalcin and Ersan, 2007). This parameter can be related to the static efficiency of friction. The closer a seed is to a perfect sphere, the lower the static efficiency of friction. This parameter will be used during the design of the hopper side slopes and cleaning system. However, to design the hopper and cleaning system, the sphericity of both the pods and nuts is required. Sphericity can be calculated by using the dimensions of the Bambara groundnuts (Gupta and Das, 1997 ; Bart-Plange and Baryeh, 2003 ; Pliestic *et al.*, 2006). Equation 2.2 is used to calculate the sphericity of a seed (Bart-Plange and Baryeh, 2003 ; Kibar and Ozturk, 2008).

$$\emptyset = \frac{(LWT)^{\frac{1}{3}}}{L} \qquad (2.2)$$

Where

$\emptyset$= sphericity of a seed,

L= length of a seed (mm),

W= width of a seed (mm), and

T= thickness of a seed (mm).

2.5.5 Seed porosity

Porosity can be defined as the free spaces between the packed seeds which are not occupied by the seeds, this parameter is used during the design of storage facilities of the seed (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007). The porosity can be calculated by using true density and bulky density of the seeds (Gupta and Das, 1997 ; Yalcin and Ersan, 2007 ; Mpotokwane *et al.*, 2008). Equation 2.3 is used to determine the porosity for seeds and pods (Yalcin and Ersan, 2007 ; Mpotokwane *et al.*, 2008).

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad (2.3)$$

Where

ε= seed porosity (%),

ρ_t= true density ($kg.m^{-3}$), and

ρ_b= bulky density ($kg.m^{-3}$).

The bulk density is the ratio of mass of the sample to its total volume and this parameter can be determined by filling 50 ml container with seeds and measures the weight (Aydin, 2002 ; Yalcin and Ersan, 2007 ; Mpotokwane *et al.*, 2008). True density is the density of the groundnuts without space in between the pods, and the standard methods used to measure true density is called toluene displacement (Aydin, 2002 ; Bart-Plange and Baryeh, 2003 ; Zewdu, 2011). The groundnuts are filled in 100 ml container and toluene chemical is used to measure the volume of the free space in the container.

2.5.6 Static coefficient of friction

The static of coefficient of friction can be determined on different surfaces of materials, including rubber, galvanised steel, stainless steel and plywood (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007). The nuts and kernels should be placed on adjustable tilting plates. The plate is raised until the material on top starts to slide, and at that point, the angle is recorded (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007 ; Mpotokwane *et al.*, 2008). This method is repeated on different materials that are used for transporting, processing and harvesting equipment. In shelling machines, the static coefficient can used to determine the inclination angle of hopper and cleaning systems (Aydin, 2002 ; Mpotokwane *et al.*, 2008).

2.5.7 Maximum cracking force

The force required to crack the nuts and kernels can be measured with laboratory Texture universal testing machine. This machine compresses the seed and records the maximum force that induced to the groundnut before cracking it (Pliestic *et al.*, 2006). There is no available literature on measuring the cracking force for bambara groundnuts. However, there is an available method was adopted to an available literature were (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007) measuring cracking force for filbert nuts.

2.6 Processing Involve During Post Harvesting

The post-harvesting process in different types of groundnuts will be outlined in this section including harvesting, drying, shelling and cleaning.

2.6.1 Harvesting

Bambara groundnuts are harvested manually when the plant leaves start to turn yellow (Swanevelder, 1998 ; Zewdu, 2011). During harvesting, the whole plant is pulled out from the ground gently to avoid pod loss (Aydin, 2002 ; Oluwole *et al.*, 2007a). In small scale-farming, there is no available equipment to harvest these type of groundnuts, so harvesting is done manually. **Error! Reference source not found.** illustrates manual harvesting that was done by a rural family (Swanevelder, 1998).

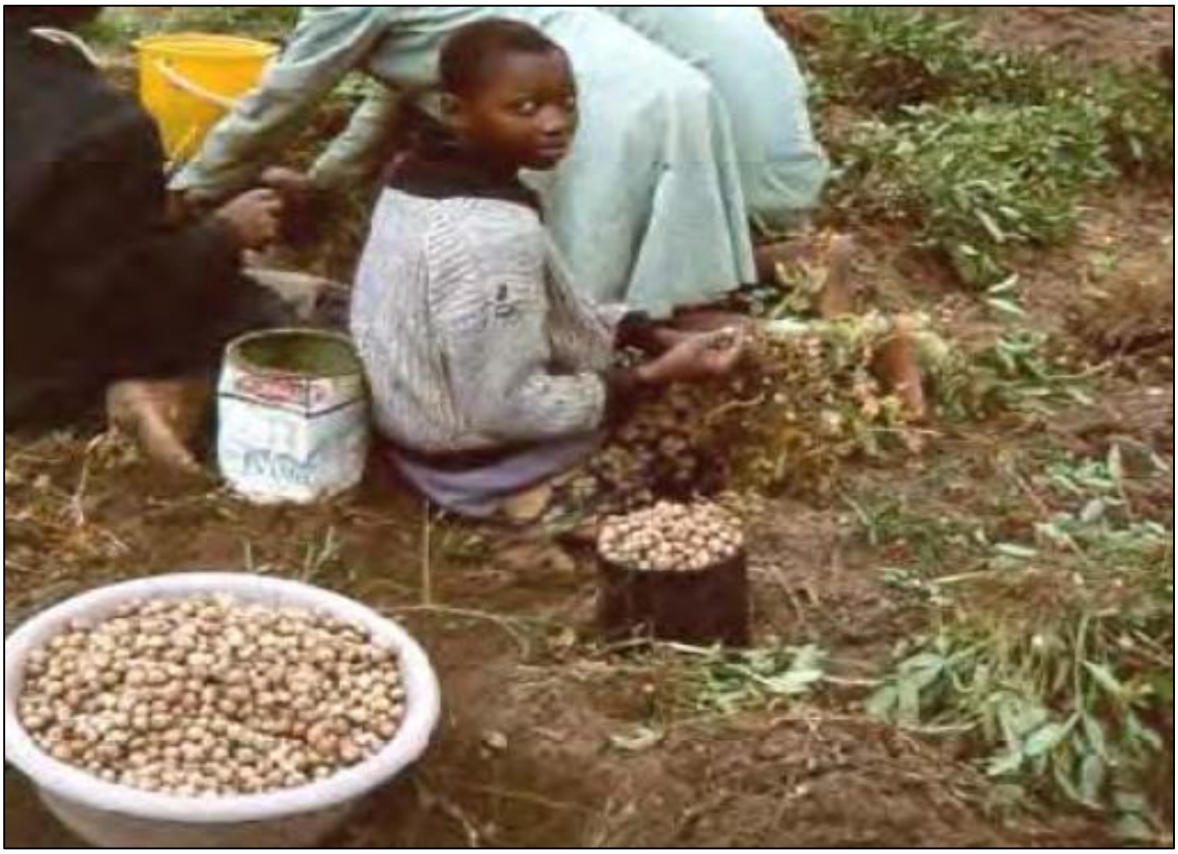

Figure 2.2 Manual harvesting of bambara groundnuts (Swanevelder, 1998)

The pods can also be harvested while green to be boiled and served as snacks, during this time the harvester should pull off the plant to avoid pod loss and the remaining pods are removed by hoe (DAFF, 2011). Commercially, other types of groundnuts are harvested using a conventional combine equipment. This equipment combines activities including harvest, threshing, and shelling at the same time (L. Butts *et al.*, 2009 ; Torres *et al.*, 2014). According to Torres *et al.* (2014), the groundnuts harvested with a conventional combine harvester have 11% of foreign material.

