MODIFICATION AND PERFORMANCE EVALUATION OF IAR GROUNDNUT SHELLER FOR SOME SELECTED VARIETIES OF PULSES

BY

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DECLARATION

Ideclare that the work in this thesis entitled Modification and performance evaluation of IAR groundnut sheller for some selected varieties of pulses has been carried out by me in the Department of Agricultural Engineering under the supervision of Dr. U. S. Mohammed and Prof. D. D. Yusuf. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this Thesis was previously presented for another degree or diploma in this or any other institution.

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CERTIFICATION

This thesis entitledMODIFICATION AND PERFORMANCE EVALUATION OF IAR GROUNDNUT SHELLER FOR SOME SELECTED VARIETIES OF PULSESby Ibrahim Babangida DALHA meets the regulations governing the award of the degree of Masters of Science in Agricultural Engineering ofAhmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation

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DEDICATION

This work is dedicated to my parents Mal. Dalha Ibrahim Shanono and Malama Aishatu Dalha Ibrahim and to my precious wife Maryam Isah Musa for their patience, sacrifice, support, love and encouragement throughout the conduct of this program.

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ABSTRACT

IAR groundnut sheller was developed in 1985 and the design was based on the properties of the then groundnut variety known as Ex-Dakar. New varieties were later developed whose acceptability in practice override, this called for its modification and determination of the characteristics of new varieties.The machine size was modified resulting in the modification of all its components for pulse shelling. The machine consists of the hopper, shelling cylinder, removable concave, blower, chaffs outlet, grains delivery chute, clearance adjuster and frame. The machineperformance was comparatively evaluated using groundnut and cowpea as test crops. A combination of four cylinder speed levels; 2.59, 2.79, 2.98 and 3.18 m/s (130, 140, 150 and 160 rpm), three feed rates (8, 10, and 12 kg/min) and three concave clearances (19, 21 and 23 mm) were used for the performance evaluation of themodified shelling machine using groundnut while a combination of three speed levels; 2.39, 2.59, and 2.79 m/s (120, 130 and 140 rpm) and three feed rates (12, 15 and 18 kg/min) were used for cowpea crop. The results were analyzed statistically in a completely randomized block design. Least Significant Difference (LSD) method was employed to assess the effect of parameter levels while a t-test was used to assess the differences in the machines performance. The basic geometric, complex geometric, and some mechanical properties of four selected varieties each of groundnut and cowpea were determined. The optimum performance of the developed machine using groundnut was found at a speed of 3.18 m/s (160 rpm) with a feed rate of 8 kg/min and 21 mm concave clearance. These resulted in shelling efficiency, cleaning efficiency, scatter loss, damaged grains and output capacity of 94.90%, 97.22 %, 6.29 %, 14.00 % and 254.99 kg/h respectively. When evaluated with a cowpea, the optimum performance was found at a speed of 2.79 m/s (140 rpm) with a feed rate of 12 kg/min and 10 mm concave to cylinder

clearance. These resulted in shelling efficiency, cleaning efficiency, scatter loss, damaged grains and output capacity of 93.24 %, 98.31 %, 0.625 %, 0.00 % and 546.18 kg/h respectively. The levels of the independent variables were found to have highly significant differences with most of the performance indices for groundnut shelling but otherwise for cowpea. Generally, the output capacity of the modified machine was superior over that of the existing machine while its performance on cowpea was superior over that of the groundnut.

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GLOSSARY

IAR:	Institute for Agricultural Research
GATE:	Greater Access to Trade Expansion
FAO:	Food and Agricultural Organization
GDP:	Gross Domestic Product
SAMNUT:	Samaru groundnut variety
SAMPEA:	Samaru cowpea variety
USDA:	United State Department of Agriculture
D_P:	Diameter of the prime mover pulley
N_P:	Speed of the prime mover pulley
D_f:	Diameter of the fan pulley
N_f:	Speed of the fan pulley
D_C:	Diameter of the cylinder pulley
N_C:	Speed of the cylinder pulley
L_{bf}:	Length of the fan belt
L_{bc}:	Length of the cylinder belt
RCBD:	Randomize Complete Block Design
ANOVA:	Analysis of Variance
LSD:	Least Significant Difference
DF:	Degree of Freedom
MS:	Mean Squares
SS:	Sum of Squares
Fcal:	Calculated F values
Ftab:	Tabulated F values
NS:	Not Significant

