MODIFICATION AND PERFORMANCE EVALUATION OF A SOAKED COWPEA (*Vigna unguiculata*) DEHULLING AND SEPARATING MACHINE

BY

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ABSTRACT

The most common method of dehulling and separation of soaked cowpea seeds in Nigeria is the manual method of rubbing between the thumb or the use of mortar and pestle to dehull the soaked cowpea seed coat. This method is time consuming and has high demand of human energy. Although, there are some available locally dehulling and separating machines that have been developed by institutions like Nigerian Stored Products Research Institute, Kano and Department of Agricultural and Biosystems Engineering, University of Ilorin. These machines developed by these institutions has limitation in terms of water recycling system. Hence, this study is to modified the existing dehulling and separating machine. A soaked cowpea dehulling and separating machine was developed using locally available materials to reduce drudgery attached to traditional dehulling of the seeds. The machine consist of dehulling unit made from 2.0 mm thick galvanized metal sheet, where the dehulling operation takes place, and a separating unit where hulls and cotyledon are separated. The dehulling mechanisms obtain its drive from a 2 hp electric motor with a speed of 1430 rpm. The principle of operation of the machine is by rubbing action principle between the cylindrical drum and the wall of the dehulling chamber. The performance evaluation of the cowpea dehulling and separating machine was done using D-optimal factorial experiment in a Randomized Complete Block Design involving speed, soaking time and cowpea variety each at 3, 3, and 3 levels respectively. These were replicated three times. The developed soaked cowpea de-hulling and separating machine performs optimally at 250 rpm speed, 8 minutes soaking time, and with Kananado variety. The test performance carried out on the machine showed that the effective de-hulling efficiency, separating efficiency, and output capacity obtained were 96.2%, 67.0%, 40.8kg/h/batch respectively. Generally, the performance of the modified machine was better in terms of dehulling and output capacity while the existing machine excel in terms of separation of cowpea seeds.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Cowpea (*Vigna unguiculata*) also known as Southern pea, China pea, Black-eye bean or Cow gram is an edible legume that falls into the family of *Fabaceae* (Ibrahim *et al.*, 2017). It represents an important source of proteins (27.4%) and carbohydrates (66%) (Weng *et al*., 2019). It is well known to be of African native and is widely cultivated and consumed in tropical and sub-tropical areas of Africa, Latin America, Southeast Asia and in the Southern United States (Ano & Ubochi, 2008).

It has been estimated that worldwide area of production of cowpeas is approximately 10.1 million hectares with annual global grain production being approximately 4.99 million tons. The largest areas under cultivation are in Central and West Africa. In India, cowpea is grown on an area of 3.9 million hectares with a production of 2.21 million tons with the national productivity of 683 kg per ha Food and Agricultural Organization Corporate Statistical Database (FAOSTAT, 2019).

Due to the nutritional and functional benefits of cowpea, it has gained industrial importance for being used as a potential ingredient in food formulations. World Cowpea Conference 2010, demands understanding of the physical properties of the seed. For instance, the knowledge of dimensions is very useful in determining aperture sizes in the design of grain handling machinery. Similarly, knowledge of geometric surface would help in deciding the clearance between the abrasive surfaces for dehulling and would also help in designing the grader, cleaner and separator for the seeds (Tchiagam *et al*., 2011).

Cowpea production is widely distributed throughout the tropics, with Central and West Africa account for over 64% of the area with about 8 million hectares, followed by about 2.4 million hectares in Central and South America, 1.3 million hectares in Asia and 0.80 million hectares in East and Central Africa (Abate *et al*., 2011). Cowpea can be regarded as the fulcrum of sustainable farming in semi-arid lands. Nigeria is the world's leading cowpea producing country, followed by Brazil. Other countries in Africa are Senegal, Ghana, Mali and Burkina Faso. Ghana, Niger and Cameroon are significant producers. The major production areas elsewhere in the world are Asia and the Americas (US, Brazil) of the developed countries. Table1.1. show the harvested areas and the production values of cowpea across the world (Abate *et al*., 2011).

Table1.1: Harvested areas and the production values of cowpea across the world

Countries	**Harvested area (ha)**	**Production (tonnes)**
Nigeria	3425	1691
Niger	3268	359
Mali	322	79
Burkina Faso	201	156
Senegal	95	32
Ghana	85	57
Cameroon	38	31
United State	21	41
Asia	127	94
Brazil		817

Source: Abate *et al*. (2011)

Cowpea is gaining popularity and has several advantages over other food crops. The reason being its simplicity of preparation and the wide variety of edible forms available, such as tender green shoots, leaves, unripe whole pods, green peas or beans and dry seeds. Dehull cowpea seeds are versatile food ingredient used in the making of fried bean cake *Kosei* in Hausa, *Akara* in Yoruba, *Akala* in Igbo language and boiled cake *Alele* in Hausa, *Moimoi* in Yoruba and Igbo language (Ngalamu *et al*., 2014).

De-hulling is the removal of seed coat (hull) from the seed, by separation of cotyledons from the hulls (Ajayi & Akinjayeju, 2011). In the rural area, the wet method of dehulling process is still part of the house wife's manual work in food preparation. The cowpea seeds absorb moisture and swell, thereby facilitating de-hulling process. If it is well soaked, the seed coats can be removed by rubbing hands. If not, the aid of a grinding stone or a mortar is needed to roughly bruise the skins with a stirring action (not pounding). The reason for dehulling or decortication of cowpeas is to improve the appearance, texture, aroma and taste and to reduce the cooking time (Phillips, 2012).

Cowpea is one of the most economically and nutritionally important indigenous African grain legumes produced throughout the tropical and subtropical areas of the world (Fatokun *et al*., 2000). In Africa, despite the values of cowpea, the methods involved in its production, harvesting and shelling are mostly manual. For instance, shelling is done by pounding in a mortar with a pestle or spreading the dried crop on the floor where it is beaten with a stick (Dauda, 2001).

The production of cowpea on a large scale is likely to continue to increase with the adoption of improved production technology and availability of wider market. This would mean a higher demand on labour for all farming operations particularly harvesting, threshing, cleaning and grading (Irtwange, 2009). Most of the imported shelling machines are very costly and hence beyond the reach of Nigerian small-scale farmers. Some have been found unsuitable for shelling the local varieties (Adewumi *et al.,* 2007).

Cowpea has potential of becoming an industrial crop and widespread consumption of convenience foods containing significant amounts of cowpea substantially increased the demand and value of cowpea seed (Fatokun *et al.,* 2000). In order to boost cowpea production, farmers have to be provided with the means by which their products can be processed with minimum drudgery, cost and achieving good quality products (Ibrahim *et al.,* 2010).

There are some designed works carried out on soaked cowpea dehulling machine, but they have their limitations. The work of Roland (2016) and Khamaldeen *et al.* (2017) presented a machine that is capable of de-hulling a wet cowpea. The limitation to their work is the inability to separate the hull from its cotyledon. However, Olaoye and Olotu (2015) were able to design an improved hydro-separating cowpea de-huller which has the ability to dehull and separate hull from its cotyledon. The limitation to the work is the use of a large volume of water in the separation process. It was found that about 65 Litres of water is required to dehull 2kg of soaked cowpea. The main issues that still remain to be addressed in the work of Olaoye and Olotu (2015) is a design that will recycle and reduce water usage in de-hulling and separation process, and that is why this research work become imperative.

1.2 Statement of the Problem

The research study on soaked cowpea de-hulling and separation machine has been based on large scale production of Nigeria local foods like; cooked bean cake (*Alele/Moi-Moi*), fried bean cake (*Akara/Kosei*), thick bean soup known as *(Miyan wake)* in Hausa, *(gbegiri)* in Yoruba and *(Agwa ofe)* in Igbo language (Onyenekwe *et al*., 2000). The most common method of soaked cowpea dehuller in Nigeria is the manual method of crushing between thumbs or the use of mortar and pestle to de-hull soaked cowpea seed coat. Likewise, the same manual method is employed to separate the hull from its cotyledon. With the high usage of cowpea in Nigeria, the mostly used means of processing still remains manual. Although, there are some available locally dehulling machines that have been developed and used effectively with good efficiency.

However, one drawback with the hydro-cowpea dehulling and separating machine is the lack of portability for easy transportation. Major limitation of the existing hydro machine is the lack of water conservation; that is, for it to dehull 2 kg of soaked cowpea seeds, it requires about 65 litres of water to carry out the operation (Olaoye & Olotu, 2015). Invariably, this operation may be labour intensive in water scarcity area. Therefore, this study modified and fabricated an efficient dehulling and separating machine that will be portable and water conservative.

1.3 Aim and Objectives

The aim of the study is to modify a soaked cowpea de-hulling and separating machine for selected varieties of cowpea.

The objectives are:

i. to modify existing cowpea dehulling and separating machine

ii. to construct and test the modified machine

iii. to evaluate and compare the performance of the modified and existing machine

1.4 Justification of the Study

Cowpeas are of great economic and natural benefit to humanity. Nigeria is the largest cowpea producer in the world. Therefore, a soaked cowpea dehulling and separating machine will help to bridge the overtime disparity in its performance improvements. It will provide an avenue for improving cowpea productivity. It will also help to increase the number of viable machines available for dehulling and separating cowpea. Drudgery is generally conceived as physical and mental strain, fatigue, monotony and hardships experienced while doing a job (Renuka, 2007). It is certain that, if appropriate drudgery reducing machinery are made available to the rural farmers, it would contribute to more drudgery reduction in labour productivity, increased capability, and consequently reduction in greater workload thereby improving labour efficiency. Chima (2013) stated that, one important strategy used by China, India, Indonesia, Pakistan and Brazil, the nations with large populations in their quest for industrial and economic development was strong internal demand/consumption of their manufactured goods. Therefore, producing high quality products like cowpea dehulling and separating machines will contribute meaningfully to the country’s GDP and enhances its global competitiveness. It will also contribute in disabling the importation opportunities in the country.

1.5 Scope of the Study

The scope of the study is limited to modification, fabrication and the performance evaluation of the soaked cowpea dehulling and separating machine.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Legumes Food Processing in Nigeria

In a developing country like Nigeria, legume processing into products like soymilk, soy cheese, cowpea cake and puddings are common income generating activities. Women usually carry out the processing. This food processing activity plays a vital role in the survival and sustenance of their household and in meeting domestic financial obligations. However, these products are usually prepared manually under poor sanitary conditions. Processing techniques at the household needs to be upgraded. This is to enhance productivity in terms of yield and quality to ensure food security, income generation and food safety especially in the developing countries (Fasoyiro *et al*., 2012).

2.1.1 Need for improved appropriate processing facilities

Equipment utilized in household and local processing, needs to be upgraded to allow for increased productivity, reduced drudgery and efficient time management. However, in Africa, many people are living below the poverty line of a dollar per day (Kristofer *et al*., 2019). Neglected legumes that are not commonly consumed due to the hard-to-cook phenomenon and lack of adequate knowledge on ways of utilization are usually regarded as underutilized legumes. Such include pigeon pea, African yam bean, bambara, groundnut, and lima bean. There is the need to improve the dehulling process of legumes with hard testa. To combat food crisis and poverty in the world, intensive research studies on the underutilized crops as a means to mitigate against global food insecurity need to be conducted. Many underutilised legumes such as cowpea grow well in tropical and subtropical countries in Africa, but the impeding need is the capacity to carry out intensive coordinated research studies in these countries in order to improve their utilization as food for improved nutritional status (Fasoyiro *et al*., 2010).

2.2 Cowpea

Cowpea (*Vigna unguiculata L. Walp*) is a leguminous crop widely grown as an intercrop with cereals in the marginal lands of sub-Saharan Africa. Through improved breeding lines and agronomic practices, there is potential for increased production of cowpeas despite the prevailing production challenges of declining soil fertility, unreliable rainfall, pests and diseases (Singh *et al.,* 2003).

Cowpea thus will continue to provide an opportunity for an affordable protein source in the carbohydrate-based diet of most people in West Africa, cowpeas are one of the major sources of proteins in a carbohydrate based diet, where they are consumed in different forms. Whole cowpeas are consumed after being stewed, while different products based on a wet milled paste such as fried bean cake called *akara* in Yoruba and Igbo, *kosei* in Hausa and boiled bean cake called *moimoi* in Yoruba and Igbo , allele in Hausa are also produced. Cowpea is processed into flour for the production of bakery products such as cookies and breads and other traditional products (Kristjanson, 2005). It has been proposed that the shape of cowpea seeds is dependent on the development process in the pod; kidney shaped seeds develop when there is no space restriction during development within the pod. However, if there is limited space within the pod for the development of the seed, seeds that are globular in shape develop (Davis & Zibokere, 2011). Cowpeas are also referred to be eyed (black eye peas) depending on the coloration around the hilum. Plates I and II shows cowpea seed coat with black and brown eyed peas.

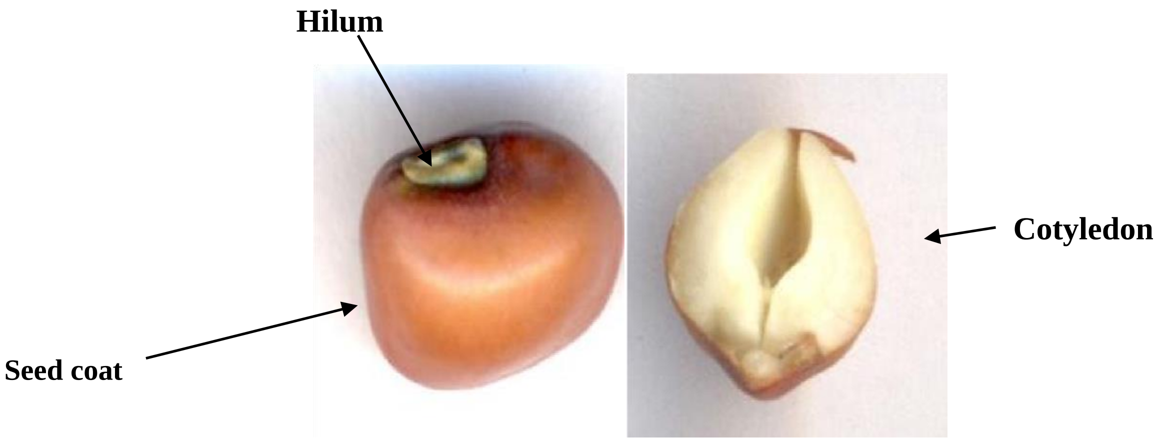

Plate I: Cowpea seed coat with brown eye
Source: Akinjayeju and Bisiriyu (2004)

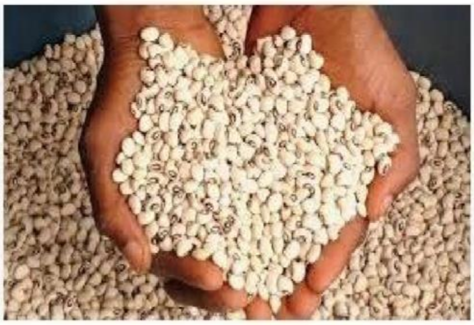

Plate II: Cowpea seed coat with black eye
Source: Akinjayeju and Bisiriyu (2004)

2.2.1 Household utilisation of cowpea

Cooked beans: This can be in the form of cooked hull beans or cooked dehulled beans. Hull beans take longer period of time to cook than dehulled beans. Hull beans are boiled for about 45 to 60 minutes on the cooking stove or gas cooker depending on the hardness of the hull at household level. It may be eaten alone or in combination with other food products like bread, gari, boiled yam with vegetable soup or fish meat sauce. Cooked dehulled beans reduce flatulence and is an excellent meal for both children and adults. The whole cooked bean can also be made into bean porridge by adding other ingredients such as palm oil, salt, pepper, onion and spices. Cooked beans prepared for income generating purpose are usually cooked with firewood which imparts a characteristic flavour. This, however, has its occupational hazards to processors. Long term effect of wood smoke in contact with eyes has its health and cost implications (Fasoyiro *et al.,* 2012).