2.6.2 Drying

After the groundnuts have been harvested, the rural farmers leave the pods on the ground for sun drying for one or two days (Mkandawire, 2007 ; DAFF, 2011). However, this practice could lead to post-harvest loss. Proper drying and storage facilities are required to avoid food loss (Aydin, 2002 ; Mkandawire, 2007). The required moisture content of the groundnuts before shelling ranges between 5 to 8 % dry basis, which can be achieved by leaving the pods in the sun to dry for approximately 6-7 days (Oluwole *et al.*, 2007a).

2.6.3 Shelling

Rural farmers use manual shelling where sticks and stones are used to remove the groundnut kernels. However, this traditional method was found to be inefficient, time-consuming, and laborious with low output (Nigam *et al.*, 2004 ; Mohammed and Hassan, 2012). On shelling machine, the manual machine was found to have low machine capacity with high mechanical compared to engine drive machine (Atiku *et al.*, 2004 ; Mohammed and Hassan, 2012).

Conventional combine harvesters that are used in large-scale farming are not suitable for harvesting bambara groundnuts. There, therefore, exists a need to modify the conventional combine harvester so it can accommodate bambara groundnut harvesting (Hillocks *et al.*, 2012 ; Torres *et al.*, 2014). The physical properties of bambara groundnuts will be required to adequately modify the conventional combine harvester. The combine harvester can achieve up to 62 % shelling efficiency while outfield shelling machine achieved up to 80 % (Atiku *et al.*, 2004 ; Mohammed and Hassan, 2012 ; Ugwuoke *et al.*, 2014).

Shelling machines suitable for bambara groundnuts are not yet available in South African. This is due to limited research focus on the physical properties of bambara groundnuts. This challenge is a constraint to the large-scale production of bambara groundnuts. (Atiku *et al.*, 2004 ; Butts *et al.*, 2009).

2.6.4 Cleaning

There are two cleaning systems that are commonly used to remove chaff and foreign material namely, manual and mechanical systems. These two systems are outlined in this section.

(a) Manual cleaning

After manual shelling, the groundnut seed, chaff, and kernel are mixed together, so a cleaning system is required to separate the nuts from the rest of the material. In rural farming, a winnowing process is used to remove the chaff and foreign material from the groundnuts (Nigam *et al.*, 2004). This method can also be classified as density separation because wind is used to separate the chaff and foreign material from nuts. According to Atiku *et al.*, (2004), the winnowing process can be done by vigorously moving a container with shelled materials up and down. As the material fall by gravity, the air passes through the groundnuts removing the chaff from the nuts. This method is the basic-indigenous cleaning system.

(b) Mechanical cleaning

Mechanical cleaning of groundnuts can be achieved either by blowing or sieving, depending on the process at which this system had been installed (Nigam *et al.*, 2004 ; Ugwuoke *et al.*, 2014). This system can either be combine or work separated.

Vibrating sieves are commonly used to eliminate chaff, sand and broken pods. However, this system cannot remove empty or large kernels. The blowing process uses an airflow fan which removes the empty pods based on density. The combination of vibration sieves and blowing is a more efficient process for cleaning groundnuts after shelling (Atiku *et al.*, 2004 ; Ugwuoke *et al.*, 2014).

During sizing of a blow fan, the terminal velocities of the kernels and nuts are required, these parameters are important to prevent the nuts from being blown out during the cleaning process (Atiku *et al.*, 2004 ; Özgüven and Vursavuş, 2005 ; Oluwole *et al.*, 2007a). The terminal velocity of the kernels is usually low compared to the terminal velocity of the nuts, and this parameter is also dependent on the density of the materials (McHale *et al.*, 2009). Özgüven and Vursavuş (2005) used a theoretical equation to find the terminal velocity of pine nuts. The average terminal velocities of the nuts and kernels was found to 8.23 and 6.98 $m.s^{-1}$

respectively. Equation 2.4 is used to calculated terminal velocity of any groundnuts (Özgüven and Vursavuş, 2005).

$$V_t = \frac{R_e * \mu_f}{D\rho_f} \tag{2.4}$$

Where

V_t= terminal velocity ($m.s^{-1}$),

R_e= renould's number,

D= geometric mean diameter (m),

μ_f= absolute vascosity, and

ρ_f= mass density of air ($kg.m^{-3}$).

2.7 Machinery used for Processing Groundnuts

The unavailability of groundnut processing machines, especially those for shelling, has had a negative impact on the commercialisation of bambara groundnut production (DAFF, 2011 ; Raghtate and Handa, 2014). The lack of shelling machines and other processing equipment has caused a decline in the production of bambara groundnuts over the years (Aydin, 2002 ; DAFF, 2011 ; Hillocks *et al.*, 2012). There are post-harvest processing machines that are used in industry to process groundnuts. These include threshing and shelling machines.

2.7.1 Threshing machines

Commercially, groundnuts are harvested using a combine conventional threshing machine, these types of machines are usually mounted onto a tractor (L. Butts *et al.*, 2009). Small scale farmers use threshing machines that are use electric, human and fuel power. Threshing machines have six major components including the frame, threshing drum, cleaning, and transmission system (Maduako *et al.*, 2006). The threshing drum is the most important component. This component includes hollow pipes, shaft and rubber flaps, which separate the kernel from nuts (Maduako *et al.*, 2006 ; Ali, 2007 ; Ogunlade *et al.*, 2014). Figure 2.3 illustrates the structure of a threshing drum.

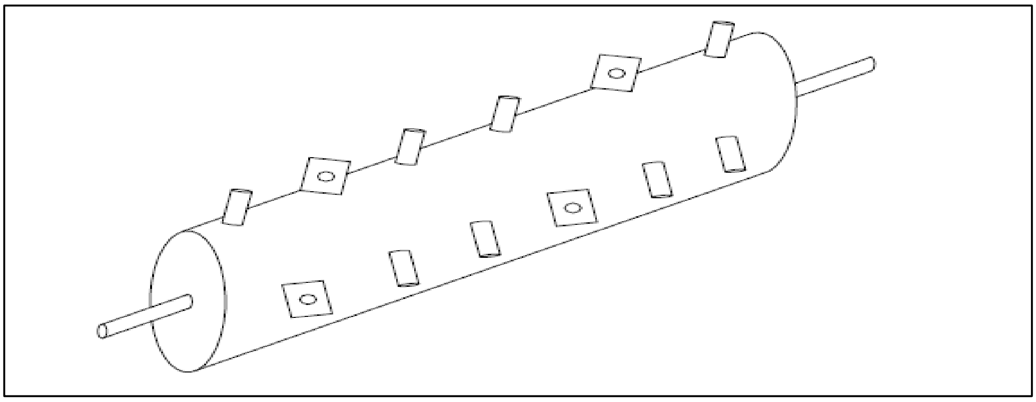

Figure 2.3 Threshing drum (Ogunlade *et al.*, 2014)

The pods are primarily stored in the hopper, and then the groundnuts are released from the hopper to the threshing chamber where the kernels are broken down by the threshing drum. The threshed material is transported to the cleaning system which removes chaff and foreign material (Ogunlade *et al.*, 2014). The cleaning system includes a sieve, blowing fan and transmission system (Ali, 2007 ; Ogunlade *et al.*, 2014). Table 2.1 shows a summary of specifications and machine performances of available threshing machines for small scale farmers (Ali, 2007 ; Ogunlade *et al.*, 2014). The performance of the threshing machines depends on the moisture content. Increasing moisture content has direct proportionality with mechanical damage and reduces the threshing efficiency (Ali, 2007 ; L. Butts *et al.*, 2009 ; Ogunlade *et al.*, 2014). The fully assembled threshing machine can be seen in Appendix, **Error! Reference source not found.**.