CF:	Correction Factor
CSS:	Crude Sum of Square
PSE:	Pooled Sum of Square
Tical:	Calculated Independent t - values
Titab:	Tabulated Independent t - values
TRTM:	Treatment
CRC:	Concave Clearance
SPD:	Cylinder Speed
FDRT:	Feed Rate
S_e:	Shelling Efficiency
C_e:	Cleaning Efficiency
M_d:	Mechanical Grain Damage
S_L:	Scatter Loss
C_P:	Output Capacity
Q_D:	Quantity of damaged groundnut in sample
Q_g:	Total quantity of grains collected per unit time
Q_G:	Quantity of shelled groundnut
Q_L:	Quantity of scattered, damaged, and unshelled grains
Q_T:	Total quantity of groundnut sample
Q_U:	Quantity of unshelled groundnut
T:	Total time of shelling
W_C:	Weight of whole materials collected at the outlet
W_S:	Weight of scattered groundnut

1.0 INTRODUCTION

1.1 General Backgrounds

Pulses are annual leguminous crops yielding grains or seeds used for food, feed and sowing purposes. Pulses are crops yielding from one to twelve seeds of variable size, shape, and colour within a pod. In addition to their values as food and feed stuffs, pulses are also important in cropping systems for their ability to produce nitrogen and thus increase the fertility of the soil (FAO, 2011). Included in the pulses are groundnut and cowpea.Groundnut (*Arachis hypogaea L.*) also known as peanut,is a member of the family *papilionaceae*, the largest and most important of the three divisions of *leguminasae* (Alonge and Adegbulugbe, 2005).The groundnut seed composed of approximately equal weight of fatty and none fatty oil; the relative amount of each depends upon its variety and maturity (Young, and Ahmed, 1982). It is one of the world's most popular crops cultivated throughout the tropical and sub-tropical areas where annual precipitation is between 1000 – 1200mm for optimum growth of the crop.Groundnut is the 13^{th} most important food crop of the world (John, 2010). It is the world's 4^{th} most important source of edible oil and 3^{rd} most important source of vegetable protein (Taru *et al*., 2008). The crop is native to South America, Mexico, and Central America. It was first cultivated in a valley in Peru. The leading world producers of the crop are China, India, Nigeria, USA, and Senegal. Nigeria ranks third among the major producers (Abubakar and Abdulkadir, 2012). In Nigeria,agriculture was the dominant sector of the economy before independence;with groundnut cultivation as one of the vital areas of its economic built up (Ani *et al*, 2013). Emergence of petroleum products, poor

government sustenance, and inadequate viable as well as qualitative farm machinery are some of the factors contributing toNigeria's declining economic buoyancy (Yusuf, 2011). The total world output of the groundnut crop in 2008 was 34.8 million metric tons out of which Nigeria accounted for 3.8million metric tons (FOA, 2008). In Nigeria, the processing of groundnut into various products is mostly done by women either for home consumption or for commercial purposes (Ibrahim *et al*., 2010). The most common commercial products of groundnut are; groundnut oil, groundnut cake and fried groundnut which are sold at market places or hawked on the streets. The processing of groundnut is both the source of income and employment to a large proportion of rural women in northern Nigeria(Ibrahim *et al*., 2010).

In developed countries groundnut processing is highly mechanized but in most developing countries, manual processing is still the norm despite the drudgery and time wastage involved (Maduako *et al*., 2006). The manual shelling method is achieved by applying pressure to crack the shell. In some cases, the groundnuts are first moistened with water and parked in a small sack whereby pressure is applied by beating the bag on a stone or any hard surface. Groundnut shelling machine is used to remove the shell of groundnut so as to obtain the groundnut seeds. Harvesting and shelling of groundnut are the most important and labour intensive operations in groundnut cultivation(Akcali and Onur, 1990). According to the authors, the present practice of these manual processes consumes huge amount of labor to the magnitude of 84 man-h ha^{-1}. During peak seasons delay in harvesting

and threshing resulted in heavy loss due to non-availability of labor at peak period of harvesting. One of the solution for increasing the profit and productivity is to mechanize the operations in groundnut cultivation. For mechanizing threshing operations, power operated groundnut machinery such as; harvesters, strippers, and sheller have been developed. The adoption level is very low due to varying constraints(Akcali and Onur, 1990).