Bean soup: In this food preparation, beans are washed, soaked, dehulled, boiled, mashed and sieved. The sieved paste is then cooked with palm oil along with other ingredients such as pepper, spices and seasoning with or without fresh or dried fish to taste to produce *Miyan wake/*gbegiri. It is eaten with reconstituted yam flour product *amala* (Fasoyiro *et al.,* 2010).

Bean cake and pudding: beans are washed, soaked, dehulled and milled into paste. In making the bean cake, the paste is mixed to a fluffy texture by trapping in air. Other ingredient such as onion and pepper are milled with the dehulled beans and the paste is fried with oil. The mixture is packaged in leaves and steamed. Steaming of the pudding however today may be done in stainless steel cups. Some local processors use polyethylene bags in steaming the paste. Use of polyethylene bag is however being discouraged due to leaching of the chemicals in the package into the product which may lead to future health complications. Bean cakes and pudding are excellent diets that are usually consumed with fermented maize gruel *Akamu/ogi*, bread, *gari,* or just on its own (Fasoyiro *et al.,* 2010). Bean cake and pudding are usually consumed as a breakfast meal, but can also be consumed during lunch and supper too (Ngalamu *et al.,* 2014). Plates III, IV, V and VI show boiled bean cake steamed with leave, boiled bean cake steamed with polythene bag, fried bean cake and cooked beans.

Plate III: Boiled bean cake with Leave
Source: Ngalamu *et al*. (2014)

Plate IV: Boiled bean cake polythene
Source: Ngalamu *et al*. (2014)

Plate V: Fried bean cake (*Akara*)
Source: Ngalamu *et al*. (2014)

Plate VI: Cooked beans
Source: Ngalamu *et al*. (2014)

2.2.2 Engineering properties of cowpea

The increase in agricultural products together with the complexity of modern technology for production, processing and storage need a better knowledge of their engineering properties so that machine processes and handling operations can be designed for maximum efficiency. Engineering properties includes; physical, mechanical and thermal properties.

2.2.2.1 *Physical properties of cowpea*

Physical properties affect the conveying characteristics of solid materials by air or water and cooling and heating loads of food materials. For instance, sphericity is one of the most important properties because it affects how easily cowpea can be processed by the food industry (Khattab *et al*., 2009). Cowpea seed's average length, width, thickness, geometric mean diameter, sphericity index, fruit mass, thousands of fruit mass and volume of fruit were 9.28 mm, 6.55 mm, 6.08 mm, 7.16 mm, 77.2%, 0.2063 g, 2050 g and 0.18 cm^{-3}, respectively. The bulk density and porosity were 0.69 g cm^{-3} and 38.88%, respectively (Khattab *et al*., 2009). Some physical properties of cowpea seeds are shown in Table 2.1.

Cowpea seeds	**Min**	**Max**	**Mean**	**S.d**
Angle of repose (^{o})	16.15	22.18	18.41	0.0355
Porosity (%)	35.58	40.06	38.88	11.8911
Sphericity (%)	73.41	80.51	77.2	0.0425
Mean diameter (mm)	5.98	8.125	7.160	0.5771
Surface area (mm^2)	145.98	185.206	161.104	25.4846
Length (mm)	8.95	9.75	9.28	0.9227
Width (mm)	5.81	6.98	6.55	0.5601
Thickness (mm)	5.57	6.45	6.08	0.5931
Mass (g)	0.1978	0.2156	0.2063	1.0547
Thousand (g)	1970	2165	2050	159.201
Fruit density (g cm^{-3})	0.98	1.23	1.13	0.1909
Bulk density (g cm^{-3})	0.60	0.72	0.69	0.0264
Aspect ratio (%)	64.9	71.5	70.5	0.0124
Volume (cm^3)	0.15	0.21	0.18	0.0356
Terminal velocity (m s^{-1})	1.78	2.98	2.21	0.0543

Table2.1: Some physical properties of cowpea

Source: Khattab *et al*. (2009)

2.2.2.2 *Mechanical properties of cowpea*

Knowledge of mechanical properties of agricultural products (such as compressive and tensile strength) under static or dynamic loading is aimed at textural measurement of unprocessed and processed food material. The probability of fracture of a particle under tension depends on the applied macroscopic stress and the size of the particle. A farm product machine designer needs knowledge of the tensile stress of cowpea for process design and handling. Hardness is defined as the ability of a material to resist indentation or abrasion. This property is required for the design of agricultural processing to minimize breakage and wastage (Roland, 2016).

Abrasive strength is the force required to remove or protect the very tight coated membrane on grains such as cowpea seeds. In food processing, for example, the membrane will have to be removed or protected depending on the nature of the grain processing involved. Chukwu and Sunmonu (2010) submitted that the mean compressive strength, tensile strength, hardness, abrasive strength, shear strength and torsion strength of Sampea 7 cowpea are 66.25 N, 65.53 N,7.98 kg, 64.55 N, 65.20 N and 65.00 N, respectively and for Tvx 3236 cowpea they are respectively 93.65 N, 93.55 N, 11.96 kg, 92.56 N, 93.50N and 92.75 N. The coefficient of static friction on rubber, plywood and galvanized sheet were0.4511, 0.3965 and 0.3854, respectively. Organic matter content, protein, K, Ca, P and N amount were 90.58%, 20.31%, 0.0058%, 0.00106%, 0.142% and 3.25%,

respectively (Khattab *et al*., 2009). Table 2.2 shows the coefficient of static friction of cowpea seeds on different surfaces.

Table 2.2: Coefficient of static friction of cowpea seeds

Cowpea seeds	**Min**	**Max**	**Mean**	**S.d**
Galvanized sheet	0.3678	0.4012	0.3854	0.0470
Rubber sheet	0.4385	0.4608	0.4511	0.0530
Plywood sheet	0.3841	0.4032	0.3965	0.0443
Projected area (mm[1])	46	51	45	0.0695

Source: Khattab *et al*. (2009)

2.3 Methods of Dehulling Cowpea Seeds

Dehulling simply means the removal of hulls (seed coat) from the seed. The methods include traditional, and mechanical

[1] **.3.1 Traditional method**

Most house wives and vendors dehull and separate cowpea manually by hand, an inefficient and labour intensive process. In this method, cowpea is rinsed and soaked in a volume of water. After soaking for at least 10 minutes the seed coats will be ready for removal. Some black-eyed cowpeas may be soaked for shorter periods. If thoroughly soaked, the seed coats can be removed by hand. If not, the aid of a grinding stone or a mortar is needed to roughly bruise the skins with a stirring action (not pounding) before washing. The cotyledons are separated from the coats by washing in sufficient of water. When washed in adequate water, the seed coats float whereas the cotyledons sink. The amount of water absorbed by the cowpeas affects their suitability for certain preparations.

For instance:

(a) For fried cowpea dishes (*Kosei/Akara*), it is better to have cowpeas soaked for shorter periods before dehulling.

(b) For steamed cowpea dishes (*Alele/Moi-Moi*), it is better to have cowpeas soaked for longer periods before dehulling because increased water absorption improves the quality of the dish; and

(c) For cowpeas that are to be manually ground on a grinding stone for thick bean soup (*Miyan wake/Gbegiri*), it is better to soak for longer periods to aid in grinding. Plate 2.6 show a mortar and pestle used in loosen the seed coat of cowpea.

Plate VII: A Mortar and pestle used to loosen wet cowpea seed coat
Source: Singh (2003)

2.3.2 Mechanical method

Mechanical method of dehulling cowpea could be employed in different ways depending on the power source. These could be hand operated or motorized machinery.

2.3.2.1 *Hand operated cowpea dehulling machine*

Mechanized method involved the use of Hand operated machinery, which is to primarily decorticate the hull from the seeds by manually operating the machine with hand. Plate VIII (Khattab *et al*., 2009) shows a manually hand operated cowpea dehulling machine.

Plate VIII: Manually operated hand machine
Source: Khattab *et al*. (2009)

2.3.2.2 *Motorized Cowpea Machinery*

A small motorized cowpea machine was developed by (Khamaldeen *et al*., 2017) which meet the dehulling needs of the housewives and food vendor's. The machine developed was used to dehull wet cowpea with least injury or damage. The experiment was carried out at the Nigerian Stored Products Research Institute, (NSPRI), Kano State, Nigeria, where the wet cowpea de-hulling machine was fabricated. The performance indices that were used include; De-hulling efficiency (%) and Output capacity (kg/h). Plate IX shows a wet cowpea dehulling machine.

Plate IX: Wet cowpea dehulling machine
Source: Khamaldeen *et al*. (2017)

Olaoye and Olotu (2015) also developed a motorized dehulling and separating machine. The machine is operated by a 2 hp electric motor and has the following features such as hopper, dehulling unit and cleaning unit. The hopper is where the soaked beans is fed into, the dehulling unit consist of an auger that convey the soaked cowpea that gets dehulled by rubbing action principle as it moves along the length of the screw conveyor. The auger discharges dehulled cowpea seeds into the separating trough.

The cleaning chamber which is to separate the hull from the cotyledon consist of an agitator made of blades attached to a shaft and fixed at the top of a separating trough where the cleaning takes place. The agitator stirs the water inside separating trough as the clusters of hull and cotyledon dropped inside the trough for separation. The lighter hull floats and flows out through its outlet as the water from the water tank continually fills the separating chamber during operation. The water that filled chamber allow the mechanical agitator to easily and constantly stirs the dehulled seeds and hull for easy separation of the materials, hence, allow the heavier cotyledons to settle to the bottom of the separating chamber while the lighter hulls float and flow out with the flowing water.

The hulls are collected by a chaff/water collector through a pipe while the cotyledons sink down and settle at the bottom of the separating trough. After the dehulling operation, the separating trough is pulled out from its seat, the water is then drained and the cleaned cotyledons are packed for further processing.

The electric motor simultaneously powers the screw conveyor shaft in the dehulling chamber where the soaked cowpea seeds are being dehulled and the agitator shaft that agitates the water inside separating/cleaning chamber. The machine has an efficiency of 95.2% for 6 minutes soaking period and dehulling speed of 438rpm. Plate X shows an hydro-separating wet cowpea dehuller.

Plate X: Hydro-separating wet cowpea dehuller
Source: Olaoye and Olotu (2015)

2.4 Review of Related Works

Roland (2016) developed a wet legume dehulling machine. The author found that the best performance of the machine was achieved at effective dehulling speed of 438 rpm and a maximum efficiency of 95.2% for 6 minutes soaking period for cowpea, 72.2% efficiency for soya-beans soaked in hot water for 30 minutes and 62.5% efficiency for 15 hours cooking period for locust beans, The approximate abrasive forces required to dehull cowpea Tvx 3236 and sampea 7, at a feed rate of 20 seeds per minute was given as 92.56N and 64.55N, by Chukwu and Sunmonu (2010). The effective power for dehulling required from the motor as well as speed of rotation of the motor is 562.57 Watts and 146.6 rad/s.

Olaoye and Olotu (2015) developed an Improved hydro-separating cowpea dehuller. The test performance carried out on the machine showed that its effectively dehulled the cowpea seeds and separate the hull from the cotyledon. It gave 95.06% as the highest dehulling efficiency and 70.98% as lowest dehulling efficiency of the machine. The cleaning efficiency of dehuller was 70.21%; the feed rate of the machine was 157.02kg/h while output capacity of the machine was calculated to be 18.63kg/h./batch.

The power requirement for a screw conveyor was estimated from the sum of the power required to turn the empty screw and the additional power required to move the solids as stated by (Skilling, 2001). The power required to move empty screw conveyor was estimated to be 0.00013 kW while the power to move material is estimated to be 0.000104 kW. Therefore, the power requirement was calculated to be 0.00023 kW. The pulley design has two operating shafts namely; screw conveyor (auger) shaft and agitator shaft and they are to use different pulley diameter. The design and selection of appropriate power requirement for rotation of screw conveyor and the agitator was selected based on the speed of the driving motor, speed reduction ratio and centre to centre distance between the shafts at the conditions under which the dehulling and separation/cleaning action must take place. An AC motor with 1410 rpm was used with pulley diameter of 70 mm. The dehulling operation speed of 318.4 rpm was desired. A low speed of auger shaft rotation is expected during dehulling operation, because according to (Singh, 2003) dehulling of cowpea seeds at lower speed is more efficient than dehulling at higher speed. The operating speeds of the agitator is expected to be in ratio 1:4 of the speed of screw conveyor, since, it is expected to agitate the water without splashing. The pulley diameters of the agitator and screw conveyor were calculated to be 250 mm and 300 mm. BEE

(2004) stated that the fan operate under a predictable set of laws concerning speed, power and pressure. A change in speed revolution per minute (rpm) of any fan in operation will predictably change the pressure rise and power necessary to operate it at the new rpm.

This law can be applied to agricultural equipment that uses blade to carry out its operation. This Law is applicable because speed from the screw conveyor is being transferred to the agitator during the dehulling operation. Therefore, the power required by the agitator shaft was calculated to be 3.6 x10-6 kW. The shaft design for the Screw Conveyor (Auger) and agitator is subjected to combined twisting moment and bending moment, so the shafts were designed based on two simultaneous moments on them. The shaft diameter selected for screw conveyor was 25 mm based on its maximum bending moment of 37.23 Nm while the shaft diameter selected for the agitator was 20 mm based on its maximum bending moment of 4.82Nm using equation given by (Khurmi & Gupta, 2005). Khamaldeen *et al.* (2017) studied the performance evaluation of wet cowpea dehulling machine.

The performance evaluation of the cowpea de-hulling machine was done using a factorial experiment in a completely randomize design involving speed, soaking time and cowpea variety each at 3, 3, and 2 levels respectively. These were replicated three times. LSD was used to further analyze the significant means. The results showed that the speed, soaking time and cowpea variety had significant effect on de-hulling efficiency and output capacity for the developed de-huller while only soaking time and speed had significant effect on mechanical damage. The developed de-huller performs the best at 120 rpm speed, 11 mins soaking time, and with Dan-barere variety. Based on these variables, the performance indices obtained were 90.75 %, 74.27 kg/h. and 0.39% for de-hulling efficiency, output capacity and mechanical damage respectively. Akintola and Akinlosotu (1991) developed a motorized soybean dehulling machine for small Scale farmers. The de-hulling machine was based on abrasion between the beans and the wall of the de-hulling chamber. The machine consists of the inlet hopper, the de-hulling chamber which included the barrel and the auger specially designed to create abrasion on the beans as it is carrying them towards the outlet end, 1 hp geared motor with pulley and belt to make up the transmission unit.

The overall dimensions of the machine are 460 mm x 750 mm x 250 mm. The machine has de-hulling capacity of 40.00 to 54.55 Kg/h and efficiency of 87% to 93% with the highest efficiency gotten when 2 kg of the samples were soaked for five hours before dehulling. Therefore, it is recommended for small soybeans processors. Adejuyigbe and Bolaji (2005) designed and fabricated a beans dehulling machine using locally available materials. The performance of the machine was evaluated and the results showed that the higher the feed regulator opening the higher the dehulling rate. The average capacity of the dehulling machine is found to be 6.37 kg/h and the efficiency also is 75.7 %. Oladeji *et al*. (2019) developed and carried out performance evaluation of cowpea dehuller. The machine dehulling mechanism obtains its drive from a 3 phase 15 kW electric motor with a speed of 750 rpm. The performance of the machine was evaluated based on soaking time and dehulling time. The result showed that the dehulling rate increases with increase in time of soaking. The optimum efficiency is achieved at 98 % for 6 minutes and 15 minutes time of soaking and time of dehulling respectively. Table 2.3 shows a related reviewed work.