Table 2.1 A summary of the available threshing machines performance at an average moisture content of 8% (Ali, 2007 ; Ogunlade *et al.*, 2014)

Parameters	Threshing Machines Performance
Operational speed	290 rpm to 300rpm
Capacity	345.5 to 3532 kg.hr^{-1}
Cleaning efficiency	46-64 %
Mechanical loss	Up to 30 %
Power consumption	4.5 kW
Threshing efficiency	65-89 %

2.7.2 Shelling machines

There are two types of shelling machines that are commonly used to shell bambara groundnuts, namely roller and centrifugal crackers (Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b ; Mohammed and Hassan, 2012). The roller cracker mechanism consists of a hopper, shelling units (rollers), winnowing system and power system (Atiku *et al.*, 2004). The hopper inclination depends on the angle of repose for the groundnut pods. The shelling units consist of two rollers: one stationary and the other driven by a pulley and belt (Atiku *et al.*, 2004). Furthermore, the winnowing system consists of a sieve and blowing fan which remove the chaff from the nuts. The roller cracker uses electrical motor.

A centrifugal shelling machine for bambara groundnuts consists of a hopper, shelling unit (impeller), separation units and the power system (Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b ; Mohammed and Hassan, 2012). The working principles of the centrifugal and roller crackers are the same but the difference is that the centrifugal machines use impellers in the shelling units instead of rollers. Mohammed and Hassan (2012), investigated both manual and electrically powered centrifugal shelling machines, concluding that the manual machine had higher mechanical loss and less capacity compared to electrically powered machine.

Atiku *et al.* (2004) developed a shelling machine for bambara groundnuts which used the roller cracker. This machine caused 20 % mechanical damage. In Nigeria, a centrifugal shelling machine was also developed. The performances of this machine was better compared to the roller cracker technique that was developed by Atiku *et al.* (2004). Oluwole *et al.* (2007b) concluded that the centrifugal was the best method to be used for shelling groundnuts. Table 2.2

Table 2.1 shows the summary of performances that are available in centrifugal shelling machines that were found in literature.

Table 2.2 Summary of shelling machine performances (Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b ; Mohammed and Hassan, 2012)

Parameters	Shelling Machines Performances
Operation speed	1000-1300 rpm
capacity	96.3 to 215.8 $kg.hr^{-1}$
Cleaning efficiency	79.5 to 85 %
Shelling efficiency	65 to 89 %
Mechanical loss	Up to 20%
Power consumption	2.6 Kw

2.8 Energy used During the Processing of Groundnuts

During the processing of groundnuts, various types of energy are used such as manual, petroleum, renewable energy, and electrical power. These types of power will be outlined in the following section.

2.8.1 Manual power

Manual power can be used in machines in different ways, such as pedalling and hand cracking. Pedal power has become the most reliable power system that can be used to power machines for rural farmers or small-scale farmers. Human beings can produce 50 to 250 watts during pedalling (Farina *et al.*, 2004 ; Megalingam *et al.*, 2012). Pedalling can power a machine either by mechanical power or converting mechanical power to electrical power using a dynamo (Farina *et al.*, 2004). According to Megalingam *et al.* (2012), the maximum pedalling speed was found to be 120 rpm. However, available shelling machines operate at speeds of 1000 to 1300 rpm, so using pedalling power will require excess transmission system to increase the pedalling speed. In addition, this can increase initial and operating costs of the machine.

Hand cracking machines can be operated by turning wheels. This type of power can produce either mechanical power or electric power (Wu *et al.*, 2007). Hand cranking mechanism can produce power ranging from 50 to 70 W at a speed of 60 to 95 rpm, these machines were mostly used during maize shelling (Nkakini *et al.*, 2007 ; Wu *et al.*, 2007). According to Wu *et al.* (2007), pedalling is the most suitable power compared to manual power, and also hand cranking cause muscle discomfort which result in muscle injuries. Mohammed and Hassan (2012), developed a hand cracking machine that was used for shelling groundnuts, and the machine capacity, mechanical loss, and shelling efficiency were 65%, 2.8% and 118.9 $kghr^{-1}$ respectively. There is no available manual powered-machine which is used to processing bambara groundnuts.

2.8.2 Petroleum energy

There are two petroleum engines that can be used in agricultural machines, namely diesel and petrol engines. Diesel engines are more efficient compared to petrol engines, so most small agricultural machines use diesel engines during operation (Chintala *et al.*, 2017). Ogunlade *et al.* (2014), developed a groundnut threshing machine that uses fuel engines. The machine was found have a threshing efficiency of 80 % and a machine capacity of 3.5 tonnes per hour. These machine is portable, that means rural farmers can share them during shelling and will be able to increase their production. **Error! Reference source not found.** in Appendix illustrates the schematic diagram of the diesel engine drive shelling machine.

2.8.3 Renewable energy

Agricultural machines usually use power from photovoltaic systems which generate energy from solar radiation. These renewable systems include solar panels, batteries, charge controls and electrical cables (Boxwell, 2010 ; Jacobson and Delucchi, 2011). The solar energy is used to power electrical motor from the transmission system of shelling machines.

2.8.4 Electrical power

The current shelling machines for bambara groundnuts use electrical motors to power the transmission system, so this machine can be used on farms where electricity or solar power is available (Atiku *et al.*, 2004 ; Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b). However, bambara groundnuts are currently grown by small-scale or rural famers in areas where grid electricity is limited (Nigam *et al.*, 2004). To increase the production of bambara groundnuts on rural farmers, manually or fuel powered equipment is required to be developed. Currently, bambara groundnuts are processed manually which results in low production, resulting in failure to meet market demand (Nigam *et al.*, 2004 ; Hillocks *et al.*, 2012).

2.9 Engineering Challenges Related to Processing Bambara Groundnuts

Bambara groundnuts are grown by rural families. Therefore, the planting, weeding, harvesting, and shelling are done manually (Nigam *et al.*, 2004 ; DAFF, 2011). During the design of processing equipment for agricultural material, the physical properties need to be considered (Atiku *et al.*, 2004 ; Mpotokwane *et al.*, 2008). The lack of bambara groundnut processing equipment is caused by limited availability of physical properties in literature. As result, the production of these groundnuts became slowly and time consuming (Atiku *et al.*, 2004). In order to develop a shelling machine, the physical properties for whole nuts are required to size the hopper, shelling units, transmission and cleaning systems (Mpotokwane *et al.*, 2008).

The existing shelling machine for bambara groundnuts uses electrical power during operation. However, these types of groundnuts are grown by rural farmers where access of electrical power is limited. As a result, the production of bambara groundnuts remains low as compared to other types of groundnuts (Atiku *et al.*, 2004 ; Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b). To industrialise bambara groundnut production, engineers are required to develop processing machines that will accommodate the rural farmers and these machines should be affordable, low maintenances, portable, and uses manual, petroleum or renewable power.