Cowpea is one of the most economically and nutritionally important indigenous African grain legumes produced throughout the tropical and subtropical areas of the world (GATE, 2008).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). 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 machineries 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). If there has to be increased production of cowpea, farmers have to be provided with the means by which their products can be processed with minimum drudgery, cost and achieving good quality products.

1.2 Statement of the Problem

Abubakar and Abdulkadir (2012) reported that, traditional method of shelling groundnut has proved to be inefficient, time consuming, laborious, and low output. Due to the lack of an efficient motorized machine to shell groundnut, small scale farmers generally depend upon manual shelling. These are time consuming operations and do not match the shelling requirements within a limited period of time. Manual processing is still the norm in Nigeria despite the drudgery and time wastage involved. The search for more efficient and cost effective way of shelling raised the demand for the modification of IAR groundnut shelling machine.IAR groundnut sheller was developed in 1985 and the design was based on the properties of the then variety known as Ex-Dakar. The performance of the sheller was satisfactorily optimum withthroughput capacity of 200 kg/h as reported by IAR (1987). New varieties were later developed whose acceptability in practice override, this has conspicuously affects the performance of the IAR groundnut shelling machine which is not yet modified for the new varieties. A preliminary test of the sheller was carried out using groundnut variety; SAMNUT 23, and its performance was evaluated. The results (Appendix E1) indicated a very low output capacity of 76.50 kg/h, which was determined at a combination of 160rpm and 3kg/min cylinder speed and feed rate, respectively. This could be attributed to the effects of some factors such as varietal difference, inappropriate sieve type required among others

Cowpea cultivation is also very essential in Nigeria;it plays a key role in the agriculture and food supply of the country. Nigeria is the largest producer and consumer of cowpeas, accounting for about 45 percent of the world's cowpea production (GATE, 2008). However, most ofthe farmers grow it as inter crop (Rowland, 1993), though its post-harvest operations are mostly done manually due to lack of precise machinery for such operations and this curtailed its effective productivity.

1.3 Justification

Groundnut and cowpea are of great economic benefit to mankind. Therefore, developing the pulse sheller will help to bridge the overtime disparity in its performance improvements and subsequent modifications. It will provide an avenue for improving groundnut and cowpea productivity, reduction of drudgery on such processes, and subsidize the cost of procuring groundnut and cowpea shelling machinery by the farmers. It will also help to increase the number of viable machines available for shelling of groundnut, cowpea and other related crops. 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 machineries 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. According to Chima (2013),manufactured goods in agriculture are one of the preferred sectors of an economy and therefore the bedrock of

economic and technological advancement. Chima (2013) further 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 pulse sheller will contribute meaningfully to the country's GDP andenhances its global competitiveness. It will also contribute in disabling the importation opportunities in the country.

1.4 Aim and Objectives of the Study

The aim of the study is to modify the existing IAR groundnut shelling machine for selected varieties of groundnut and cowpea crops.

The objectives of the study are:-

(i) to determine the related physical and mechanical properties of the selected varieties of groundnut and cowpea

(ii) to carry out the design analysis for the modified pulse shelling machine

(iii) to construct and test the modified pulse shelling machine

(iv) to evaluate and compare the performance of the modified and existing machines