Table 2.3: Comparison of related reviewed work

S/n	Paper title	Author/year	Focus	Method	Metric	Strength	Limitation	Remark
1	Design and Fabrication Of Hydro-Separating Cowpea Dehuller	Olaoye, and Olotu (2015)	Design of an Improved Hydro-Separating Cowpea De-Huller	Use of continues flow of water from the tank	Evaluation based on cowpea variety and soaking time.	Ability to dehull and Separate hull and cotyledon completely	Operation requires the use of large amount of water of about 75 litres	
2	Design, Fabrication and Testing of a Wet Legume Dehulling Machine	Roland (2016)	Design and fabrication of wet legume dehulling machine	Using principle of compression for the splitting of the soaked seed coat.	Evaluation based on cowpea variety and abrasive force	Ability to dehull completely	Unable to separate the hull from the cotyledon	To modify a machine that will dehull and separate hull from its cotyledon as well as incorporate a system that will conserve/reduce water usage
3	Performance Evaluation of the Cowpea Wet DeHulling Machine	Khamaldeen *et al.* (2017)	Design and fabrication of dehulling machine	Use of auger to dehull the cowpea	Evaluation based on operating speeds, soaking time, and varieties of cowpea.	Ability to dehull completely	Unable to separate the hull from the cotyledon	
4	Design, Fabrication and Performance Evaluation of Beans Dehuller	Adejuyigbe and Bolaji (2005)	Design, fabrication and performance evaluation of bean dehuller	Use of roller to dehull the cowpea	Evaluation based on feed regulator opening and dehulling rate	Ability to dehull completely	Unable to separate the hull from the cotyledon	
5	Development and Performance Evaluation of Cowpea Dehuller	Olajide *et al.* (2019)	Design, Development and Performance Evaluation of Cowpea Dehuller	Use of roller to dehull the cowpea	Evaluation based on soaking time and dehulling time	Ability to dehull completely	Unable to separate the hull from the cotyledon	

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials and Equipment Used

The bio-materials used are three varieties of cowpea namely;

i.

Ka

nan

nad

o

ii.

Ife

Bro

wn

and

iii.

Iro

n

Be

an

The aforementioned varieties of cowpea were determined based on which, the machine was modified and fabricated. The varieties are readily availability in Nigeria markets and are affordable.

The equipment used in carrying out this research work includes, venier calliper, tilt table, electric weighing balance, metre rule, try square, pincer, hammer, marking knife, cutting machine and welding machine. For the performance evaluation of the modified machine, the materials used were stopwatch for recording the dehulling time, tachometer for the measurement of cylinder speed and weighing balance for quantifying the feed rate.

3.2 Description of the Existing Machine

The existing machine shown in plate 3.1 is operated by a 2 hp electric motor and have the following features such as hopper, dehulling unit and cleaning unit. The hopper is where the soaked cowpea is fed into. The dehulling unit is where the soaked cowpea gets dehulled as it moves along the length of the screw conveyor while the cleaning chamber separate hulls from its cotyledon with the aid of an agitator to stirs the water inside the separating trough. The clusters of hull and cotyledon dropped inside the trough for separation, to enable lighter hull floats and flows out through its outlet as the water from the water tank continually fills the separating chamber during operation. Figure 3.1 show the exploded view of the existing machine.

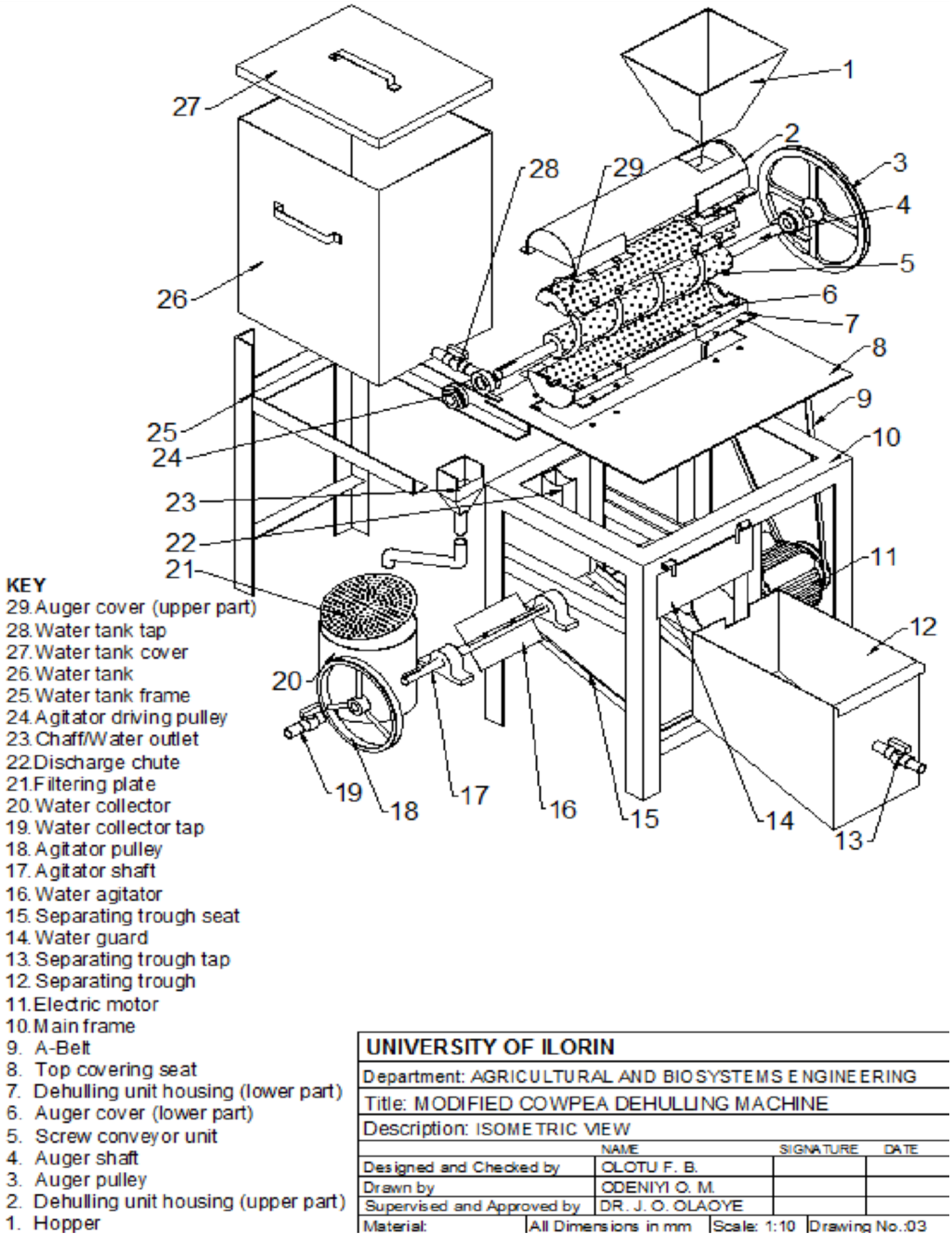

Figure 3.1: Exploded view of the Existing machine
Source: Olaoye and Olotu (2015)

Plate XI: Existing Hydro Separating Cowpea Dehuller **Source**: Olaoye and Olotu (2015)

To improve on the existing hydro-separating cowpea dehuller shown in Plate 3.2, three major components were considered to include the dehulling unit, separating unit and a pumping machine for recycling water. Table 3.1 show the components to be modified in the existing machine.

Table 3.1: Modified Components of the Existing Cowpea Dehulling Machine

Component	**Existing (UniIlorin)**	**Modified (Futminna)**
Throughput	Throughput Capacity is 18.63 kg/h	Throughput capacity is 43.3 kg/h
Water tank	Large amount of water (about 65 Litres) required for its operations	Designed with water recycling trough which is operated with about 31Litres maximum amount of water
Pumping machine	No pumping required	Pumping machine deployed to recycle the water for conservations.

3.3 Testing of the Existing Machine

The machine designed by Olaoye and Olotu (2015) was tested at the University of Ilorin, Department of Agricultural and Biosystems Engineering Ilorin, Nigeria. The test was carried out using three cowpea varieties which are Kanannado, Ife Brown and Iron Bean. Two kilograms (2 kg) of cowpea seeds each were soaked for six minutes before it was fed into the machine hopper. After the test was conducted, the following results were obtained Olaoye and Olotu (2015)

Test using Kanannado cowpea D_E= Dehulling efficiency

S_E= Separating efficiency

D_{E1} = Dehulling efficiency of Kananado cowpea

S_{E1} = Separating efficiency of Kananado cowpea

D_{E2} = Dehulling efficiency of Ife brown cowpea

S_{E2} = Separating efficiency of Ife brown cowpea

D_{E3} = Dehulling efficiency of Iron bean cowpea

S_{E3} = Separating efficiency of Iron bean cowpea

W_1 = Total weight of soaked cowpea seeds feed into the machine = 2 kg

W_2 = Weight of dehulled cowpea seeds =1.16 kg

W_3 = Weight of undehulled cowpea seeds =0.44 kg

W_4 = Weight of chaffed collected =0.15 kg

W_5 = Weight of chaff remaining inside the cleaning chamber =0.09 kg

$$D_{E1} = \frac{W_2}{W_2 + W_3} = 72.5\%$$

$$S_{E1} = \frac{W_4}{W_4 + W_5} = 62.5\%$$

i. Test using Ife Brown cowpea seeds

W_1 = Total weight of soaked cowpea seeds feed into the machine = 2 kg

W_2 = Weight of dehulled cowpea seeds =1.23 kg

W_3 = Weight of undehulled cowpea seeds =0.26 kg

W_4 = Weight of chaffed collected =0.175 kg

W_5 = Weight of chaff remaining inside the cleaning chamber =0.075 kg

$D_{E2} = \frac{W_2}{W_2 + W_3} = 82.6\%$

$S_{E2} = \frac{W_4}{W_4 + W_5} = 70.0\%$

ii. Test using Iron Bean cowpea seeds

W_1 = Total weight of soaked cowpea seeds feed into the machine = 2 kg

W_2 = Weight of dehulled cowpea seeds =1.45 kg

W_3 = Weight of undehulled cowpea seeds =0.19 kg

W_4 = Weight of chaffed collected =0.19 kg

W_5 = Weight of chaff remaining inside the cleaning chamber =0.05 kg

$D_{E3} = \frac{W_2}{W_2 + W_3} = 88.4\%$

$S_{E3} = \frac{W_4}{W_4 + W_5} = 79.2\%$

Therefore,

The total dehulling efficiency of the machine $D_E = \frac{D_{E1} + D_{E2} + D_{E3}}{3} = 81.2\%$

While the total separating efficiency $S_E = \frac{C_{E1} + C_{E2} + C_{E3}}{3} = 70.6\%$

3.4 Design Consideration

Fabrication materials for the modified cowpea dehulling and separating machine were sourced locally. The materials are chosen on the basis of their availability, strength, ease of maintenance, portability and ease of operation among other considerations.

Availability of Materials: The material for fabrication of the machine is a very important factor that would be consider in this design. This is to ensure the elimination of problem of materials procurement that would hinder the smooth execution of the project.

Strength: The machine was designed with materials that have the required strength to bear various loads and reactions.

Ease of Maintenance: Machine maintenance is an important and essential duty in the operation of any machine because it contributes a lot in determining its life span.

Portability: The machine considers the portability for easy transportation of the machine wherever necessary.

Ease of operation: The machine is easily operated by human being. In addition, in order to avoid possibilities of accident in operating the machine, operations such as putting on the machine, discharging and cleaning of the machine were made easy in the design.

Cost: The cost of the dehulling and separating machine is affordable by low income earners.

3.5 Methods Used for the Modified Machine

3.5.1 Experimental procedure

The selected cowpea varieties were Kananado, Ife brown and Iron bean. 20 kg of each variety were used for the evaluations. For the development of the Soaked cowpea dehulling and separating machine, the existing hydro-separating dehuller was evaluated for its performance for the identification of its weakness and faults. The properties of aforementioned varieties of cowpea were determined based on which the machine was designed and fabricated. A subsequent evaluation of the machine performance was carried out using one variety of cowpea (Kananado) and the results were analyzed eventually. Finally, the performance of the existing hydro-separating dehuller and that of the modified soaked cowpea dehulling and separating machine were compared to assess their differences. Plates XII, XIII and XIV shows the three variety of cowpea used.

Plate XII: Kananado cowpea variety

Plate XIII: Ife Brown cowpea variety

Plate XIV: Iron Bean cowpea variety

3.5.2 Design

The design analysis aims at evaluating the necessary design parameters, strength and size of materials in order to avoid failure by excessive yielding and fatigue during the required working life of the machine parts. The results of this analysis are included in the design calculation to prevent the possibility of under and over design of parts for the fabrication of the machine, so as to minimize costs.

3.6 Determination of Engineering Properties of Cowpea Seeds

The engineering properties of cowpea are good knowledge of any biomaterial under study and they are paramount in the development of any postharvest equipment either for processing, conveying, cleaning, dehulling, or storage of the biomaterial. Therefore, the following engineering properties of cowpea will be determined. Axial dimensions of cowpea seeds (Length, Width and Thickness), arithmetic mean diameter, geometric mean diameter, sphericity, coefficient of friction, hardness of the seeds, strength, compressive force, bulk density, true density, porosity, surface area, moisture content, and angle of repose. The length, thickness and width of the cowpea seeds varieties will be determined by measurements using Venier calliper. Twenty samples were randomly selected from the bulk of one hundred each of cowpea seeds Maduako and Hannan (2004).

3.6.1 Arithmetic mean diameter

The arithmetic mean diameter D_a, of the cowpea were determined using equation 3.1 (Bup *et al*., 2013).

$$D_a = \frac{(L + W + T)}{3} \quad (3.1)$$

Where: D_a= Arithmetic mean diameter, mm

L= Mean length of the seeds (mm)

W= Mean width of the seeds (mm)

T= Mean thickness of the seeds (mm)

3.6.2 Geometric mean diameter

The geometric mean diameter *Dg*, was also determined from the physical dimensions (Length L, Width W, and Thickness T) of the cowpea. It was obtained from equation 3.2 (Bup *et al*., 2013)

$$D_g = (LWT)^{1/3} \quad (3.2)$$

D_g= Geometric mean diameter, mm

The seed sizes were classified into three categories namely small, medium and large based on their length. The dimensional classification was based on the calculated average dimension (A_d) and the associated standard deviation (S_d). Then, small, medium, and large size seeds were so defined that their specific dimension (D_s) satisfies the following three inequalities (Pradhan *et al*., 2013): Plate XV shows a dimensional cowpea seeds.

Small size seeds = $D_s < A_d - S_d$ (3.3)

Medium size seeds = $A_d - S_d < D_s < A_d + S_d$ (3.4)

Large size seeds = $D_s > A_d + S_d$ (3.5)

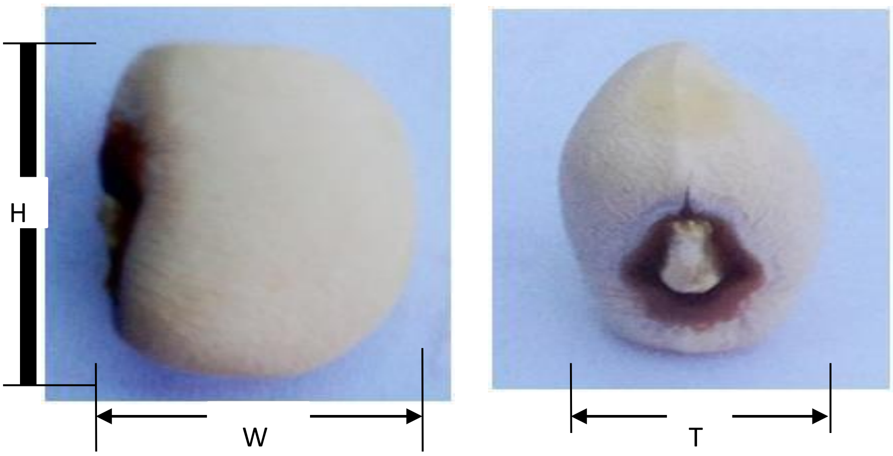

Plate XV: A dimensional cowpea seeds

3.6.3 Sphericity

Sphericity of the cowpea seeds were determined from equation 3.6 which has been used by Bup *et al*. (2013).

$$\text{Sphericity } (\emptyset) = \frac{(L \times W \times T)^{\frac{1}{3}}}{L} \tag{3.6}$$

3.6.4 Coefficient of static friction

The coefficient of friction of the cowpea were determined on plywood, glass and galvanized steel surfaces using a tilting table. The angle of inclination of the table to the horizontal at which samples started sliding were measured with the protractor attached beside the inclined plane apparatus. Measurements were replicated three times for each sample and the coefficient of friction was calculated using Equation 3.7 (Maduako & Hannan, 2004).

$$\mu = \tan\alpha \tag{3.7}$$

Where: μ = Coefficient of friction

α = Angle of inclination of the table to the horizontal at which samples just start to slide down.