2.10 Performance Evaluation for Shelling Machine

Shelling machines are tested at different pod moisture contents. Machine performance evaluation includes shelling efficiency, mechanical damages, winnowing efficiency, percentage of unshelled pods and power transmission (Atiku *et al.*, 2004 ; Maduako *et al.*, 2006 ; L. Butts *et al.*, 2009 ; Mohammed and Hassan, 2012). The shelling efficiency can be calculated using Equation 2.5 (Atiku *et al.*, 2004 ; Mohammed and Hassan, 2012).

$$\eta = \left(\frac{N_1}{N_T}\right) \times 100 \qquad (2.5)$$

Where

η=shelling efficiency,

N_1=the number or mass of fully shelled nuts without breaking, and

N_T=the total number or mass of the groundnuts.

During the shelling process some of the groundnuts are damaged by the shelling drums or impellers, and these mechanical damages can be calculated using Equation 2.6 (Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b ; Mohammed and Hassan, 2012).

$$\text{mechanical damage (\%)} = \frac{Q_B}{Q_T} \times 100 \qquad (2.6)$$

Where

Q_B= mass of damaged groundnuts (kg), and

Q_T= mass of the total groundnuts sample (kg).

After shelling, the groundnuts go to the cleaning system or winnowing system so that the chaff and kernels can be removed from the nuts, performance evaluation of this system can be calculated using Equation 2.7 (Oluwole *et al.*, 2007b ; Mohammed and Hassan, 2012).

$$\eta_s = \frac{Q_G}{W_c} \times 100 \qquad (2.7)$$

Where

η_s=mechanical efficiency (%),

Q_B=mass of shelled groundnuts (kg),and

W_c=mass of chaff recorded in the groundnuts (kg).

The percentage of unshelled pods can be calculated from Equation 2.8 (Oluwole *et al.*, 2007a).

$$\cap_u = \frac{N_4}{N_T} \times 100 \qquad (2.8)$$

Where

$\cap_U$=percentage of unshelled pods (%),

N_4=number of unshelled pods, and

N_T=total number of groundnuts samples pods.

Power transmission can be evaluated using a PCE-AT-5 instrument which measures the rotational speed of the pulleys and belts, this data can be used to calculate the power transmitted to the shelling and cleaning systems to verify if is sufficient or insufficient.

2.11 Discussion and Conclusions

Recent literature focused on the agronomical aspect of the bambara groundnuts, which has contributed to the slow growth in the production of these groundnuts. The research also shows that these groundnuts are grown by rural farmers, and the product is consumed by their families or sold in local areas (Swanevelder, 1998a ; DAFF, 2011). According to Mkandawire (2007), bambara groundnut production is lower than the world's demand. This could be caused by the slow production or insufficient equipment for bambara groundnuts.

In Africa, bambara groundnut planting, harvesting, and shelling processes are done manually which has resulted in decreased production over the years. This challenge has slowed down the process of industrialisation of groundnut production (Oluwole *et al.,* 2007b ; STATS, 2014). Literature shows that the shortage of information about bambara groundnut physical properties has slowed down the development of processing, harvesting, shelling, and planting equipment (Atiku *et al.,* 2004 ; Oluwole *et al.*, 2007b). The available literature on physical properties can improve the current yield production of this crop and enable more businesses to invest in this crop. That result significantly mitigating poverty in African continent.

In Nigeria, the current shelling machines that are available use large electrical motors during operation. However, in rural farms, electricity is usually not available, as a result these machines are not feasible for use by rural or subsistence farmers (Aydin, 2002 ; Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b). The power required to shell the bambara groundnuts is determined from theoretical formulas that were developed for other types of groundnuts. As a result, the force and power required to shell these types of groundnuts are relatively higher (Atiku *et al.,* 2004 ; Oluwole *et al.,* 2007a). The forces can be determined using the universal testing machine, and this force can be used to find the accurate power needed to crack the shell or kernel of this groundnuts.

Mohammed and Hassan (2012) developed a manual groundnut shelling machine which was operated by hand cracking. These machines can be modified to accommodate the bambara groundnuts, and also these machines can be feasible to be used in rural farms. There is also potential for renewable energy or manually powered machine instead of the electrical power, but the problem with this type of energy is that it requires large capital investment and these machines' setup is not easy to be moved from one place to another (Boxwell, 2010 ; Mohammed and Hassan, 2012). Diesel engine shelling machines can also be developed, this engine can allows the machine to be portable, and easily to be transported from one farmer to the other (Maduako *et al.*, 2006).

The literature reveals that the limit in physical properties of bambara groundnuts result in lacking of processing equipment. There are several methods that can be adopted in literature that can be used to find the physical properties of bambara groundnuts. These physical properties will used to develop processing, planting, harvesting, and shelling equipment for this type of groundnuts. By doing this, groundnut production can be industrialised easily. The design of a shelling machine that will use either manual power or low power consumption motor powered. Machines will also increase the production of these groundnuts, because the rural farmers will able to increases the rate of production after harvesting.

3. PROJECT PROPOSAL

Bambara groundnut is the third largest consumed legume crop which is mostly produced in African countries. These groundnuts can produce a reasonable yield on soils with low fertility. Therefore, planting this crop in large quantities can reduce water usage in the agricultural sector and produce more food in Africa. Bambara groundnut production is currently limited by the unavailability of equipment for planting, harvesting. The lack of information about physical properties of the pods, seed, and kernels for bambara groundnuts has made a big contribution to this challenge (Atiku *et al.*, 2004 ; Oluwole *et al.*, 2007b). The physical properties of bambara groundnuts have an effect on how they need to be processed, stored and consumed, so there are also required during the design of processing machinery including planters, harvesting, and sheller (Oluwole *et al.*, 2007a ; Mpotokwane *et al.*, 2008). Current shelling machines use electrical power during operation. These machines also use large energy powered motors (Atiku *et al.*, 2004 ; Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b). As a result, the majority of rural farmers cannot use these machines because these farmers had no electricity in farms. Further development of this type of machines is required to accommodate small-scale producers with no electricity in infrastructure available in the farms.

3.1 Rationale

Mpotokwane *et al.* (2008) conducted an experiment to find the physical properties of bambara groundnuts for only the nuts. Since, during the design of a shelling machine, the physical properties of the whole groundnuts are required to find the power requirements for shelling and sizing various parts of processing machines. Currently, the force required to crack bambara groundnut pods is assumed based on other types of groundnuts which have similar properties, as the result the required power calculated mighty not be accurate. Also, bambara groundnuts is produced mostly by rural farmers where there is no grid electricity. However, current shelling machines use electrical motors, thus this creates a stumbling block to use these current machines in rural areas (Nigam *et al.*, 2004 ; Ntare *et al.*, 2008). The development of a shelling machine that uses low power consumptions can improve bambara groundnuts production in South Africa. For this development, the determination of physical properties is critical, for sizing of the shelling machine components.

3.2 Research Questions

The following are the research questions:

(a) What is the effect of moisture contents in the physical properties of bambara groundnuts?
(b) What is the most suitable moisture content for bambara groundnuts during the shelling process?
(c) How moisture content affects the cleaning system in shelling machines?

3.3 Objectives

The objectives of this research are:

(a) To determine the physical properties of both unshelled and shelled groundnuts at different moisture contents,
(b) To develop a portable bambara groundnuts sheller that can be operated using a less power consumption, and
(c) To develop a pneumatic bambara groundnuts cleaner that will separates the kernels, and nuts.

3.4 Material and Methods

This study will be conducted in two phases. In phase one, the physical properties of bambara groundnut shelled and unshelled will be investigated through experimentation. In phase two, the physical properties will be used to design a portable bambara groundnut sheller.