2.0 LITERATURE REVIEW

2.1 Review of Related Works

Kittichai (1984)developed a power-operated groundnut shelling machine. The author found that the best performance of the machine was achieved at 20mm clearance and shelling bar speed of 180rpm. At these parameters the machine capacity, shelling efficiency and percentage of breakage were 210.5kg-kernels/h, 98% and 5.3%, respectively. The power consumption of the machine ranged from 1.0 to 1.1kW. Gore *et al.* (1990) classified the groundnut shelling machineries, depending on their power sources, into manually operated and power-operated. Based on shelling action, the machines could be classified into reciprocating type and continuous or rotary type. The manually operated groundnut shelling machineries could be classified into three subclasses such as a) semi rotary type, b) hand-operated type with shelling cylinder which was rotated by hand, and c) foot operated type. Abou El-Kheir and Shoukr (1993)studied the effect of some operating parameters of shelling machine and natural properties of crop material on shelling efficiency. The increase in number of drum beaters from 4 to 8 increased the number of hits per unit time and increased shelling efficiency from 74 to 80.6% at drum speed of 1.83m/s and from 87 to 92.5% at drum speed of 4.58m/s, shelling efficiency using rubber drum, was less than that of both steel and wooden drum. Singh (1993)tested two types of concave in manual shelling machine, the first was wire mesh concave and the second was slotted grate. Shelling capacity with wire mesh concave was higher (86kg/h) compared to that of slotted grate (60kg/h). This is due to increased opening area. For wire mesh concave the shelling efficiency

ranged from 83 to 89% compared to the slotted type, which ranged from 82 to 84%. Also, the percentage of breakage ranged from 3.7 to 6.7% and from 8.4 to 12.6% for wire mesh and slotted grate respectively. Younis *et al*. (1997)developed a peanut shelling machine. Results of the machine evaluation indicated that breakage was reduced from 57 to 54%, cleaning efficiency increased from 67 to about 96%, and separation efficiency increased from 28 to 93% and total loss was also decreased from 57 to about 4% in comparison with the initial performance of the shelling machine. Helmy (2001)designed, built and evaluated a reciprocating shelling machine to study the effects of some operating parameters on shelling peanut from the pods. The author concluded that, the peanut shelling efficiency was 95.44% at about 17.12% moisture content on dry basis, when the speed, the clearance and feed rate were 1.4m/s, 18mm and 80kg/h respectively. Dauda (2001) designed, constructed and evaluated the performance of a manually operated cowpea thresher for small scale farmers in Northern Nigeria. Results obtained gave a threshing efficiency of 85.9, 84.6 and 84.1% for Kanannado, Borno Brown and Aloka local respectively. Seed damage was 1.8, 2.3 and 1.9% for Kanannado, Borno Brown and Aloka local, respectively. Winnowing efficiency at 372 rpm fan speed was 92.75, 92.5 and 92.35% for Kanannado, Borno Brown and Aloka local respectively. Throughput capacity was 95.4, 93.5 and 92.8 kg/h for Kanannado, Borno Brown and Aloka Local, respectively. Mulleriyawa (2008) reported a star product called “Mahaweli Agro Multi Thresher”, a highly versatile machine which threshes, and cleans grains in one operation. The machine can be used for a variety

of crops such as green gram, black gram, cowpea and soybean. It can also thresh corn by changing the drum.

2.2 Machine and Operation Factors

Shelling of grain crop is a unit operation that requires attainment of sets of processing condition that must be attained for effective shelling action to be accomplished through manual or mechanical operation. Inappropriate shelling conditions in a manual shelling process reduces the grain output with respect to excessive and high energy input (Olaoye, 2002). In a mechanical shelling process the effect of the inappropriate operating conditions does not only affect the effective recovery of the grains from other materials but it also leads to high grain loss. Grain losses are measured in terms of the damage to the grain kernel, loss to the mechanical elements and germination inability of the seeds. Proper adjustment of the operating conditions in a mechanical shelling has been determined as the most critical success factors in grain shelling(Olaoye, 2002, Olaoye, 2004). The key variables of interest are generally classified as the machine parameters, crop characteristics and influencing environmental or processing conditions, the fundamental and influencing environmental processing conditions with direct bearing on the effective performance of shelling systems are moisture content and feed rate (Olaoye, 2004). It had been concluded that cylinder peripheral speed, effective concave clearance, and fan speed are the major machine variables that can influence shelling performance while the extrinsic factors that are established on machine through the interactions of machine variables are the effect of the

environment and crop characteristics (Olaoye, 1998). According to Olaoye (2002) some crop parameters and machine variables are known to influence the performance of threshers, each or combination of these parameters has an impact on threshing ability and grain damage. He noted that the influence of both threshing ability and grain damage translate to measurable grain losses if not properly managed. To minimize losses in a mechanical shelling, performance of the shelling machine must be evaluated using machine, crop and processing variables such as cylinder speed, moisture content, among others. The crop and machine variables are relevant to the performance evaluation of the machinery.