3.6.5 Determination of bulk density

As reported by Bup *et al*. (2013), a container (100.00 mm height and 90.5.00 mm diameter) was filled with cowpea seeds samples and weighed using an electric balance of 0.001g accuracy. The procedure was repeated three times using different sets of cowpea and the bulk density was calculated from Equation 3.8 (Bup *et al*. 2013). The bulk density were used to determine the volume of hopper.

Bulk density (ρ_b) = $\frac{m}{v}$ (3.8)

Where, m is the mass of cowpea seeds (kg) and

V is the volume of the container used (m^3)

3.6.6 Determination of true density

The true density was determined using liquid displacement method as reported by (Ozturk *et al.*, 2009), where a container of known volume were filled with toluene.

Twenty 20 seed, of known mass were immersed into a measuring cylinder containing toluene. Toluene (C_7H_8) was used in place of water because it absorbed seeds to a lesser extent. The amount of toluene displaced by seeds was collected and measured, and the true density was calculated using Equation 3.9

True density (ρ_t) = $\frac{M}{V_t}$ (3.9)

Where: M is the unit mass of cowpea seeds, kg

V_t is the unit volume of toluene displaced, m^3

3.6.7 Determination of porosity

The porosity (ε) values were calculated from the values of true density and bulk density using Equation 3.10 as stated by (Bup *et al.*, 2013).

Porosity (ε) = $(1 - \frac{\rho_b}{\rho_t}) \times 100$ (3.10)

Where: ρ_b is the bulk density, kg/m^3

ρ_t is the true density, kg/m^3

3.6.8 Determination of surface area

The surface area was determined by analogy using Equation 3.11 as stated by (Francis, 2012).

$$\text{Surface area } (A_s) = \frac{\pi d l^2}{2l - d} \qquad (3.11)$$

Where: $d = (wt)^{0.5}$ l = length of seeds t = thickness of seeds w = width of seeds

3.6.9 Determination of moisture content

The moisture content of cowpea is determined randomly by selecting samples from the bulk samples. A known mass of each sample was measured using an electronic weighing balance with a sensitivity of 0.001 and placed in an oven set at temperature of 102±3°C and monitored over a period of 72 hours. Measurements were replicated thrice and the average moisture content was taken on wet basis. The moisture content (wet basis) was calculated as the weight of moisture (initial weight minus final weight of sample) divided by the initial weight of sample and expressed in percentage in Equation 3.12 as stated by

(Balami *et al*., 2014).

$$MC = \frac{W_1 - W_2}{W_2} \times 100\% \qquad (3.12)$$

Where: W_1 = Mass of the sample before drying, g

W_2 = Mass of the sample after drying, g

3.6.10 Determination of angle of repose

Maduako and Hannan (2004) reported that a cylindrical container was filled with cowpea seeds of different varieties and gently lifted up 20 mm above the surface where the bottom of the container was uncovered. The lifting of the container continued gradually until all the cowpea seeds formed a conical heap on the floor. The height and diameter of the heap were measured. The angle of repose was used to determine the

Angle of repose (θ) $=\tan^{-1}(\frac{2H}{D})$ (3.13)

Where: H = Height of the heaps, (mm)

D = Diameter of the heaps, (mm)

3.7 Design Calculations

The design calculations of the component parts of the cowpea dehulling and separating machine are as follows:

3.7.1 Hopper

The design of the hopper allows for convenient flow of the soaked cowpea seeds into the barrel of the machine. The volume of the hopper was computed using Equation 3.14 as stated by Balami *et al*. (2014).

Hopper volume $(V_h) = \frac{M}{\rho}$ (3.14)

Where: M = mass of soaked cowpea seeds fed into the hopper, (kg) = 8.3 kg

ρ = bulk density of soaked cowpea seeds, (kg/m^3) = 873.2 kg/m^3

$\frac{8.3}{873.2} = m^3$= 0.009505 m^2

Hence, the required volume of the hopper that will allow the flow of soaked cowpea without causing arching and ratholing (Fadeyibi *et al*., 2014) or any other flow problem was 0.009505 m^3.

3.7.2 Hopper capacity

Assuming the hopper is in the form of frustum, enclosing two concentric cones as shown in Figure 3.2. The height of the outer and the inner cones were assumed as 280 mm and 150 mm respectively. All assumptions were made based on the study of existing hopper design and previous research experience. The radius 0.8 m of the hopper was computed from Equation 3.15 by Fadeyibi *et al*. (2017).

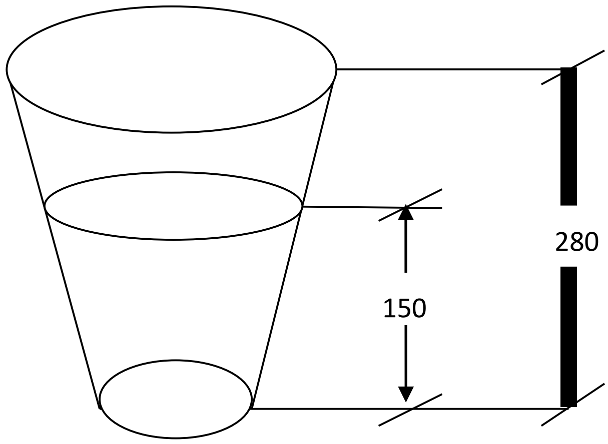

Figure 3.2: Hopper geometry

Volume of cone (V_h) = $\frac{\pi r^2 h}{3}$ (3.15)

Where: r= Base radius of frustum, mm
h = height of hopper, mm

Since the hopper is a frustum, we have to account for the two cones using Equation 3.16.

$V_h = \frac{\pi R^2 h_2}{3} - \frac{\pi r^2 h_1}{3}$ (3.16)

Where:V_h=0.0

09505 m^3 R =

0.45 m h_1 =

0.28 m

h_2 = 0.15 m r

= Based radius of

frustum (m) Thus:

$$0.009505 = \frac{3.142 \times 0.45^2 \times 0.15}{3} - \frac{3.142 \times r^2 0.28}{3}$$

0.009505= 0.01166 – 0.0293r^2

∴ r = 0.8 m

3.7.3 Power requirement of the cowpea dehulling and separating machine

The power required by the machine is a function of the total force required to rotate the dehulling drum and to operate the blades/spikes in the separation unit as reported by Gana, (2011).

$P_t = \frac{2\pi N\tau_t}{60}$ (3.17)

Where, P_t= the total power required by the machine (KW)

τ_t= Total torque (Nm)

Total torque (τ_t) = $\tau_D + \tau_S$ (3.18)

Where, τ_D = torque in the dehulling unit and τ_S = torque in the separating unit

But, $\tau_D = F_{td} \times r_d$ and $\tau_S = F_{ts} \times r_b$ (3.19)

The total force or weight on the shaft in the dehulling unit and the separating units are given by;

$F_{td} = (M_c + M_{Dd} + M_{pd})g$ (3.20)

$F_{ts} = (M_B + M_{ps})g$ (3.21)

Where, F_{td} =the total force or weight on the shaft in the dehulling unit and F_{ts} =the total force or weight on the shaft in the separating unit.

r_d =Radius of the dehulling drum (m)

r_b =Radius of the blade in the separating unit (m) M_c = the mass of the cowpea seed to be dehulled (kg) M_{Dd} = the mass of the dehulling drum (kg) M_{pd} =the mass of the pulley in the dehulling unit (kg) M_B =the mass of the blade in the separating unit (kg) M_{ps} =the mass of the pulley in the separating unit (kg) g =acceleration due to gravity (ms^{-2}) N =the speed of the electric motor in revolution per minutes (rpm)

3.7.4. Determination of mass of the soaked cowpea to be dehulled

The mass of soaked cowpea seeds to be dehulled at a time is a function of volume and bulk density of the soaked cowpea seeds. Assuming the volume of the soaked cowpea seeds to be dehulled in an hour is 0.0395m^3 and the time required for both loading and unloading is 9 minutes. The bulk density of the soaked cowpea was gotten using a cylindrical height of 900mm and radius of 45mm to calculate the volume of the soaked cowpea. Then, the mass of the material to be processed is given in Equation 3.22 as stated by Gana (2011).

$$M_N = \rho b\left(\frac{VNxTb}{Td}\right) \qquad (3.22)$$

Where, M_N = the mass of soaked cowpea seeds to be dehulled in a batch (kg)

P_b = the bulk density of the soaked cowpea (kg/m^3) = 873.2 kg/m^3

V_N = the volume of the soaked cowpea to be dehulled in an hour (m^3/h) = 0.0395m^3

T_b = the time required to dehull a batch (minutes) = 9 minutes

T_d = the total time required to dehull the material in an hour ≈ (51)

minutes By substituting values into the equation above.

M_N = 873.2 ($\frac{0.0295 \times 12}{51}$)= 6.12 kg Per batch operation

3.7.5. Determination of mass of the drum

The total mass of the drum is essential in the determination of the power requirement of the machine as reported by Gana (2011).

$$M_D = M_{cp} + M_{mb} \tag{3.23}$$

$$M_{cp} = \sigma(\pi r_a^2 h_a)N_c \tag{3.24}$$

$$M_{mb} = \sigma(L_c B_c T_c)N_p \tag{3.25}$$

But, $N_p = \frac{C_c}{D_c}$ (3.26)

$$M_D = \sigma(\pi r_a^2 h_a)N_c + \sigma(L_c B_c T_c)\frac{C_c}{D_c} \tag{3.27}$$

Where, M_D = the mass of the drum (kg)
M_{CP} = the mass of the circular plate (kg)

M_{mb}= the density of blades (kg/m^3)

σ = the density of mild steel (kg/m^3)

= 7840 r_a = the radius of the circular

plate (m) = 0.086 t_a = thickness of

the circular plate (m) 0.002

N_c = the number of circular plate = 2

L_c = the length of the blade (m) = 0.22

B_c = the breadth of the blade (m) = 0.02

T_c = the thickness of the blade (m) = 0.002

N_p = the number of blades

C_c = the circumference of the circular plate (m) = $2\pi r_a$

D_c = the distance between the blade (m) = 0.01

M_D
$= 7840\ [((3.142 \times 0.086^2 \times 0.002) \times 2 + (0.3 \times 0.02 \times 0.002)(\frac{2 \times 3.142 \times 0.086}{0.01}))] = 7840[9.295^{-5} +$

$4.76^{-4}]$ = 4.46 kg

3.7.6. Design of the machine pulley sizes

The decorticating or dehulling speed ranging from 100 – 450 rpm had been used by researchers such as Francis (2012), Balami *et al*. (2012), and Onyechi *et al*. (2014).

Therefore, for this design, machine speeds of 250, 350 and 450 rpm were selected. Speed and the diameter of the electric motor pulley were taken to be 1430 rpm and 0.05 m, respectively. The diameter of the machine pulleys at the three selected speed of 250, 350 and 450 rpm of the electric motor were determined according to the method reported by Gana (2011).

$$N_1 D_1 = N_2 D_2 \qquad (3.28)$$

But, $D_2 = \frac{N1D1}{N2}$

Where, N_1 = the speed of the electric motor (rpm) = 1430 rpm

D_1 = diameter of the electric motor pulley (m) at the three selected machine speed.

D_2 = big diameter of the dehulling shaft pulley, m

D_3 = medium diameter of the dehulling shaft pulley, m

D_4 = small diameter of the dehulling shaft pulley, m

$D_2 = \frac{1430 \times 0.05}{250} = 0.28$ m

$D_3 = \frac{1430 \times 0.05}{350} = 0.20$ m

$D_4 = \frac{1430 \times 0.05}{450} = 0.15$ m

3.7.7. Determination of masses of pulley in the dehulling and separating units

The mass of the pulley is also essential in the requirement determination and it was determined using conventional method for mass determination as reported by Gana

(2011).
This is given as;

$$M_{Pd} = \rho_p (\pi r_1^2 T_p) \quad (3.29)$$

Where, M_{pd} = mass of the machine pulley in the dehulling

unit (kg) P_p = density of the machine pulley (kg/m^3) = 7840

π = a constant

r_1 = radius of the machine pulley in the dehulling unit (m) = $\frac{D4}{2} = \frac{0.16}{2} = 0.08$

T_p = thickness of the machine pulley (m) = 0.02

M_{pd} = 7840 (3.142 x 0.08^2 x 0.02)

= 3.15 kg

$$M_{ps} = \rho_p (\pi r_2^2 T_p) \quad (3.30)$$

r_2 = radius of the machine pulley in the separating unit (m)=$\frac{D1}{2} = \frac{0.05}{2} = 0.025$ m

M_{ps} = 7840 (3.142 x 0.025^2 x 0.02)

= 0.31 kg

3.7.8. Determination of the mass of the agitator blade

This was calculated using the following equations as reported by Gana (2011).

$M_b = N_b(\rho_b V_b)$ (3.31)

But, $V_b = L_b B_b T_b$ (3.32) $M_b = N_b[\rho_b(L_b B_b T_b)]$ (3.33)

Where, M_b = mass of the agitator blade (kg)

V_b = volume of the blade (m^3)

P_b = density of the blade material (kg/m^3) = 7840

N_b = number of the blades = 4

L_b = length of the blade (m) = 0.22 m

B_b = breadth of the blade (m) = 0.08 m

T_b = thickness of the blade (m) = 0.002 m

$M_b = 4[7840(0.22\times0.08\times0.002)]$

= 1.104 kg

The total mass on the shaft in the dehulling unit is the calculated mass of the drum, the two pulley on the left and right hand side of the drum and the mass of the soaked cowpea seeds to be dehulled in batch

$M_{ts} = (M_N + M_D + M_{PS})$ (3.34)

M_{ts} = Total mass on the shaft (kg)

M_N = 8.6 kg

M_D = 4.46 kg

M_{PS} = (3.15 × 2) kg = 6.3 kg
M_{ts} = 8.6 + 4.46 +6.3

M_{ts} = 14.36 kg

The total weight (W_T) on the shaft is the total mass multiplied by the acceleration due to gravity (g = 9.81 m/s^2).

$F_{ts} = M_{ts} \times g$

= 14.36 × 9.81

= 140.87 N

The toque (τ_D) developed in the dehulling unit is the total weight (W_{td}) multiplied by the radius of the drum in the dehulling unit, (r_d) = r_d = 0.086 m

$\tau_D = F_{td} \times r_d$

= 140.87 × 0.086

= 12.11 Nm

Then total mass on the shaft in the separating unit is the calculated mass of the agitator blade, and the mass of the pulley on the shaft.

M_{ts} = (M_b + M_{PS})

M_{ts} = Total mass on the shaft (kg)

M_b = 1.104 kg

M_{PS} = 0.31 kg
M_{ts} = 1.104 + 0.31

M_{ts} = 1.414 kg

The total weight (W_{ts}) on the shaft in the separating unit is the total mass multiplied by the acceleration due to gravity (g = 9.81 m/s^2)

F_{ts}= M_{ts} × g

= 1.414 × 9.81

= 13.87 N

The toque (τ_S) developed in the dehulling unit is the total weight (W_{ts}) multiplied by the radius of the agitator blade in the separating unit r_b = 0.04 m

τ_S = F_{ts} × r_b

= 13.8 × 0.04

= 0.552 Nm

The total toque (τ_t) = τ_D + τ_S

τ_t= 12.11 + 0.552

= 12.66 Nm

Hence, the torque transmitted by the dehulling drum shaft was 12.11 Nm while the agitator shaft was 0.552 Nm.