3.4.1 Bambara groundnuts sheller description

Bambara groundnut shelling machine will consist of a hopper, shelling chamber, cleaning system, transmission system and power source. The hopper will made from a galvanised steel sheeting. The angle of inclination of the hopper will depend on the static coefficients of friction of the whole seed (Atiku *et al.*, 2004). The size of the hopper depends on the machine capacity specifications.

There are two shelling components that are commonly used in the shelling chamber which include shelling drum and the impellers. According to Oluwole *et al.* (2007b), the shelling impellers were found to be the most efficient method for shelling bambara groundnuts compared to the shelling drum components. Therefore, in this project eight shelling spikes will be incorporated in the shelling camber. **Error! Reference source not found.** illustrates conceptual drawing for the proposed design. The design is made from different parts include a shelling spikes which will be welded on the shaft. The machine will used less power consumption motor or engine that will enable the machine to be affordable on rural farmer.

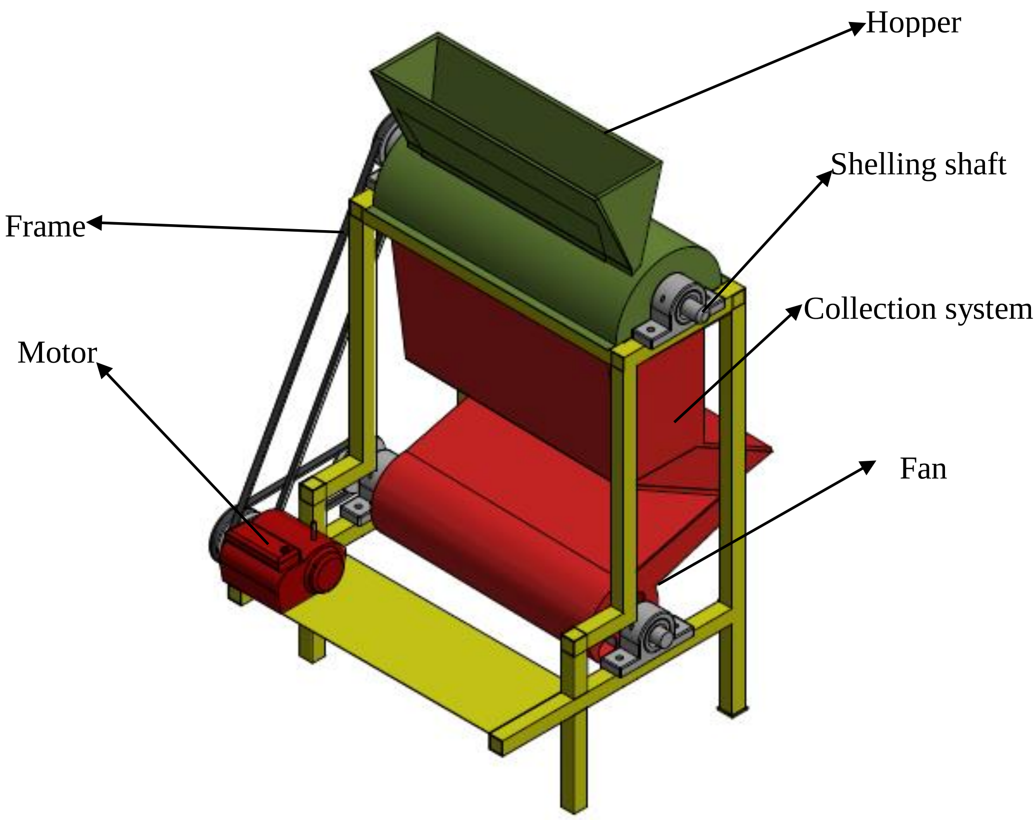

Figure 3.1 The proposed conceptual drawing of a bambara groundnuts sheller

The cleaning system will includes a blower which will separate the chaff and nuts (Atiku *et al.*, 2004 ; Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b). The recommended power system is a small petrol engine or electric motor (1.1 kW).

3.4.2 Experimental design

The experiment will consist of three phases. Phase 1, the physical properties of the bambara groundnut pods (unshelled nuts) will be measured at three different moisture contents (6, 15, and 20 %). After that, the groundnut pods will be shelled manually and separates the kernels from the nuts. Phase 2, the physical properties will be measured from the kernels and the properties required include thickness, and weight. Phase 3, the properties will be measured from the nuts (shelled groundnuts), these results will be compared with the properties for whole groundnuts. Figure 4.3, illustrates the experimental layout. The physical properties required include dimensions, weight, volume, and static coefficient of friction, porosity, cracking force, bulk and true density.

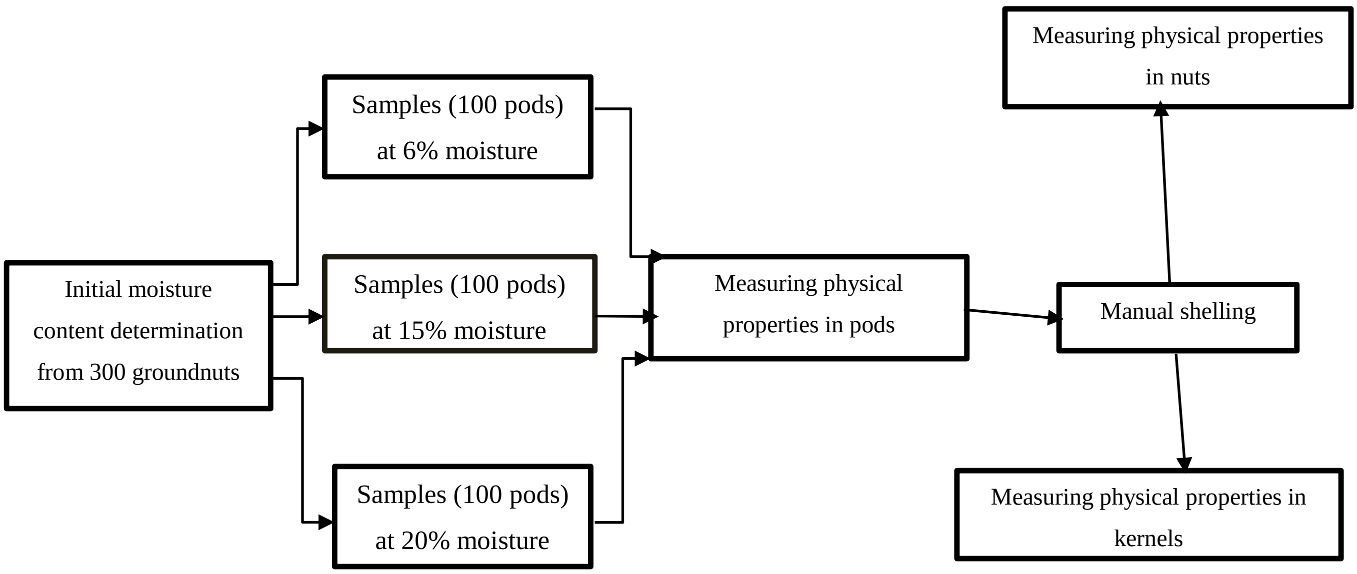

Figure 3.2 Experimental design layout

3.4.3 Data collection

The methods of data collection are outlined in this section.