2.3 Institutes for Agricultural Research (IAR) Groundnut Sheller

IAR groundnut sheller was designed to adapt motorized shelling method. The sheller shells and cleans. The two processes are achieved in one operation with the delivery of clean seeds at the grain outlet. It consists of the prime mover and the shelling unit (Plate I). The prime mover could be a petrol engine of 3 or 5hp, or an electric motor of equivalent capacity. The components of the shelling unit are; hopper, shelling chamber, blower, chaffs outlet, grains outlet and frame. The hopper is where the unshelled groundnut is fed-in. The shelling chamber consists of shelling cylinder and stationary concave. The blower is an axially flow fan powered by the prime mover with the aid of a pulley and belt. The frame acts as a support for all the machine components. As the cylinder rotates, the spike tooth bars beat and rub the unshelled groundnut pods against the stationary concave to effects the breaking of the pods and release of the groundnut seeds with minimal damage. As

the blower rotates, it generates a stream of air current which passes through the bottom of the concave sieve. The stream of air blown off the broken shells through chaff outlet and allow the shelled seeds to pass across the air current to the seed outlet (Isiaka, 2005).



Plate I: A Pictorial View of the IAR Groundnut Sheller

2.4 Groundnut Shelling Methods

2.4.1 Manual shelling methods

Most groundnut farmers shell their groundnuts manually by hand, an inefficient and labor intensive process. Hand shelling method is achieved by applying pressure to crack the shell with fingers and to some extent is achieved by hitting against the surface of hard materials. According to Isiaka (2005), shelling is done by beating a heap of whole plant with sticks on a specially prepared piece of hard ground. This breaks up the shells and the dry haulms that are then winnowed. The author added that motor and pestle are equally used instead of floor beating. Though a slow process, this produces cleaner nuts than the floor beating. In some cases, the groundnuts are first wetted and parked in a small sack whereby pressure is applied by beating the bag on a stone or any hard surface.

2.4.2 Mechanized shelling method

Mechanized shelling method could be employed in different ways depending on the type of machinery power source. These could be hand operated or motorized machinery.

2.4.2.1*Hand operated shelling machinery*

Mechanized method involved the use of hand operated machinery, which is to primarily separate groundnut seeds from the pods without cleaning. The cleaning or winnowing is done as a separate operation (Isiaka, 2005). A small, hand operated machinery were developed for this purpose, which

meet the shelling needs of the farmers for their domestic consumption. The machine developed by IAR was used to shell groundnut pods with least injury or damage for use as seed. The unit consists of a hopper, double crank lever mechanism, and an oscillating sector, all fixed on a frame. In the oscillating unit, a number of cast iron peg assemblies are fitted. The whole unit assembly oscillates close to a concave sieve fitted just below. A hopper is fitted at the top of the unit and the pods are fed through it gradually. The groundnut pods are cracked between the oscillating unit and the fixed perforated concave. Both shells and kernels are collected through a spot at the bottom of the machine, while the cleaning or winnowing operation is done as a further process.

2.4.2.2*Motorized shelling machinery*

In motorized shelling method, the processes of shelling and cleaning are achieved in one operation with delivery of clean seeds at the grain outlet (Isiaka, 2005). The shelling chamber consists of shelling cylinder and stationary concave. The cylinder has spike tooth as shelling bars which is driven by the prime mover with the aid of a belt and pulleys. As the cylinder rotates, the spike tooth bars beat and rub the unshelled groundnut pods against the stationary concave to effects the breaking of the pods and release of the groundnut seeds with minimal damage. The blower is powered by the prime mover, while rotating; it generates a stream of air current which passes through the bottom of the concave sieve. The stream of air blown off the broken shells through chaff outlet and allow the shelled seeds to pass across the

air current to the seed outlet. Some machinery is equipped with rollers; Shells of the groundnut are crushed, typically by passing the groundnuts between rollers that have been adjusted for specific groundnut variety. The gap between rollers must be narrow enough to crack the groundnut hulls, but wide enough to prevent damage to the kernels. A curved drum, with a perforated bottom and a rotating beater, is also used to hull groundnuts. The rotating beater crushes the groundnuts against the drum, pushing both the shells and groundnuts through the perforations. The clearance between the cylinder and the beater can be adjusted for different sizes of groundnuts, to avoid damaging the groundnut kernels. Shells are aspirated from the groundnut kernels as they fall from the drum. The crushed shells and groundnut kernels are then separated with oscillating shaker screens and air separators. The separation process also removes undersized kernels and split kernels.