The power required was calculated as reported by Bup *et al.* (2013)

$$P_t = \frac{2\pi N\tau_t}{60} \tag{3.35}$$

P_t = The power required (kW)

N = Speed of the electric motor (1430 rpm)

τ_t = Total toque developed in the machine = 16.89 Nm

π = constant (3.142)

$$P_t = \frac{2\times3.142\times1430\times12.66}{60}$$

= 1896.07 W

= 1.89 kW

3.7.9. Determination of the diameter of the shaft

The diameter of the shaft is important in designing and in determination of the power requirement of the machine. This is determined as reported by (Bup *et al.*, 2013).

$$\sin\alpha \ \frac{d2-d1}{2x} \tag{3.36}$$

Where d_2 = Diameter of the driven pulley = 0.15 m d_1 = Diameter of the driving pulley = 0.05 m c = Centre distance between the driving and driven pulleys 0.2m (assumed)

$\alpha = \sin^{-1} [\frac{d2-d1}{2c}]$ (3.37)

$= \sin\text{-}1\ [\frac{0.15-0.05}{2\times0.2}] = 14.48^o$

The angle of contact between the belt and the driven pulley is given as;

$\theta = (180\ \text{-}2\alpha)\ \frac{\pi}{180}$ (3.38)

$= [180 - 2\ (14.48^o)]\ \frac{\pi}{180}$

$= [180 - 2\ (14.48^o)]\ \frac{\pi}{180} 2.64$ rad

The tension between the right side (t_1) and the slack side (t_2) of the belt is given as;

$\frac{t1}{t2} e\mu\theta$ (3.39)

The coefficient of friction μ, is taken as 0.3 for rubber on cast iron or steel (Onyechi *et al*., 2014).

$\frac{t1}{t2} = e^{\ 0.3x\ 2.64} = 2.21$

$t_1 = 2.21\ t_2$

But, $(t_1 - t_2)r_p = \tau_t$ (3.40)

$r_p = \frac{0.25}{2} = 0.125\ m$

τ_t =21.89 Nm

$t_1 - t_2 = \frac{21.893}{0.125} = 175.144$ N

By substitution

$2.21t_2 - t_2$

$= 175.144$

$1.21t_2 =$

175.144

$t_2 =$

144.747 N

Therefore, $t_1 = 2.21t_2 =$

$2.21(144.747)$

$t_1 = 319.89$ N

Resolving the vertical and horizontal component of the tension t_1 and t_2 from Figure 3.3 gives;

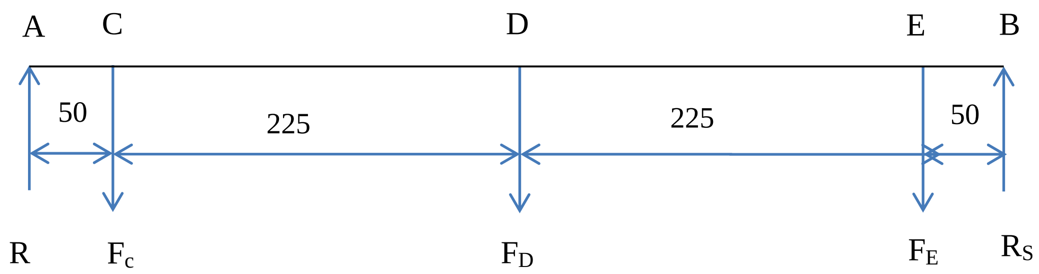

Figure 3.3. Force Resolutions.

All dimensions in millimeter (mm)

$F_{1v} = t_{1v} \cos \alpha = 319.891 \text{ x } \cos 14.48 = 309.730$ N

$F_{1h} = t_{1h} \sin \alpha = 319.891 \text{ x } \sin 14.48 = 79.986$ N

$F_{2v} = t_{2v} \cos \alpha = 144.747 \text{ x } \cos 14.48 = 140.149$ N

$F_{2h} = t_{2h} \sin \alpha = 144.747 \text{ x } \sin 14.48 = 36.193$ N

$F_{tv} = F_{1V} + F_{2V} = 309.730 + 140.149 = 449.879$ N

Also, $W_{ps} = M_{ps}$ x g = 7.693 x 9.81 = 75.468 N

$F_C = F_E = W_{ps} + F_{tV} = 449.879 + 75.468 = 525.347$ N

Since the weight of the drum acts at its centre and at the centre of the drum;

$F_D = M_D$ x g = 4.988 x 9.81 = 48.932 N

Also, $R_A + R_B = 525.347 + 525.347 + 48.932 = 1099.626$ N

Taking moment about A;

R_B x 0.4 – 525.347 x 0.35 – 48.932 x 0.2 – 525.347 x 0.05 = 0

RB = $\frac{219.925}{0.4} = 549.813\ N$

Therefore, R_A = 1099.626 – 549.813 =

549.81 N The maximum bending moment

acts at C and E. $M_{max} = R_A$ x 0.05 =

549.813 x 0.05 = 27.49 N m

The equivalent twisting moment (T_e) is given as

$T_e = \sqrt{(k_t \times T_T)^2 + (K_B \times M_{max})^2}$ (3.41)

Also $T_e = \frac{\pi}{16} \times S_s \times d^3$ (3.42)

Where, d = the shaft diameter (m)

S_s = the allowable shear stress (55 x 10^6 N/m^2) for shaft without key way)

K_b = combined shock and fatigue factor applied to bending moment
K_t = combined shock and fatigue factor applied to torsional moment

For load applied gradually, $k_b = 1.5$ and $k_t = 1.0$

M_{max} = maximum bending moment

Te = $\sqrt{(1.5 \times\ 27.491)^2 +\ (1\ \times 21.893})^2$

= 46.69 N m 46.688 = $\frac{\pi}{16} \times 55\ \times 10^6 \times d^3$

$d^3 = \frac{46.688 \times 16}{3.142 \times\ 55\ \times 10^6}$ = 4.3233 x 10^{-6}

d = $\sqrt[3]{4.3233\ \times 10^{-6}}$

= 0.0163 m = 16.29 mm

d = 16.29 + ($\frac{20}{100} \times\ 16.29$) = 16.29+ 3.258 = 19.55 mm

Hence, a shaft of 20 mm was selected for the design.

3.7.10 design of the dehulling unit clearance

The design of the dehulling unit clearance is one of most important aspect in the design of a dehulling machine and this was determined as reported by Onyechi *et al*. (2014). This was calculated using Equation 3.43;

Dehulling Unit Clearance = $\frac{a+b}{2}$ (3.43)

Where, a = The major diameter of the seed (mm) b = The minor diameter of the seed (mm) Dehulling Unit Clearance

$= \frac{8.125+5.98}{2} = 7.053\ mm$

3.7.11. Power requirement of the pump

In any pumping system, the role of the pump is to provide sufficient pressure to overcome the operating pressure of the system to move water/liquid at a required flow rate (Bup *et al.* 2013).

Flow rate of 2 Litre/minute was assumed for this design.

Where: P_h = Horse

power Q =

flow rate (L/min)

h = head = 3 ft

SG = Specific gravity of water = 1

Total dynamic head (TDH) = head + friction loss

$$P_h = \frac{Q \times TDH \times SG}{3960} = 0.00197 \text{ kW} \qquad (3.44)$$

3.7.12 Length of belt

The minimum obtainable distance between the central axis of the electric motor shaft and the radius of the outer cylindrical drum housing for dehulling operation as well as the distance between drum shaft and the agitator shaft influenced the choice of this parameters and it was calculated using Equation 3.45.

$$L = \frac{\pi}{2}(D_1 + D_2) + 2c + \frac{(D_1 - D_2)^2}{4c}$$

3.45

Where: L = Total length of belt (m)

D_1= Diameter of driving pulley (m)
D_2 = Diameter of driven pulley (m)

C = shaft to shaft centre; was selected to be 0.15 m dehulling and 0.1 m for agitator

The machine design required a set of 3 pulleys; prime mover pulley (D_p=0.05m), cylinder shaft pulley (D_{cp}=0.15 m), agitator shaft pulley (D_a=0.05 m).

$L_{bc}=(0.05+0.15)+2\times 0.15+\frac{(0.05+0.15)^2}{4\times 0.15}$

= 0.567m

$L_{ba}= (0.05+0.05)+2\times 0.1+\frac{(0.05+0.05)^2}{4\times 0.1}$

= 0.325 m

Hence, the cylinder belt length (L_{bc}) was determined to be 0.567 m while the agitator belt length (L_{ba}) was 0.325 m.

3.8 Determination of the Machine Evaluation Parameters

The performance of the modified soaked cowpea dehulling and separating machine was evaluated based on the following indices; dehulling efficiency, separating efficiency and output capacity. These were achieved using the procedure outline by Olaoye and Olotu (2015) and are calculated using Equation 3.46 to 3.48 respectively.

i. Dehulling Efficiency, D_E (%)

$$D_E = \frac{W_1}{W_1+W_2}\times 100 \qquad (3.46)$$

Where, W_1= weight of dehulled cowpea seeds (kg)

W_2= weight of undehulled cowpea seeds (kg)

ii. Separating Efficiency, S_E (%) = 67%

$$S_E = \frac{W_4}{W_4+W_5} \times 100 \tag{3.47}$$

Where, W_4 = Weight of chaffed collected = 0.118 kg

W_5 = Weight of chaff remaining inside the separating chamber = 0.069 kg

iii. Output Capacity, O_c (kg/h) = 40.8 kg/h

$$O_c = \frac{Q_g}{T} \tag{3.48}$$

Where, Q_g = Total weight of soaked cowpea seeds fed into the machine (kg)

T= Total time of feeding (hr)

3.9 Experimental Design and Analysis

The experimental results were analyzed graphically and statistically using D-optimal factorial based on Randomized Complete Block Design (RCBD). Three different levels of speeds, soaking time and cowpea (250, 350 and 450 rpm), (4, 6, and 8 mins) and (Kananado, Ife brown and Iron bean) respectively were considered for the evaluation of the modified soaked cowpea machine. Analyses of Variance (ANOVA) were used to investigate the effect of the variables, and their interactions on the performance evaluation of the existing and modified machines.

3.10 Cost Analysis

S/No.	Item	**Specification**	**Quantity**	**Unit cost (₦)**	**Total cost (₦)**
1	Mild steel pipe	1"x1", 1.5 thick	2.5	2,500	6,250
2	Galvanized metal sheet	2mm thick	0.5 sheet	7,500	7,500
3	Galvanized metal sheet	1.5 thick	1 sheet	5,900	5,900
4	Angle iron	2"x2", 1.5 mm thick	1 length	4,500	4,500
5	Dehulling pulley	$\emptyset 250\ mm$	1	5,000	5,000
6	Agitator pulley		1	3,500	3,500
7	Pump pulley	$\emptyset 175\ mm$ $\emptyset 100\ mm$	1	2,000	2,000
8	Electric motor pulley	$\emptyset 50\ mm$	1	1,500	1,500
9	Dehulling shaft		1	2,500	2,500
10	Agitator shaft		1	1,200	1,200
11	Water pump	$\emptyset 50\ mm$ $\emptyset 50\ mm$	1	6,000	6,000
12	Dehulling ball bearing	$\emptyset 75\ mm$	2	2,500	2,500
13	Agitator ball bearing	$\emptyset 50\ mm$	2		
14	Bolts and nuts	Assorted	8	70	560
15	miscellaneous			7,000	7,000
	Total				**61,810**

3.11 Machine Construction and Principle of Operation

The machine frame is cuboid in shape and gives a rigid support to the whole system. It has an over dimension of 800 mm x 500 mm x 400 mm. The fabrication was done by marking and cutting out the material into different lengths using power hacksaw and mild steel sheet into rectangular shape then welded together to form the frame.

The modified cowpea dehulling and separating machine is operated with a 2hp electric motor and has capacity of 43.3 kg. The machine comprises three units: the dehulling unit, cleaning unit (separation chamber) and recycling unit. The dehulling unit consist of a perforated drum that dehulled the soaked cowpea by principle of rubbing action and discharges the dehulled cowpea seeds into the separating unit through an opening. The separating unit which is to separate the hull from the cotyledon consist of an agitator made of blades attached to a shaft and fixed at the top of a separating trough where the cleaning takes place. The water inside the separating trough continue to recycle as the clusters of hull and cotyledon dropped inside the trough for separation. The lighter hull floats and flows out through an outlet as the water from the recycling unit continually fills the separating chamber during operation. The water that filled the chamber allow the mechanical agitator to easily and constantly stirs the dehulled seeds and hull for easy separation of the materials, hence, allow the heavier cotyledons to settle to the bottom of the separating chamber while the lighter hulls float and flow out with the flowing water.

The hulls are collected by a sieving plate while the cotyledons sink down and settle at the bottom of the separating trough. After the dehulling operation, the separating trough is pulled out from its seat, the water is then drained and the cleaned cotyledons are packed for further operation.

The electric motor simultaneously powers the dehulling drum shaft in the dehulling chamber where the soaked cowpea seeds are being dehulled and the agitator shaft agitates the water inside separating chamber. Figure 3.4 show the orthographic view of the modified soaked cowpea dehulling and separating machine.

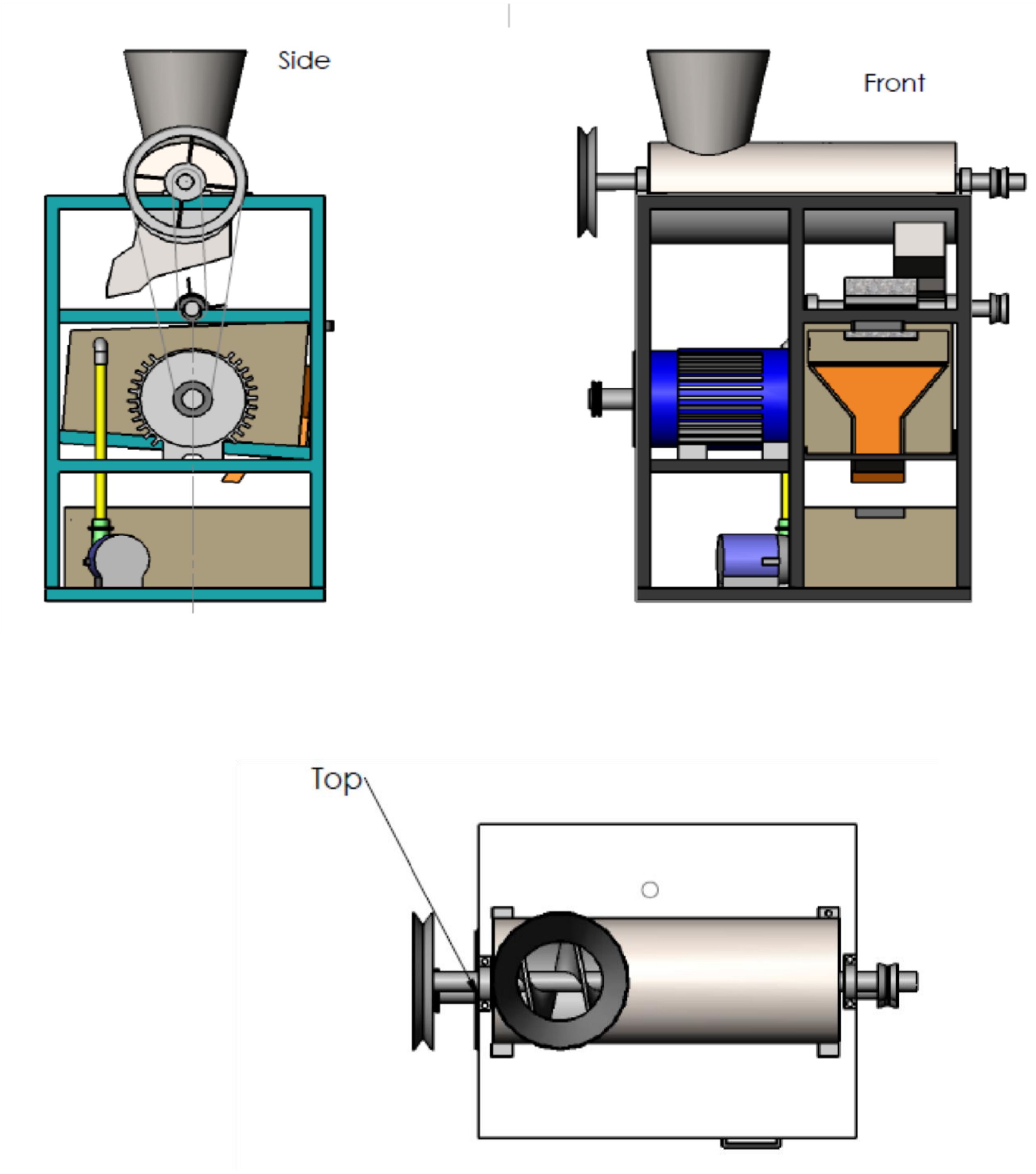

Figure 3.4: Orthographic view of the modified machine

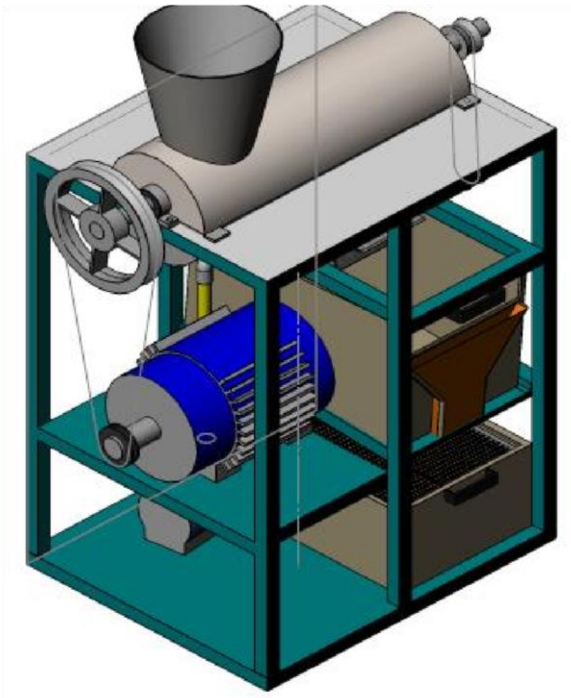

Figure 3.5: Isometric view of the soaked cowpea dehulling and separating machine

Figure 3.6: Pictorial view of the modified soaked cowpea dehulling and separating machine