(a) Moisture content determination

Bambara groundnut physical properties will be tested at different moisture contents of 6, 15, and 20 % (wet basis). The initial moisture content will be measure using the standard oven method, were the groundnuts initial mass of groundnuts is measure and let the sample dries for 24 hours (AOAC, 2002 ; Koocheki *et al.*, 2007 ; Oluwole *et al.*, 2007b). The moisture content is rate of weight loss over the initial mass. The desired moisture content of bambara groundnuts will be set by adding the calculated amount of distilled water on the pods, the pods will then be sealed in plastic bags, and the samples will be stored for 72 hours at a 5 °C refrigerator (Koocheki *et al.*, 2007). The amount of water required to be added in the pods will be calculated using Equation 3.1 (Koocheki *et al.*, 2007).

$$W_2=W_1\times\frac{M_1-M_2}{100-M_1} \tag{3.1}$$

Where

W_2=mass of distilled water required (kg),

W_1=initial sample mass in (kg),

M_1=initial moisture (%), and

M_2=required moisture content.

(b) Dimensions, sphericity, and volumetric determinations

During the measurement of the dimensions, the groundnuts will be set at different moisture contents. The method of Mpotokwane *et al.* (2008) will be adopted during the dimension measurements, a Digital Caliper will be used to measure the length (L), width (W), and thickness(T).

The following physical properties (viz., sphericity, volume, and geometric mean diameter) depend on the dimensions of the groundnuts, and the average dimensions (length, width, and breath) will be used to calculate these parameters (Oluwole *et al.*, 2007a ; Oluwole *et al.*, 2007b ; Mpotokwane *et al.*, 2008). The volume, sphericity, and geometric mean diameter will be calculated using Equations 2.1, 2.2, and 3.2, respectively. Equation 3.2 will be used to calculate the geometric mean diameter of the groundnuts pods and nuts (Koocheki *et al.*, 2007).

$$D_g=(LWT)^{\frac{1}{3}} \tag{3.2}$$

Where

D_g= geometric mean diameter (mm),

L= length (mm),

W= width (mm), and

T= thickness (mm).

Method of Mpotokwane *et al.* (2008) will be used for measuring the weight of bambara groundnuts, and each groundnut will be measured using a digital mass scale with an accuracy of 0.001. The samples will be set at different moistures of 6, 15, and 20 %. The results will be recorded in a table form for further statistical analysis.

(c) Static coefficient of friction determination

According to Chukwu and Akande (2007), there are two types of static coefficients of friction namely: static and dynamic friction. In this experiment, only the static coefficients of friction will be determined. This parameter is required during the design of a hopper and cleaning system. The static coefficient of friction will be determined at three different moisture contents, and a galvanised surfaces will be used to measuring this parameter. The pods, nuts, and kernels will be placed on an adjustable tilting surface (Chukwu and Akande, 2007 ; Yalcin and Ersan, 2007 ; Mpotokwane *et al.*, 2008). The height (h) at which the pods, kernels, and nut starts to slide will be recorded, and the angle of repose will be calculated using Equation 3.3 (Pliestic *et al.*, 2006). This method was adopted from Chukwu and Akande (2007).

$$\propto = \tan^{-1}\left(\frac{h}{L}\right) \quad (3.3)$$

Where

$\propto$= the angle of repose (mm),

h= height at which the pods or nuts starts to slide (mm), and

L= length of the plates (300mm).

There is no available equipment to measure the angle of repose in South Africa, so an equipment will be manufactured according to the methods of (Akcali *et al.*, 2006), where an equipment with adjustable plate will be manufactured as shown in Figure 3.3.

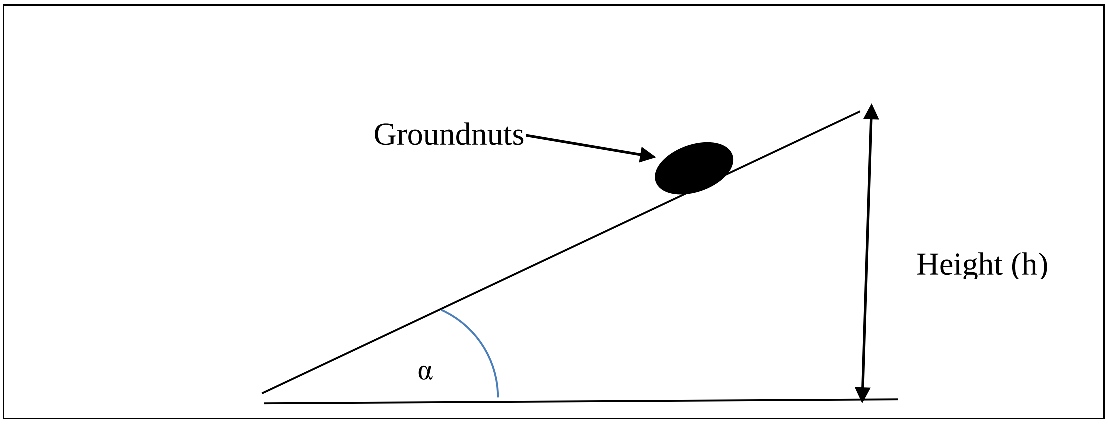

Figure 3.3 The illustration on how to measure static coefficients of friction (Akcali *et al.*, 2006)

(d) Porosity

Porosity is defined as the free spaces between the packed seeds, and this parameter is used during the design of the storage facilities of the seed such hoppers and storage tanks (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007). There are two parameters that are required to calculate the porosity of groundnuts, namely; the bulk density and the true density, as shown in Equation 2.3. The method of Yalcin and Ersan (2007) will be used to determine the porosity for the pods, kernels, and nuts. The bulk density will be measured by pouring the bambara groundnuts into a 600 ml beaker, and measuring the weight of the groundnuts that fill up the beaker, and the bulk density will be calculated by the ratio of the groundnuts mass in to volume of beaker (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007). Equation 3.4 will be used to calculate the bulky density at different moisture content.

$$\rho_b = \frac{M}{V} \tag{3.4}$$

Where

ρ_b=bulky density (kg .m^{-3}),

M=mass of the groundnuts on 600 ml beaker (kg), and

V=volume of the beaker (m^{-3}).

The true density will be determined based on the toluene method, where the liquid toluene will be poured into a 600 ml beaker. Thereafter, the groundnuts will be poured on top of the chemical, and the change in volume will be the true density (Pliestic *et al.*, 2006 ; Yalcin and Ersan, 2007). The toluene chemical is used because this chemical cannot be absorbed by the seeds or kernels.

(e) The maximum cracking force

The force required to crack the groundnuts will be measured using the universal texture analysis machine, which compresses the kernels until they start cracking. A fixed plate will be used to place the groundnuts during the cracking experiments. The dynamometer with a hammer will be used to compress the nuts, and the force will be recorded by a data acquisition system (Pliestic *et al.*, 2006). The nuts at different moisture contents will be compressed in one direction. Each nut from the sample will be measured in one direction, either on which are x, y and z planes and the average will be used as a force required to crack that groundnut (Pliestic *et al.*, 2006).

3.5 Statistical Analysis

The data will be analysed using the Microsoft Excel program, where descriptive statics will be used to determine the summary of the quantitative data. The summary statics will be analysis at 95% confidence level for the mean. In addition, frequency distribution graphs will be used to analyse the distribution of the data around the mean, and this will assist during the acquisitions of design parameters for the sheller.

3.6 Resource Requirements

The Agricultural Research Council (ARC) and the University of KwaZulu-Natal (UKZN) are the sponsors of this research project. The required resources that will used during the research will attained from UKZN and the resource are listed in Table 3.1.

Table 3.1 Resources and equipment required

Equipment	Quantity	Means of Acquisition
Weigh Scale	1	Available at UKZN
Texture Analyser	1	Available at UKZN
Oven	1	Available at UKZN
Fridge	1	Available at UKZN
Digital Caliper	1	Available at UKZN

Construction tools	1	Available at UKZN
Plastic container	6	Available at UKZN

The project budget will be attained for ARC institute of Agricultural Engineering, the project budget can be seen in Table 3.2.