3.0 MATERIALS AND METHODS

3.1 Description of the Modified Machine

The pulse sheller is a modified IAR groundnut sheller which adapts motorized shelling method. The machine shells and cleans in one operation with the delivery of clean seeds at the grain outlet. It consists of the prime mover and the shelling unit (Plate II). The prime mover is a diesel engine of 6hp capacity. The components of the shelling unit are; hopper, shelling chamber, blower, chaffs outlet, grains delivery chute and frame. The hopper is where the unshelled groundnut is fed in. The shelling chamber consists of shelling cylinder and removable concave. The blower is an axial flow fan powered by the prime mover with the aid of a pulley and belt. The frame acts as a support for all the machine components. As the cylinder rotates, the spike tooth bars beat and rub the unshelled groundnut pods against the concave to effects the breaking of the pods and release of the groundnut seeds with minimal damage. As the blower rotates, it generates a stream of air current which passes through the bottom of the concave sieve. The stream of air blown off the broken shells through chaff outlet and allow the shelled seeds to pass across the air current to the seed delivery chute.



Plate II: A Pictorial View of the Modified Pulse Sheller

3.2 Design Consideration

Helmy (2001) reported the best performance of a reciprocating peanut shelling machine at a concave clearance of 18 mm. Kittichai (1984) reported the best performance of power operated groundnut sheller at 20 mm concave clearance and 180 rpm cylinder speed. Abou El-Kheir and Shoukr (1993) reported a cylinder speed range of 1.83 – 4.58 m/s. A preliminary evaluation of the IAR groundnut sheller established the best shelling cylinder speed of 140 rpm. Therefore, this research work adopted a cylinder speed range of 130 rpm (2.59 m/s) to 160 rpm (3.18 m/s) and a concave clearance of 19 – 23 mm. The cylinder speed range was considered as the values below and above the best cylinder speed established

during preliminary evaluation. The machine height of 110 cm was adapted from the report of Smith*et al.*, (1994), for the purpose of the machine height reduction to enable easy access during operation.

Table 3.1: Key Major Dimensions of Human Body for Standing Posture

Measurement No.	Part of the body	Men		Women	
		Mean (cm)	90% confidence interval	Mean (cm)	90% confidence interval
1	Standing height	172	160-184	161	150-172
2	Eye level, standing	161	150-172	150	138-162
3	Elbow height, standing	106	98-114	97	89-105
4	Forward reach	82	75-87	70	63-77
5	Elbow to finger tip	47	43-51	42	38-46

3.3 Material Selection

Gauge 16 (low carbon steel) A36 mild carbon steel alloy with a Minimum yield stress of 250MPa and ultimate tensile strength of 400 – 550 MPa was selected for the production of machine members such as cylinder, sidesand top cover of cylinder housing while Gauge 18 was selected for blower casing, fan blades, chaffs outlet frame, feed hopper, grain delivery chute among others. Medium carbon steel alloy (C1040) with yield stress of 568.7MN/m^2 and ultimate tensile strength of 668.8MN/m^2 was selected for the shafts. A bar made up of cast iron was used for the cylinder beaters.The materials used for the determination of design related properties of the selected groundnut and cowpea varieties were 10kg each of shelled and unshelled crops for each variety, Vernier caliper, ply wood, galvanized iron, glass, tilt table, a box, electric weighing balance, a dry oven, plane sheets, and meter rule. For the performance evaluation of the machines, the materials used

were tachometer for the measurement of cylinder speed, weighing balance for quantifying the feed rate,and stop watch for recording the shelling time.