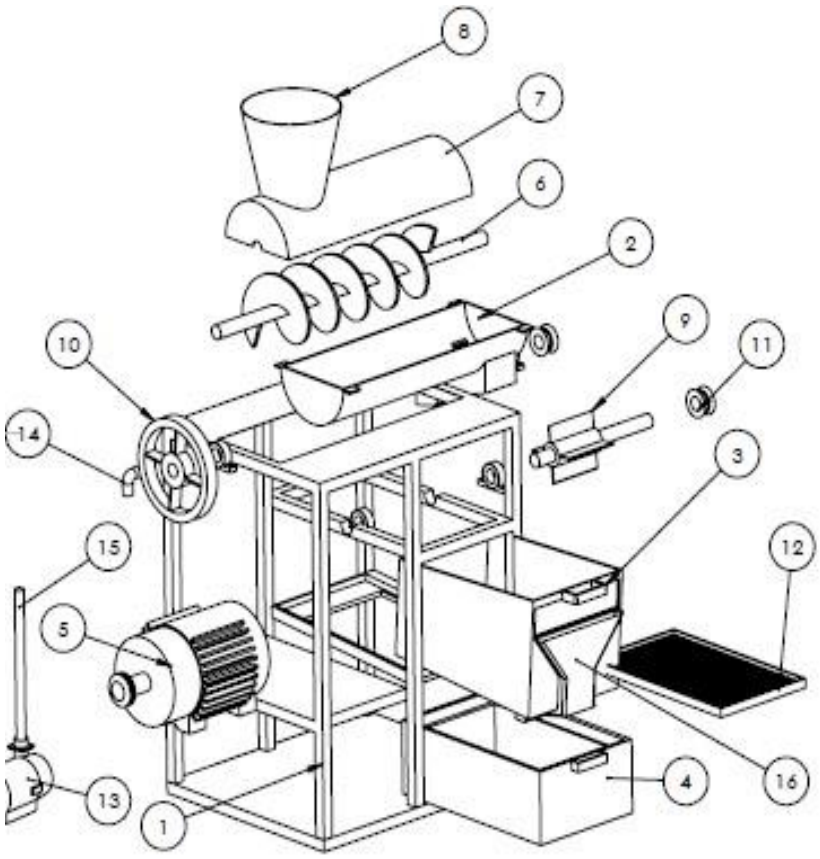

Figure 3.7: Exploded view of the modified machine

KEY

16 Discharge funnel
15 Pipe
14 Pipe joint
13 Water pump
12 Sieve
11 Agitator pulley
10 Auger pulley
9 Agitator
8 Hopper
7 Upper cylinder
6 Auger
5 Electric motor Wat

e
r
r
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ir
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l
a
ti
n
g
4 trough
3 Separating trough
2 Base cylinder
1 Body frame

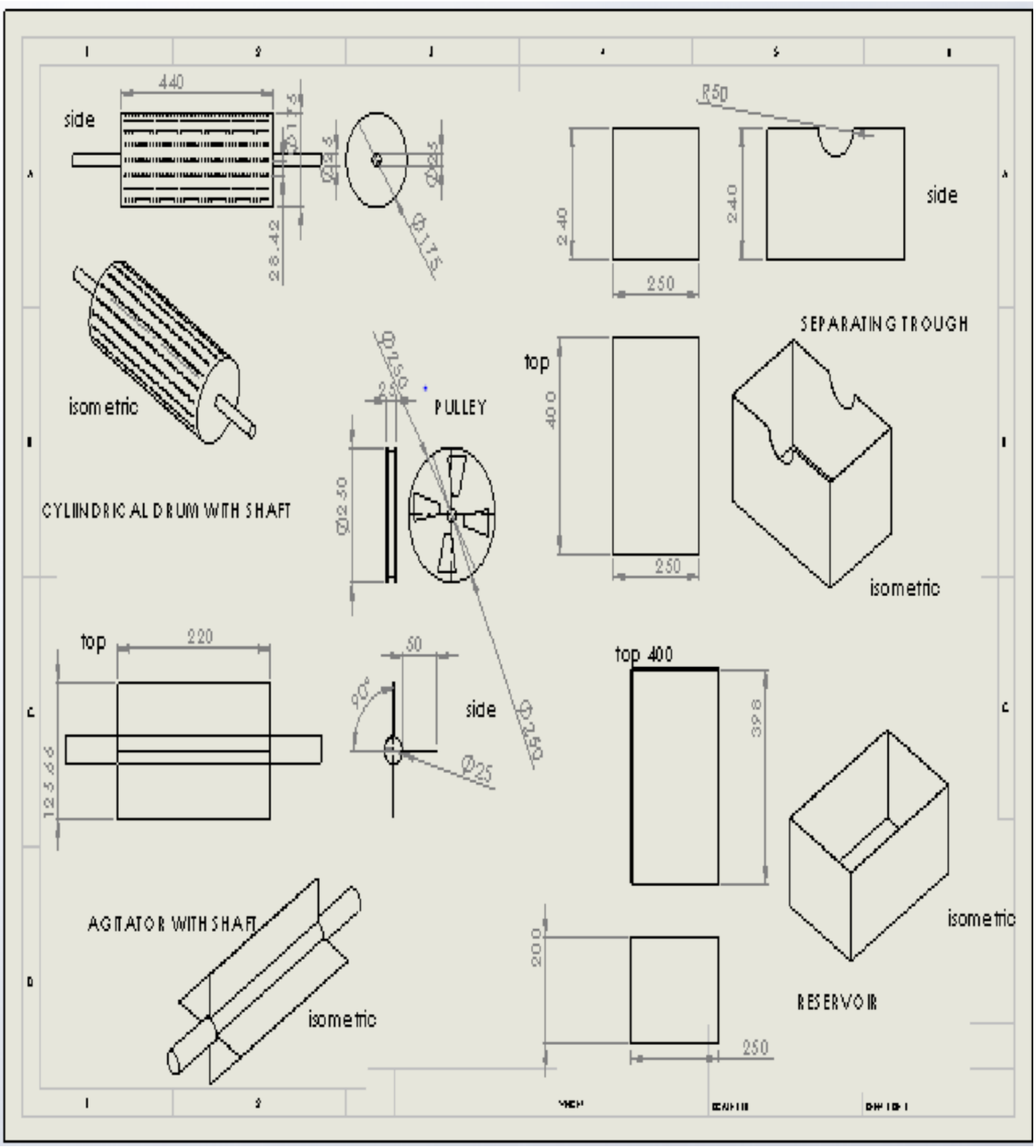

Figure 3.8: Component parts of the modified soaked cowpea dehulling and separating machine

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Effect of Operating Speed, Soaking Time and Cowpea Variety on the Machine Performance

The results obtained from the performance evaluation of the modified soaked cowpea dehuller showed that the soaked cowpea dehulling and separating machine operates an effective dehulling speed of 250 rpm and achieved an efficiency of 96.2% for 8 minute soaking period (Table 4.1), 95.8% for 4 minutes soaking period (Table 4.2) and 95.6% for 6 minutes soaking period (Table 4.3) respectively. The best dehulling efficiency were obtained at 250 rpm operating speed, 8 minutes soaking time, and with Kananado variety.

This implies that the lower the operating speed the higher the efficiency. This is in agreement with Olaoye and Olotu (2015). Dehulling of cowpea seeds at lower speed is more efficient than dehulling at higher speed. The output capacity of the machine was calculated in equation 3.49 to be 40.8kg/h/batch.

Table 4.1: Results for Kananado Cowpea Seeds

Operating speed (OS)	Soaking Time (ST)	Weight of Hull+Cotyledon (kg)	Weight of Cotyledon (kg)	Weight of Hulls (kg)	Weight of Undehulled (kg)	Weight of Broken Cotyledon (kg)	Dehulling Efficiency (%)
250	8	2.275	2.157	0.118	0.086	0.049	96.2

250	6	2.269	2.155	0.114	0.078	0.069	95.0
350	8	2.224	2.034	0.189	0.112	0.075	94.7
350	6	2.211	2.028	0.185	0.129	0.070	94.0
350	4	2.214	2.028	0.186	0.121	0.075	94.4
250	4	2.257	2.156	0.101	0.094	0.059	95.8
450	8	2.189	1.991	0.195	0.127	0.094	94.0
450	4	2.193	1.986	0.207	0.115	0.102	94.5

Table 4.2: Results for Ife Brown Seeds

Operating speed (OS)	Soaking Time (ST)	Weight of Hull+Cotyledon (kg)	Weight of Cotyledon (kg)	Weight of Hulls (kg)	Weight of Undehulled (kg)	Weight of Broken Cotyledon (kg)	Dehulling Efficiency (%)
250	8	2.277	2.145	0.131	0.104	0.029	95.4
350	8	2.211	2.016	0.194	0.134	0.065	94.3
350	4	2.199	2.014	0.176	0.155	0.065	92.9
350	6	2.185	2.016	0.161	0.204	0.021	90.8
450	6	2.206	1.991	0.212	0.115	0.092	94.5
250	4	2.249	2.148	0.101	0.095	0.066	95.8
450	8	2.201	1.989	0.215	0.103	0.106	95.1

Table 4.3: Results for Iron Bean Seeds

Operating speed (OS)	Soaking Time (ST)	Weight of Hull+Cotyledon (kg)	Weight of Cotyledon (kg)	Weight of Hulls (kg)	Weight of Undehulled (kg)	Weight of Broken Cotyledon (kg)	Dehulling Efficiency (%)
350	6	2.219	2.032	0.185	0.143	0.050	93.4
350	4	2.227	2.028	0.198	0.114	0.070	94.7
350	8	2.224	2.030	0.198	0.106	0.080	95.0
250	6	2.266	2.150	0.112	0.098	0.050	95.6
450	8	2.209	1.992	0.216	0.095	0.107	95.4
450	4	2.201	1.988	0.214	0.319	0.103	86.2
450	8	2.185	1.988	0.1988	0.119	0.106	94.8

4.1.1 **Effects of operating speed, soaking time and cowpea varieties on dehulling efficiency for weight of hulls and cotyledon**

The P-values less than 0.0500 indicate model terms are significant. In this case A is a significant model term. Values greater than 0.1000 indicate the model terms are not significant.

Table 4.4: The analysis of variance of selected factorial model that was carried out on the weight of hulls and cotyledon.

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob. > F
Model	0.0233	18	0.0013	7.72	0.0030	Significant
A-Operating Speed	0.0187	2	0.0094	55.82	< 0.0001	
B-Soaking time	0.0002	2	0.0001	0.5513	0.5966	
C-varieties'	0.0001	2	0.0001	0.3570	0.7104	
AB	0.0006	4	0.0001	0.8315	0.5413	
AC	0.0006	4	0.0002	0.9074	0.5034	
BC	0.0002	4	0.0001	0.3320	0.8491	
Residual	0.0013	8	0.0002			
Lack of Fit	0.0011	5	0.0002	3.43	0.1698	not significant
Pure Error	0.0002	3	0.0001			
Cor Total	0.0247	26				

The analysis of variance of selected factorial model that was carried out on the weight of hulls and cotyledon shows that the operating speed has significant effects on the machine efficiency with p value of 0.001 (Table 4.4). This analysis is similar to the report of Khamaldeen *et al.* (2017) where the authors designed wet cowpea de-hulling machine and was evaluated on some factor which includes the operating speed. However, the analysis of variance carried out on the weight of the hulls and cotyledon further reveals that the soaking time, cowpea variety, interaction AB, AC, and BC have no significant effects on the performance evaluation of the de-hulling machine at p-value of 0.5966, 0.7104, 0.5413, 0.5034 and 0.8491 respectively.

Figure 4.1 shows the 3-D plot of operating speed against soaking time for the weight of hulls and cotyledon, which invariably indicate that at 8 minutes soaking time and 250 rpm gave the best dehulling efficiency.