Table 3.2 Project budget

Item	Quantity	Unit	Unit Price (R)	Total Price (R)
Bambara groundnuts	3	packet	50	150
Digital Caliper	1	kit	180	180
Gloves	1	kit	50	50
Sealable polythene bags	1	packet	100	100
Respiration mask	2	packet	100	200
Project construction	1	prototype	7500	7500
Toluene chemical	1	2.5 litres	2299	2299
TOTAL				**R 10 479**

3.7 Project Planning

The project activities from February 2018 to December 2019 had be show in the table below. The alphabet from the month row, represent the first letter of the month from January 2018 to December 2020.

Table 3.3 Project planning

Month(2018-2020)	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
LR																								
LR & RP																								
C																								
E																								
MP & CO																								
DC																								
DA																								
TWU																								
FDS & C																								
FS																								

The abbreviations on the first-left column are write as follow; Literature Review (LR), Research Proposal (RP), Correction (C), Experiments (E), Material Procurement and Construction (MP&CO), Data Collection (DC), Data Analysis (DA), Thesis Write Up (TWU), First* Draft Submission (FDS), and Final Submission (FS)

4. REFERENCES

Abdualrahman, MAY, Ma, H, Yagoub, AEA, Zhou, C, Ali, AO and Yang, W. 2016. Nutritional value, protein quality and antioxidant activity of Sudanese sorghum-based kissra bread fortified with bambara groundnut (Voandzeia subterranea) seed flour. Journal of the Saudi Society of Agricultural Sciences

Adebowale, YA, Schwarzenbolz, U and Henle, T. 2011. Protein isolates from Bambara groundnut (Voandzeia Subterranean L.): Chemical characterization and functional properties. International Journal of Food Properties 14 (4): 758-775.

Akcali, I, Ince, A and Guzel, E. 2006. Selected physical properties of peanuts. International Journal of Food Properties 9 (1): 25-37.

Ali, MA. 2007. Improvement of the modified grain thresher for groundnut threshing. Yoshisuke Kishida, Publisher & Chief Editor Contributing Editors and Cooperators 38 (3): 67.

Asoegwu, S, Ohanyere, S, Kanu, O and Iwueke, C. 2006. Physical properties of African oil bean seed (Pentaclethra macrophylla). Agricultural Engineering International: CIGR Journal 8 (1):

Atiku, A, Aviara, N and Haque, M. 2004. Performance evaluation of a bambara ground nut sheller. Agricultural Engineering International: CIGR Journal 5 (1):

Aydin, C. 2002. Postharvest technology: Physical properties of hazel nuts. Biosystems Engineering 82 (3): 297-303.

Bart-Plange, A and Baryeh, EA. 2003. The physical properties of Category B cocoa beans. Journal of Food Engineering 60 (3): 219-227.

Berchie, J, Opoku, M, Adu-Dapaah, H, Agyemang, A and Sarkodie-Addo, J. 2012. Evaluation of five bambara groundnut (Vigna subterranea (L.) Verdc.) landraces to heat and drought stress at Tono-Navrongo, Upper East Region of Ghana. African Journal of Agricultural Research 7 (2): 250-256.

Boxwell, M. 2010. Solar Electricity Handbook: A Simple, Practical Guide to Solar Energy-Designing and Installing Photovoltaic Solar Electric Systems. Greenstream Publishing, United Kingdom.

Brough, S, Azam-Ali, S and Taylor, A. 1993. The potential of bambara groundnut (Vigna subterranea) in vegetable milk production and basic protein functionality systems. Food chemistry 47 (3): 277-283.

Chintala, V, Kumar, S and Pandey, J. 2017. Assessment of performance, combustion and emission characteristics of a direct injection diesel engine with solar driven Jatropha biomass pyrolysed oil. Energy Conversion and Management 148 (1): 611-622.

Chukwu, O and Akande, F. 2007. Development of an apparatus for measuring angle of repose of granular materials. Assumption University Journal of Technology 11 (1): 62-66.

Department of Agriculture and Fisheries, F. 2011. Production guideline for Bambara groundnuts. Directorate Agricultural Information Services, Department of Agriculture. Forestry and Fisheries 1-20.

Dordas, C. 2009. Role of nutrients in controlling plant diseases in sustainable agriculture: a review. Sustainable agriculture 28 (1): 33-46.

Farina, D, Macaluso, A, Ferguson, RA and De Vito, G. 2004. Effect of power, pedal rate, and force on average muscle fiber conduction velocity during cycling. Journal of Applied Physiology 97 (6): 2035-2041.

Gupta, R and Das, S. 1997. Physical properties of sunflower seeds. Journal of Agricultural Engineering Research 66 (1): 1-8.

Hillocks, R, Bennett, C and Mponda, O. 2012. Bambara nut: A review of utilisation, market potential and crop improvement. African Crop Science Journal 20 (1): 1-16.

Ibrahin, H and Ogunwusi, A. 2016. Industrial Potentials of Bambara Nut. Journal of Poverty, Investment and Development 22 (1): 1-10.

Jacobson, MZ and Delucchi, MA. 2011. Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. Energy policy 39 (3): 1154-1169.

Jain, R and Bal, S. 1997. Properties of pearl millet. Journal of agricultural engineering research 66 (2): 85-91.

Khan, F, Chai, H, Ajmera, I, Hodgman, C, Mayes, S and Lu, C. 2017. A transcriptomic comparison of two bambara groundnut landraces under dehydration stress. Genes 8 (4): 121.

Kibar, H and Ozturk, T. 2008. Physical and mechanical properties of soybean. International Agrophysics 22 (3): 239-244.

Koné, M, Kouakou, T, Koné, D, Kouadio, Y, Zouzou, M and Ochatt, S. 2009. Factors affecting regeneration of bambara groundnut [Vigna subterranea (L.) Verdc.] from mature embryo axes. In Vitro Cellular & Developmental Biology-Plant 45 (6): 769.

Koocheki, A, Razavi, S, Milani, E, Moghadam, T, Abedini, M, Alamatiyan, S and Izadkhah, S. 2007. Physical properties of watermelon seed as a function of moisture content and variety. International Agrophysics 21 (4): 349.

L. Butts, C, B. Sorensen, R, C. Nuti, R, C. Lamb, M and H. Faircloth, W. 2009. Performance of Equipment for In-Field Shelling of Peanut for Biodiesel Production. Transactions of the ASABE 52 (5): 1461.

Mabhaudhi, T and Modi, AT. 2013. Growth, phenological and yield responses of a bambara groundnut (Vigna subterranea (L.) Verdc.) landrace to imposed water stress under field conditions. South African Journal of Plant and Soil 30 (2): 69-79.

Maduako, J, Saidu, M, Matthias, P and Vanke, I. 2006. Testing of an engine-powered groundnut shelling machine. Journal of Agricultural Engineering and Technology 14 (2): 29-37.

Massawe, F, Mwale, S, Azam-Ali, S and Roberts, J. 2005. Breeding in bambara groundnut (Vigna subterranea (L.) Verdc.): strategic considerations. African Journal of Biotechnology 4 (6): 463-471.

McHale, G, Shirtcliffe, N, Evans, C and Newton, M. 2009. Terminal velocity and drag reduction measurements on superhydrophobic spheres. Applied Physics Letters 94 (6): 064104.