3.4 Methods

3.4.1 Experimental procedure

The selected groundnut and cowpea varieties were SAMNUT 23, SAMNUT 24, Bahaushiya, Fararhausa, SAMPEA 7, SAMPEA 8, Kanannado and Ironbean. Ten bags (600 kg) of groundnut variety (Bahaushiya) andsix bags (150 kg) of cowpea variety (Kanannado) were used for the evaluations. For the development of this motorized pulse shelling machine, the existing IAR groundnut shelling machine was evaluated for its performance for the identification of its weakness and faults. The properties of aforementioned varieties of groundnut and 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 each of groundnut (Bahaushiya) and cowpea (Kanannado) and the results were analyzed eventually. Finally, the performance of the existing IAR groundnut shelling machine and that of the modified pulse shelling machine were compared to assess their differences.

3.4.2 Determination of design related properties

Four different varieties of groundnut (SAMNUT 23, SAMNUT 24, Bahaushiya, and Fararhausa), and four varietiesof cowpea (SAMPEA 7, SAMPEA 8, Kanannado and Ironbean) were used for the experiment. One hundred pods of each

variety were randomly picked from the samples for the determination of size, shape, coefficient of friction, bulk density, moisture content, angle of repose, and crushing strength. These were achieved using the procedure outlined by Maduako and Hannan (2004) as follows;



Plate III: Groundnut Varieties Level A 'SAMNUT 24', B 'SAMNUT 23', C 'Bahaushiya', and D 'Fararhausa'