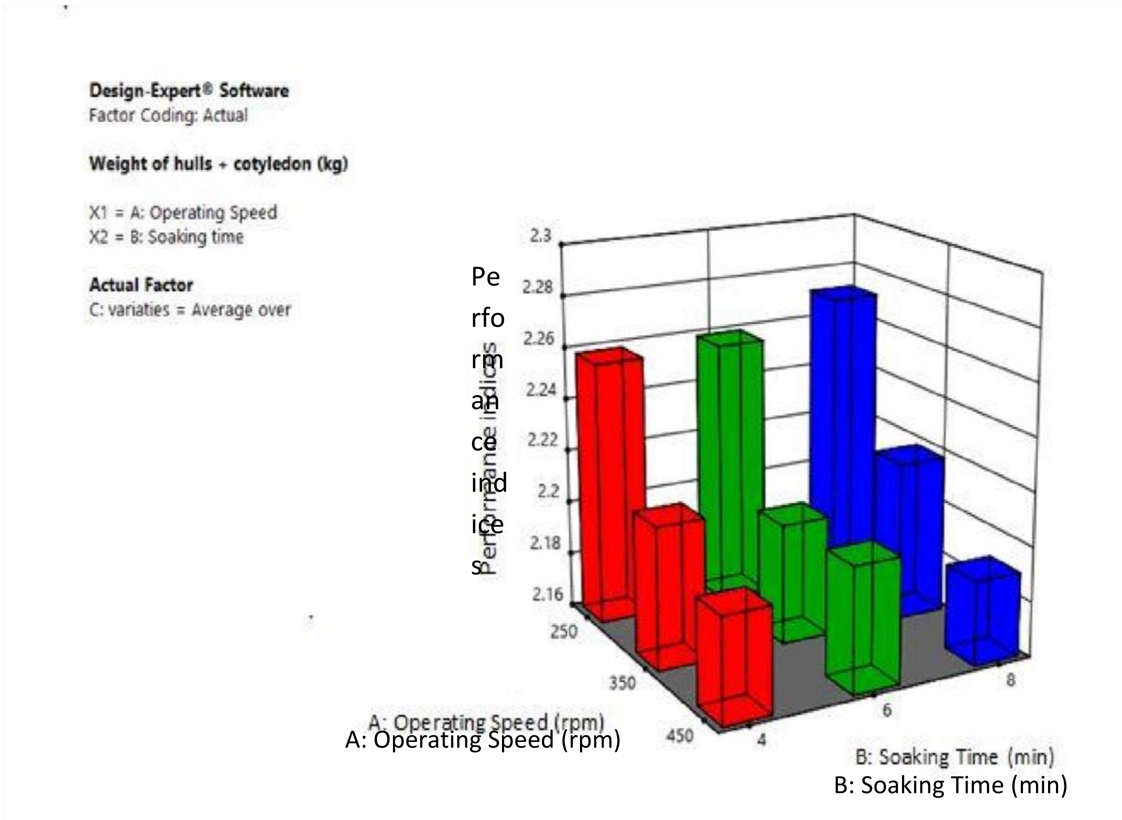

Figure 4.1: 3-D plot of operating speed and soaking time (weight of hull and cotyledon)

4.1.2 Effects of operating speed soaking time and varieties on dehulling efficiency for the weight of cotyledon

Table 4.5: The analysis of variance of selected factorial model that was carried out on the weight of cotyledon

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob. > F
Model	0.1399	18	0.0078	257.07	< 0.0001	Significant
A-Operating Speed	0.1231	2	0.0615	2035.86	< 0.0001	
B-Soaking time	0.0000	2	6.216E-06	0.2057	0.8183	
C-varieties	0.0002	2	0.0001	3.45	0.0831	
AB	0.0000	4	4.793E-06	0.1586	0.9535	
AC	0.0002	4	0.0001	1.73	0.2351	
BC	0.0001	4	0.0000	0.4524	0.7687	
Residual	0.0002	8	0.0000			
Lack of Fit	0.0002	5	0.0000	2.30	0.2621	not significant
Pure Error	0.0001	3	0.0000			
Cor Total	0.1401	26				

The analysis of variance of selected factorial model that was carried out on the weight of cotyledon shows that operating speed has significant effects on de-hulling efficiency of the machine with p value of 0.001. This analysis is in agreement with Khamaldeen *et al*. (2017) reported that the operating speed affects the dehulling efficiency of the de-hulling machine. Another similar study is Olaoye and Olotu, (2015) reported that increase in operating speed affect the output capacity of the de-huller.

Furthermore, the analysis of variance carried out on the weight of the hulls and cotyledon further reveals that the soaking time, cowpea variety, interaction AB, AC, and BC have no significant effects on the performance evaluation of the de-hulling machine at p-value of 0.8183, 0.0831, 0.9535, 0.2351 and 0.7687 respectively.

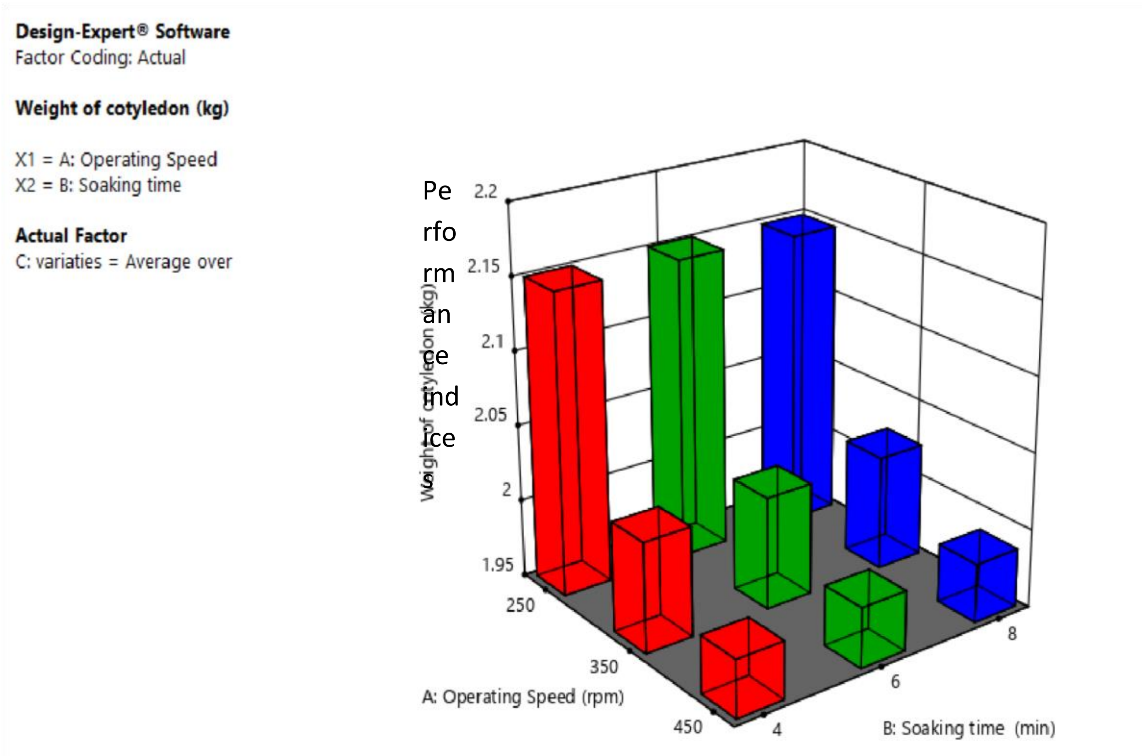

Figure 4.2: 3-D plot of operating speed and soaking time (weight of cotyledon)

Figure 4.2 shows the 3-D plot of operating speed against soaking time for the weight of cotyledon. This indicates that at 4, 6 and 8 minutes soaking time, there is higher dehulling efficiency at operating speed of 250 rpm.

4.1.3 Effects of operating speed, soaking time and varieties on dehulling efficiency for the weight of hulls

Table 4.6: The analysis of variance of selected factorial model that was carried out on the weight of hulls.

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob. > F
Model	0.0496	18	0.0028	47.08	< 0.0001	Significant
A-Operating Speed	0.0428	2	0.0214	366.04	< 0.0001	
B-Soaking time	0.0001	2	0.0000	0.7249	0.5137	
C-variaties	0.0000	2	8.824E-06	0.1508	0.8624	
AB	0.0004	4	0.0001	1.92	0.2008	
AC	0.0004	4	0.0001	1.78	0.2260	
BC	0.0006	4	0.0002	2.59	0.1175	
Residual	0.0005	8	0.0001			
Lack of Fit	0.0004	5	0.0001	5.02	0.1073	not significant
Pure Error	0.0000	3	0.0000			
Cor Total	0.0501	26				

The analysis of variance of selected factorial model that was carried out on the weight of hulls shows that operating speed has significant effects on de-hulling efficiency of the machine with p value of 0.001. This analysis is supported with the study of Babatunde (1995) and Khamaldeen *et al.* (2017) who reported that the operating speed affects the dehulling efficiency of the de-huller.

In addition, the analysis of variance carried out on the weight of the hulls further reveals that the soaking time, cowpea variety, interaction AB, AC, and BC have no significant effects on the performance evaluation of the de-hulling machine at p-value of 0.5137, 0.8624, 0.2008, 0.2260 and 0.1175 respectively.

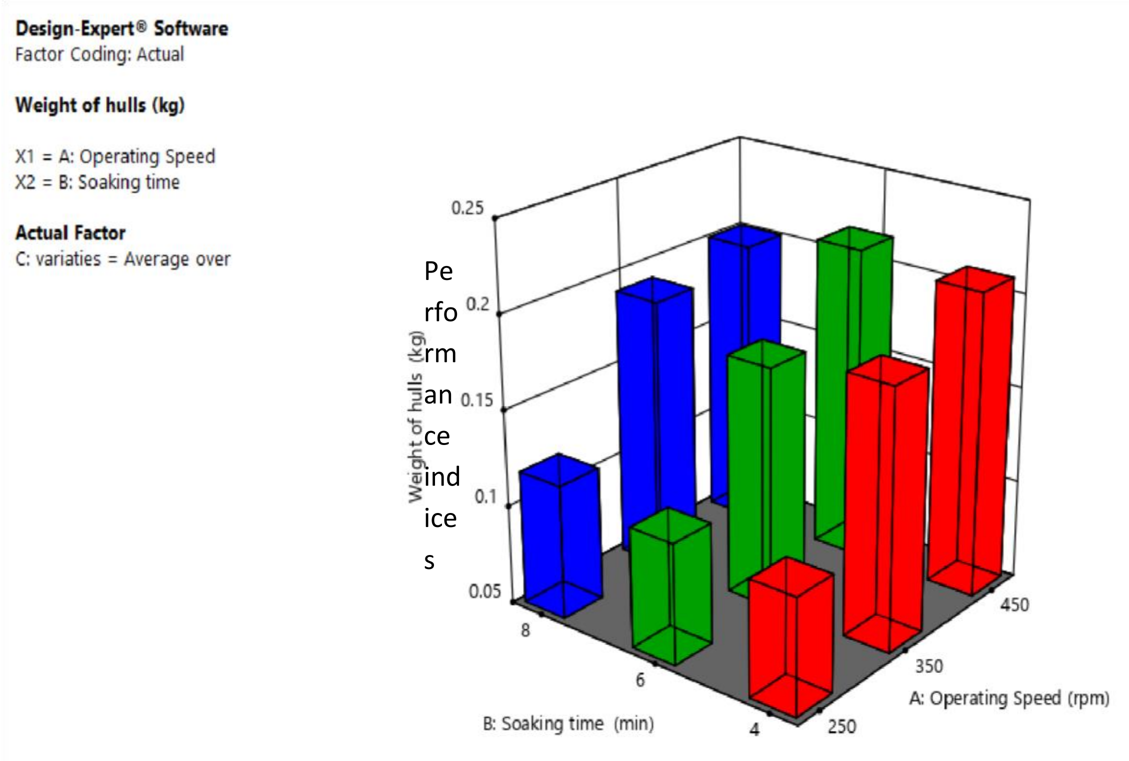

Figure 4.3: 3-D plot of operating speed and soaking time (weight of hulls)

Figure 4.3 shows the 3-D plot of operating speed against the soaking time for the weight of hulls. It indicate that at 6 minutes soaking time and 450 rpm operating speed, plenty weight of hulls were obtained.

4.1.4 Effects of operating speed, soaking time and varieties on dehulling efficiency for the weight of broken cotyledon

Table 4.7: The analysis of variance of selected factorial model that was carried out on the weight of broken cotyledon

Source	Sum of Squares	Df	Mean Square	F-value	p-value	Prob. > F
Model	0.0154	18	0.0009	9.47	0.0015	Significant
A-Operating Speed	0.0118	2	0.0059	65.32	< 0.0001	
B-Soaking time	0.0002	2	0.0001	1.12	0.3714	
C-variaties	0.0001	2	0.0001	0.7596	0.4988	
AB	0.0009	4	0.0002	2.38	0.1381	
AC	0.0003	4	0.0001	0.8096	0.5527	
BC	0.0013	4	0.0003	3.64	0.0565	
Residual	0.0007	8	0.0001			
Lack of Fit	0.0005	5	0.0001	1.56	0.3788	not significant
Pure Error	0.0002	3	0.0001			
Cor Total	0.0161	26				

The analysis of variance of selected factorial model that was carried out on the weight of broken cotyledon shows that operating speed has significant effects on the de-hulling efficiency of the machine with p value of 0.001. This results is in agreement with the study of Babatunde (1995) and Khamaldeen *et al.* (2017) who reported that the operating speed affects the dehulling efficiency of the de-huller. This is because when the operating speed increases, de-hulling efficiency increases but weight of broken de-hulled cotyledon also increases. Furthermore, the analysis of variance carried out on the weight of the broken cotyledon further reveals that the soaking time, cowpea variety, interaction AB, AC, and BC have no significant effects on the performance evaluation of the de-hulling machine at p-value of 0.3714, 0.4988, 0.1381, 0.5527 and 0.0565 respectively.

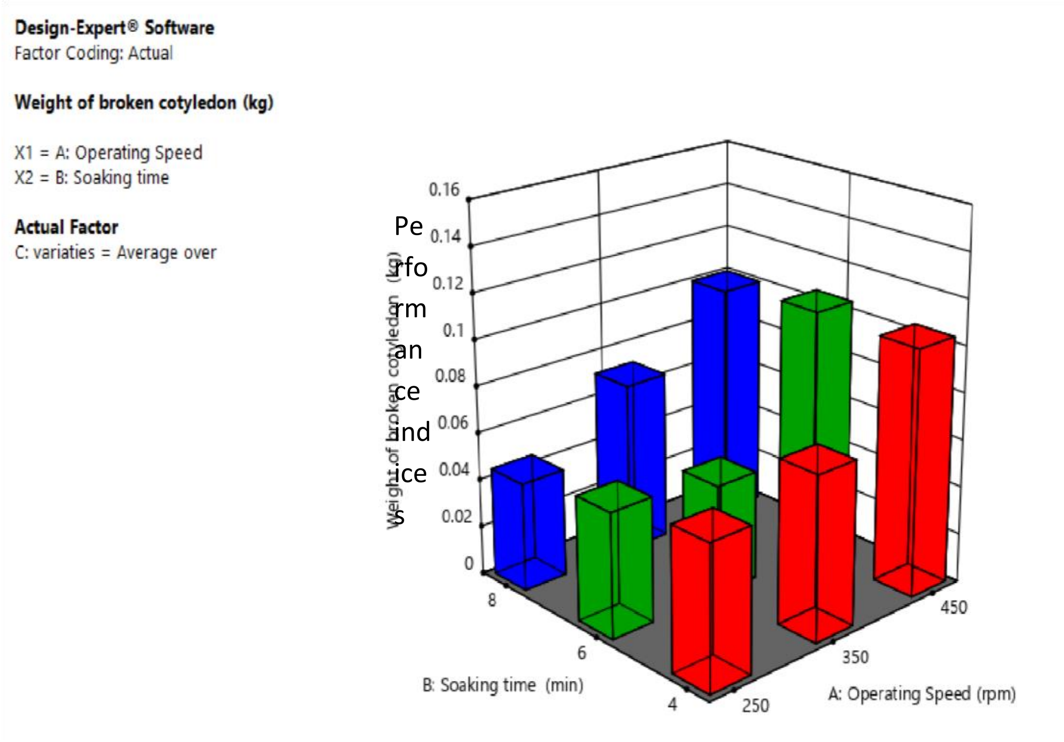

Figure 4.4: 3-D plot of operating speed and soaking time (weight of broken cotyledon)

Figure 4.4 shows the 3-D plot of operating speed and soaking time for the weight of broken cotyledon. It indicates that at high speed of 450 rpm and at all soaking time, there is higher broken cotyledon.