Megalingam, R, Veliyara, P, Prabhu, R and Katoch, R. 2012. Pedal power generation. International Journal of Applied Engineering Research 7 (11): 1473-1477.

Mkandawire, C. 2007. Review of bambara groundnut (Vigna subterranea (L.) Verdc.) production in Sub-Sahara Africa. Agricultural Journal 2 (4): 464-470.

Mohammed, A and Hassan, A. 2012. Design and Evaluation of a Motorized and Manually Operated Groundnut Shelling Machine. International Journal of Emerging Trends in Engineering and Development (UK) 4 (2): 673-682.

Mpotokwane, S, Gaditlhatlhelwe, E, Sebaka, A and Jideani, V. 2008. Physical properties of bambara groundnuts from Botswana. Journal of Food Engineering 89 (1): 93-98.

Nkakini, S, Ayotamuno, M, Maeba, G, Ogaji, S and Probert, S. 2007. Manually-powered continuous-flow maize-sheller. Applied Energy 84 (12): 1175-1186.

Ogunlade, C, Aremu, D, Akinyele, O and Babajide, N. 2014. Design, Construction and Performance Evaluation of a Coffee (Coffea Arabica) Threshing Machine. International Journal of Engineering Research and Applications 4 (1): 56-64.

Oluwole, F, Abdulrahim, A and Olalere, R. 2007a. Effect of moisture content on crackability of bambara groundnut using a centrifugal cracker. International Agrophysics 21 (2): 179.

Oluwole, F, Abdulrahim, A and Oumarou, M. 2007b. Development and performance evaluation of impact bambara groundnut sheller. International Agrophysics 21 (3): 269.

Özgüven, F and Vursavuş, K. 2005. Some physical, mechanical and aerodynamic properties of pine (Pinus pinea) nuts. Journal of food engineering 68 (2): 191-196.

Pliestic, S, Dobricevic, N, Filipovic, D and Gospodaric, Z. 2006. Physical properties of filbert nut and kernel. Biosystems engineering 93 (2): 173-178.

Raghtate, A and Handa, C. 2014. Design consideration of groundnut sheller machine. Department Of Mechanical Engineering, KDK College of Engineering, Nagpur. International Journal of Innovative Research in Science And Technology 1 (7): 8.

Swanevelder, C. 1998. Bambara food for Africa (Vigna subterranean–bambara groundnut). The National Department of Agriculture and obtainable from the Resource Centre, Republic of South Africa

Torres, A, Barros, G, Palacios, S, Chulze, S and Battilani, P. 2014. Review on pre-and post-harvest management of peanuts to minimize aflatoxin contamination. Food Research International 62 (1): 11-19.

Ugwuoke, IC, Okegbile, OJ and Ikechukwu, IB. 2014. Design and Fabrication of Groundnut Shelling and Separating Machine. International Journal of Engineering Science Invention ISSN (Online) 3 (4): 60-66.

Wu, L, Zachas, A, Harley, R, Habetler, T and Divan, D.2007. Design of a portable hand crank generating system to power remote off-grid communities. Power Engineering Society Conference and Exposition in Africa, 2007. PowerAfrica'07. IEEE, 1-8. IEEE,

Yalcin, C and Ersan, K. 2007. Physical properties of coriander seeds. Journal of Food Engineering 80 (2): 408-416.

Zewdu, A. 2011. Moisture-dependent physical properties of Ajwain (Trachyspermum ammi L.) seeds. The Philippine Agricultural Scientist 94 (3): 278-284.

5. APPENDIX

The following figure shows a coffee shelling machine which is uses diesel engine.

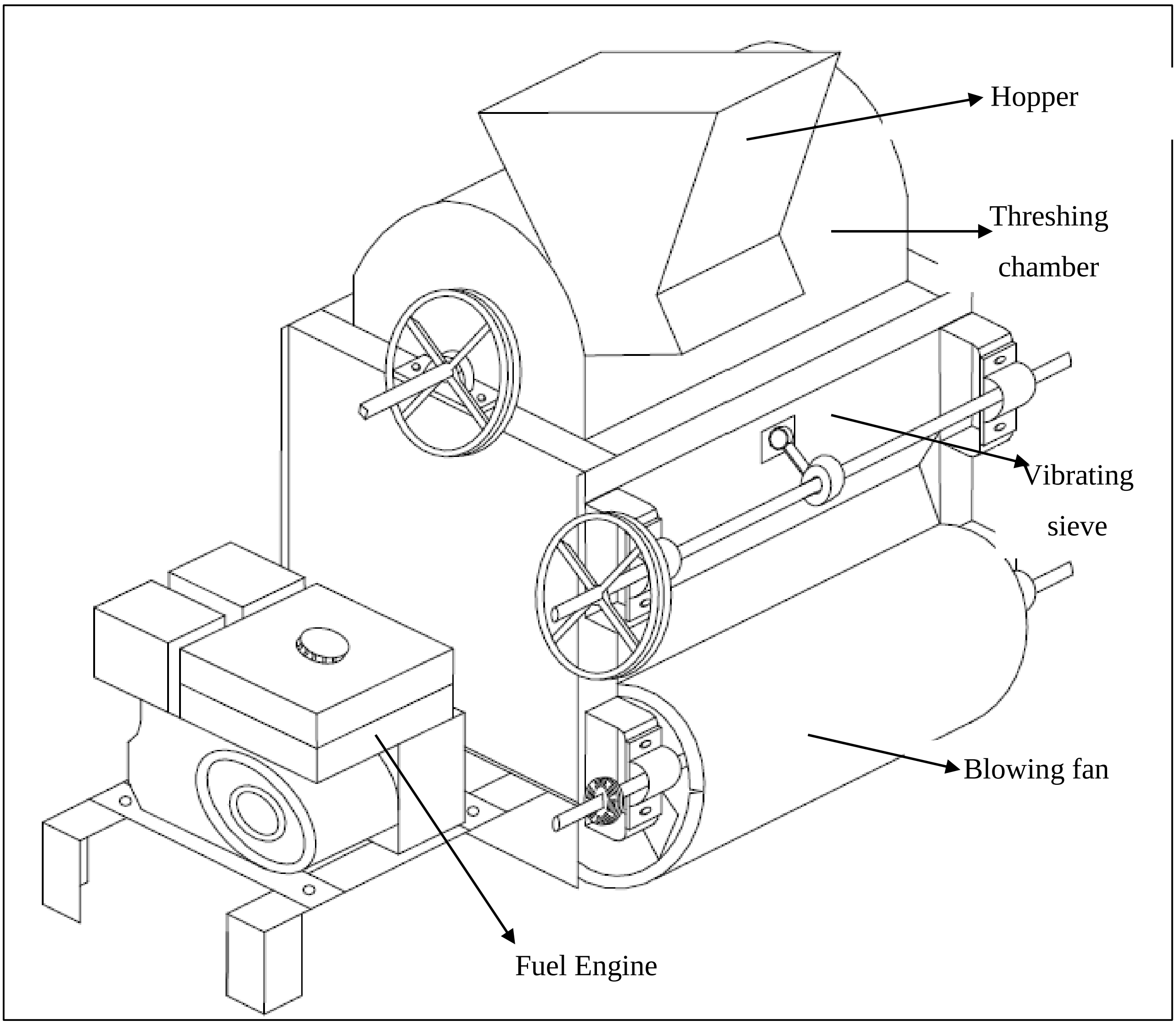

Figure 5.1shelling machines to process coffee (Ogunlade et al., 2014)