4.2 The Interaction Effect of Selected Factorial Model on De-hulling Efficiency

4.2.1 The interaction effect of soaking time and operating speed on de-hulling Efficiency

The results of the interaction effects of the soaking time and operating speed on dehulling efficiency for Iron bean is as presented in Figure 4.5

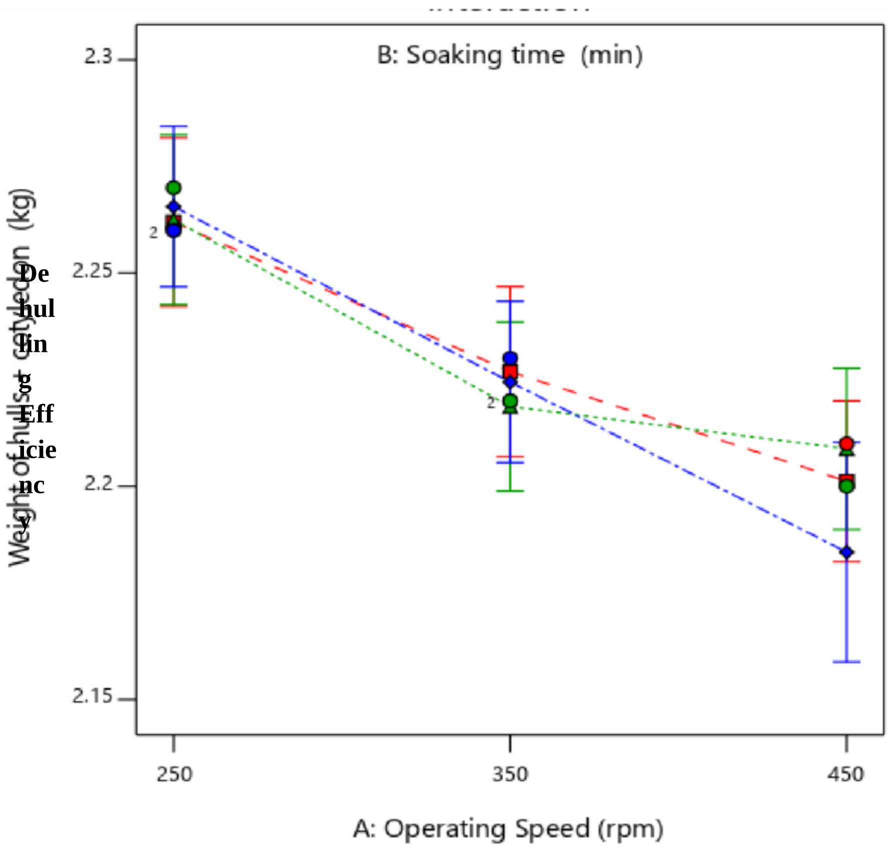

Figure 4.5: Interaction effect of soaking time and operating speed on dehulling efficiency of the dehulling machine using Iron bean cowpea variety

From the result, the interaction of the soaking time on the operating speed for the iron bean variety can be seen clearly as increase in soaking time results to the decrease in dehulling efficiency. And also, the increases in operating speed result to the decrease in the efficiency of the de-hulling machine.

Similarly**,** the results of the interaction effects of the soaking time and operating speed on output capacity for Ife brown is as presented in Figure 4.7

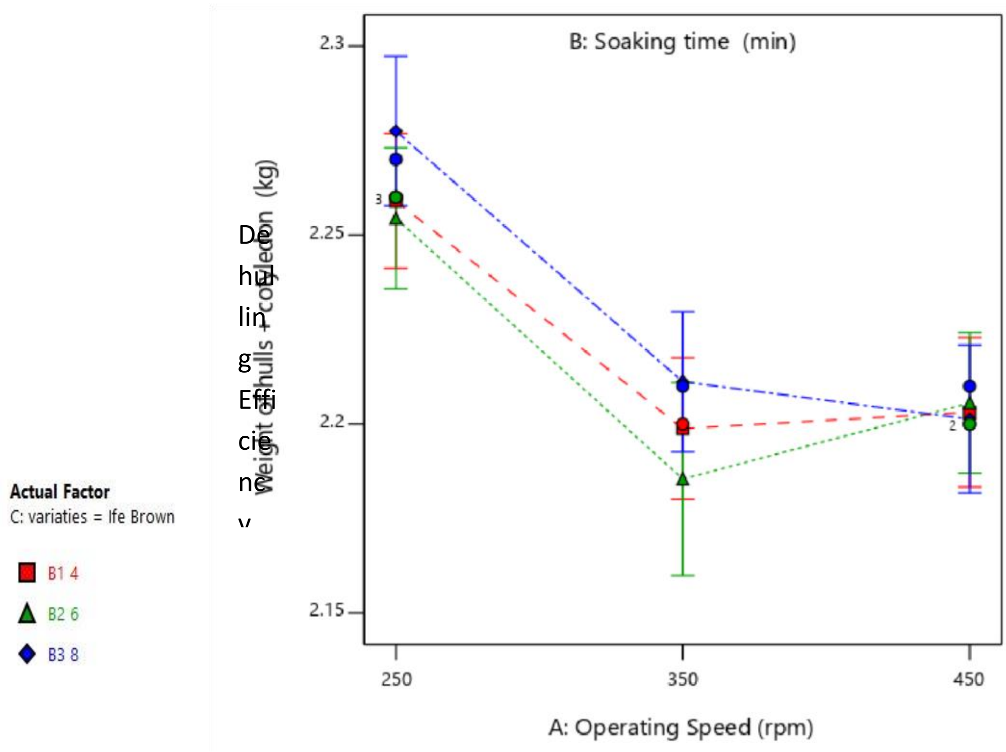

Figure 4.6: Interaction effect of soaking time and operating speed on output capacity of the de-hulling machine using Ife brown cowpea variety

From the result, the operating speed has a relationship with the soaking time and which affect the output efficiency of the machine. At operating speed of 250 rpm, the output capacity of the dehulling machine is at maximal and it decreases as the operating speed and soaking time increases to 350 rpm and 6min respectively. However, as the operating speed and soaking time is increased to 450 rpm and 8min respectively, the result reveal no definite pattern.

Also, the results of the interaction effects of the soaking time and operating speed on output capacity for Kananado is as presented in Figure 4.7

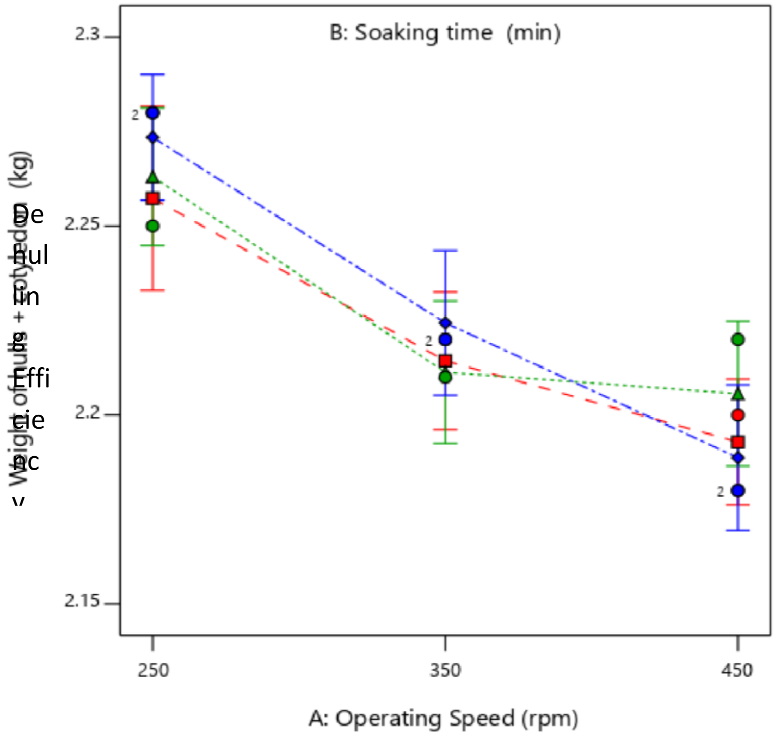

Figure 4.7: Interaction effect of soaking time and operating speed on output capacity of the de-hulling machine using Kananado cowpea variety.

From the result, the interaction of the soaking time on the operating speed for the kananado also reveals that the increase in soaking time results to the decreasing dehulling efficiency of the dehuller. And also, the increases in operating speed result to the decrease in the efficiency of the de-hulling machine.

Therefore, from the results represented in Figure 4.1, 4.2 and 4.3, when there is increase in soaking time and operating speed, the output capacity of the de-hulling machine decreases. Also, the de-hulling machine give the maximum output capacity at operating speed of 250 rpm and soaking time of 4min.

4.2.2 The interaction effect of soaking time and cowpea varieties on de-hulling efficiency

The results of the interaction effects of the soaking time and cowpea varieties on output capacity for operating speed of 250 rpm is as presented in Figure 4 8. This figure shows the interaction between the performance of the existing and the modified soaked cowpea dehulling and separating machine.

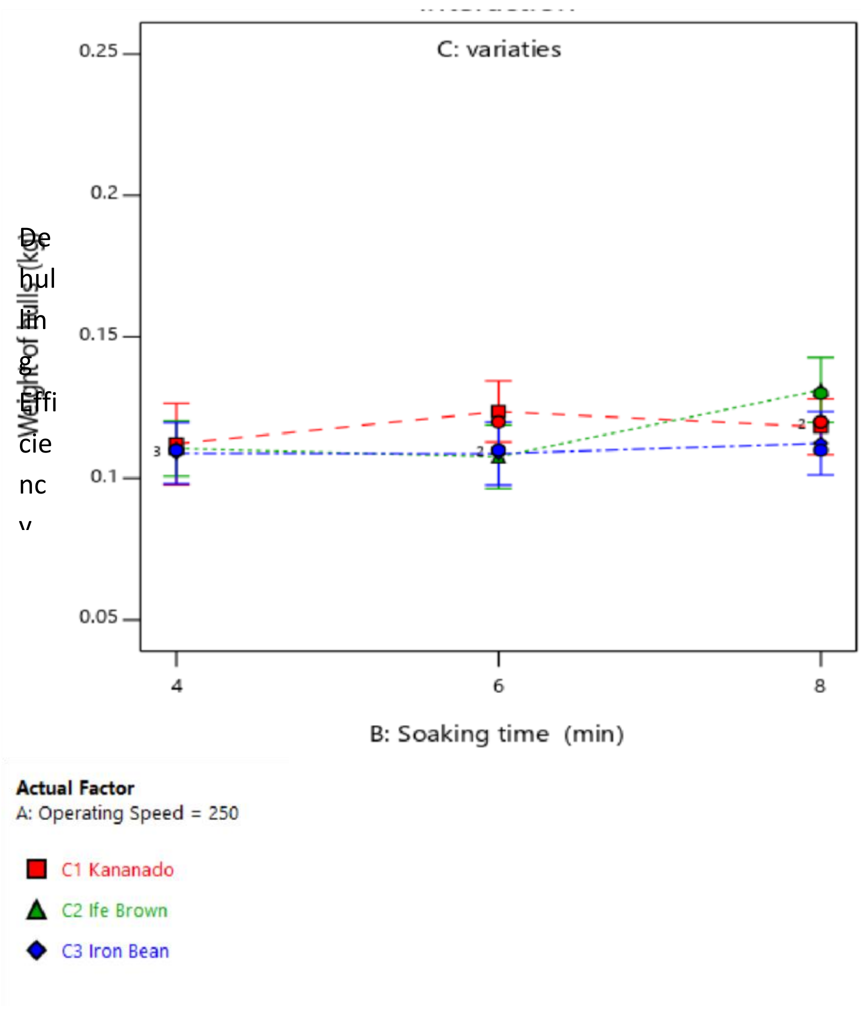

Figure 4.8: Interaction effect of soaking time and cowpea varieties on output capacity of the de-hulling machine using Kananado cowpea variety.

4.3 Comparative performance of modified and existing hydro cowpea dehuller

The performance of the modified and existing machine was compared based on there dehulling efficiencies, separating efficiencies and output capacities. The results compared for each performance are shown in Table 4.8 for modified and existing hydro cowpea dehulller.

Table 4.8: Comparative performance of modified and existing hydro cowpea dehuller

Machine	Varieties	Dehulling Efficiency (DE) %	Separating Efficiency (SE) %	Output capacity (OC) kg/h
Existing	Kananada (IAR48)	93.61	81.42	17.81
	Ife Brown (Oloyin)	81.67	79.96	18.45
	Iron Bean (YariHause)	73.24	86.6	18.63
Modified	Kananada (IAR48)	96.20	67.00	40.8
	Ife Brown (Oloyin)	95.80	65.60	36.40
	Iron Bean (YariHause)	95.60	70.10	38.00

4.3.1 Comparative dehulling performance of the machine.

For the modified machine, the dehulling efficiency ranges from 95.6% to 96.2%. However, when hydro dehuller was used the dehulling efficiency ranges from 73.2% to 93.6%. This two set of results do not indicate a similar range and the efficiencies of the modified dehulling machine were far better than those of existing hydro dehuller (Table 4.8).

4.3.2 Comparative separating/cleaning performance of the machines

The separating/cleaning efficiency of modified machine ranges from 67.0% to 70.1% while using hydro dehuller, the cleaning efficiency ranges from 86.6% to

81.4%. The two set of results are not in closed range. This signifies that the existing hydro cleaning performance is better than that of the modified machine (Table 4.8)

4.3.3 Comparative output capacity of the machines

The output capacity for the modified machine shows a range of 36.4 kg/h to 40.8 kg/h.

However, for the existing hydro dehuller, has a capacity of between17.8 kg/h to 18.63 kg/h output capacity was obtained. This implies that the modified soaked cowpea dehulling machine has a greater output capacity than the existing hydro dehuller.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The modified soaked cowpea dehulling and separating machine has been successfully redesigned, re-constructed and tested. The modified soaked cowpea dehulling and separating machine has 96.2%, 70.1% and 40.8kg/h/batch dehulling efficiency, separating efficiency and output capacity respectively.

The best dehulling efficiency, separating efficiency and output capacity were obtained at 250 rpm operating speed, 8 minutes soaking time and with kananado cowpea variety. The varietal difference has effect on the dehulling, separating and output performance of the modified machine.

Comparatively, the modified machine has 96.2% efficiency while the existing dehuller has 93.6% efficiency. This indicate that the performance of the modified machine was better to that of existing machine. For the performance of the existing and modified machine, it could be concluded that the existing machine excel in separation while the modified machine was superior in terms of dehulling and output capacity.

5.2 Recommendations

1. The separation unit should be made with light material like plastic for easy pushing and pulling.

2. The height of the machine should be reduce or made adjustable to accurately adjust the height

5.3 Contribution to Knowledge

The research work contributed to knowledge by introducing a recycling pumping machine into the existing soaked cowpea dehulling and separating machine. The modified machine is efficient in term of water consumption using 31 litres of water to dehull 6.5kg of cowpea seed as compared with the existing machine, which dehull 2kg of cowpea

using 6.5 litres of water.

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APPENDICE

Appendix A:

Researcher during cutting process of the fabrication

Researcher during welding operation

Researcher during assembly of the cowpea-dehulling machine

Appendix B

Runs	Factor 1 A:Operating Speed (rpm)	Factor 2 B:Soaking Time (min)	Factor 3 C:Cowpea Variety	Response 1 (Wgt of hulls + cotyledon in kg)	Response 2 (Wgt of cotyledon in kg)	Response 3 (Wgt of hulls in kg)	Response 4 (Wgt of broken cotyledon in kg)	Response5 (kg)
1	350	8	AA	2.22	2.03	0.19	0.07	
2	250	4	BB	2.26	2.15	0.11	0.06	
3	250	6	AA	2.25	2.15	0.12	0.07	
4	350	8	CC	2.23	2.03	0.20	0.08	
5	250	8	BB	2.27	2.14	0.13	0.05	
6	250	6	CC	2.27	2.16	0.11	0.06	
7	250	4	BB	2.26	2.15	0.11	0.08	
8	250	8	AA	2.28	2.16	0.12	0.04	
9	450	6	CC	2.20	1.99	0.21	0.10	
10	250	8	CC	2.26	2.15	0.11	0.05	
11	250	4	CC	2.26	2.15	0.11	0.05	
12	450	4	CC	2.21	1.99	0.22	0.11	
13	350	4	CC	2.22	2.03	0.19	0.07	
14	450	4	AA	2.20	1.99	0.21	0.10	
15	250	6	BB	2.26	2.15	0.11	0.03	
16	450	4	AA	2.18	1.98	0.20	0.10	
17	450	4	BB	2.20	1.99	0.21	0.11	
18	350	8	BB	2.21	2.02	0.19	0.07	
19	350	4	AA	2.22	2.03	0.19	0.08	
20	450	8	AA	2.18	1.99	0.19	0.10	
21	250	8	AA	2.28	2.16	0.12	0.04	
22	350	6	AA	2.21	2.03	0.18	0.07	
23	450	6	BB	2.20	1.99	0.21	0.10	
24	450	6	AA	2.22	1.99	0.23	0.12	
25	350	6	CC	2.22	2.03	0.19	0.05	
26	350	4	BB	2.20	2.01	0.18	0.06	
27	450	8	BB	2.21	1.99	0.22	0.10	
Note: AA=Kananado, BB=Ife Brown, CC=Iron Bean, Weight of soaked cowpea seeds per Runs = 2.41kg								