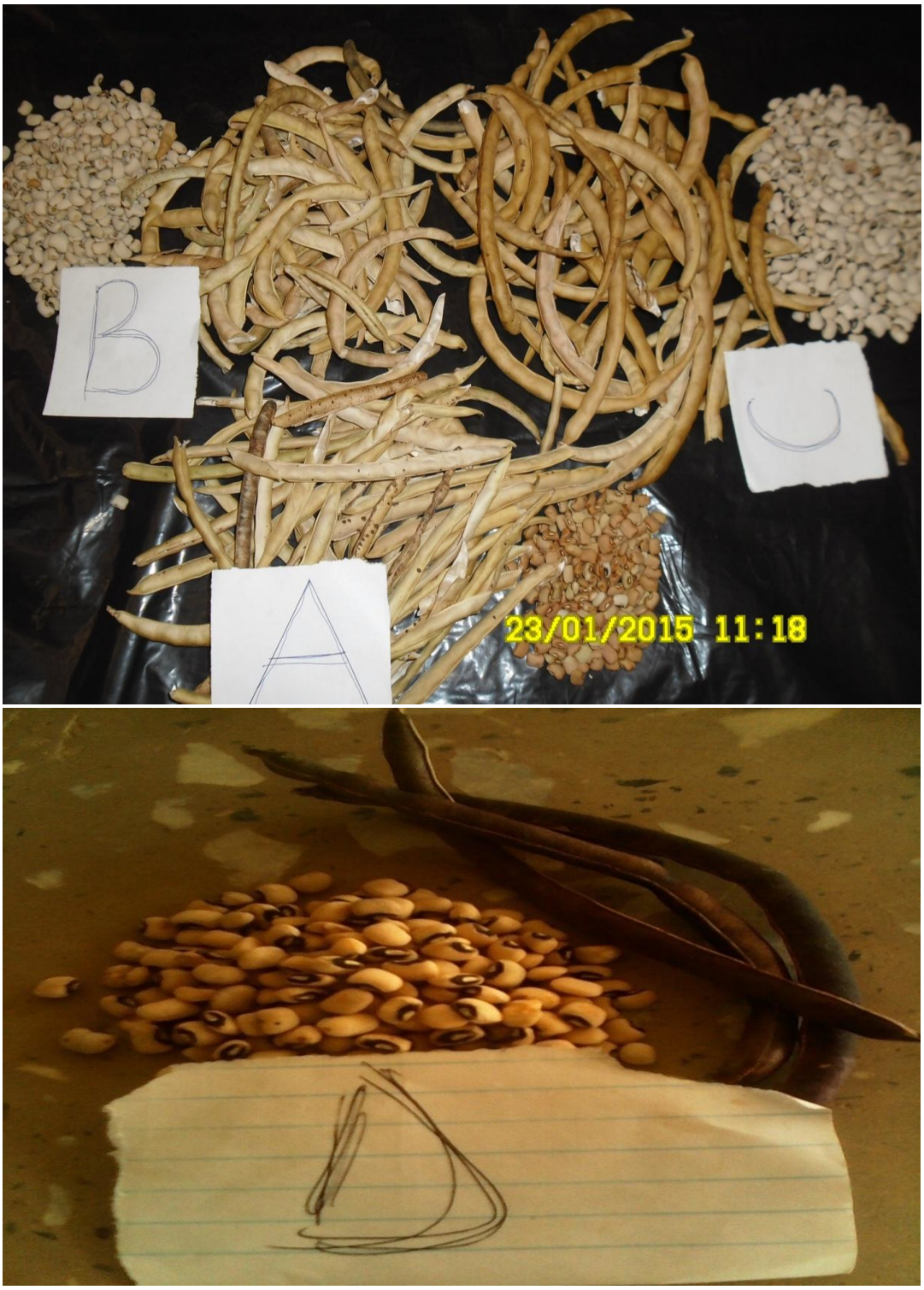


Plate IV: Cowpea Varieties Level A 'SAMPEA 7', B 'Kanannado', C 'Ironbean' and D 'SAMPEA 8'

3.4.2.1 *Determination of crops sizes*

The length,thickness and width of the pods and seeds of each groundnut and cowpea varieties were determined by measurements using Vernier caliper. Twenty samples were randomly selected from the bulk of one hundred each of groundnut and cowpea pods (Maduako and Hannan, 2004).

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

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

Where: L = Mean length of the seeds (mm)

W = Mean width of the seeds (mm)

T = Mean thickness of the seeds (mm)

The seed sizes were classified into three categories namely small, medium and large based on their length. The dimensional classification wasbased on the calculated average dimension ($\bar{X}$) and the associated standard deviation (σ_x). Then, small, medium, and large size seeds were so defined that their specific (X) dimension satisfies the following three inequalities (Pradhan *et al.*, 2013):

Small size group $X < \bar{X} - \sigma_x$ (3.3)

Medium size group $\bar{X} - \sigma_x < X < \bar{X} + \sigma_x$ (3.4)

Large size group $X > \bar{X} + \sigma_x$ (3.5)

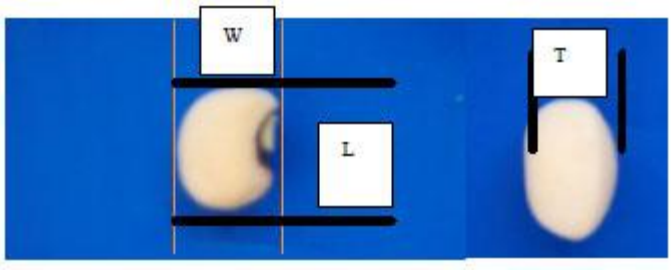


Plate V: Dimensional Axes of the Seeds

3.4.2.2 *Determination of crops shapes*

The shapes of the crops were determined from the measured aforementioned dimensions. However, the shapes of the pods and seeds were expressed in terms of roundness (R) and sphericity (S) index by Karaj and Muller (2010);

Roundness, R (%):

$$R = (\frac{W}{L} + \frac{T}{L} + \frac{T}{W})/3 \quad (3.6)$$

Sphericity, S (%):

$$S = \frac{(L*W*T)^{1/3}}{L} \quad (3.7)$$

The seeds of groundnut varieties were further classified according to Mazhar *et al.* (2013): when the ratio of length to width (L/W) fall within the range of 1.51 - 1.71 the variety was classified*Ellipticus* which is ellipsoid in shape, when the ratio fall within 1.85 - 2.31 the variety was classified *Oblongus* which is long cylindroids in shape and when the product of length and the ratio of width to thickness (W/T)*L fall within the range of 1.29 - 2.08 the variety was classified *Subcompressus*which is sub – compressed andlong in shape, while for 2.17-3.51 the variety was classified *Compressus*which is more compressed and broad in shape. The seeds of

cowpea varieties also were further classified according to USDA (2009). The shapes of cowpea varieties used were compared with the diagrammatic illustrations provided and classified according to the terms used to describe the corresponding shape as; *Rhomboid*, *Ovoid*, and *Kidney*shape.

3.4.2.3*Determination of coefficient of friction*

The coefficient of friction of pods andseeds 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 (Maduako and Hannan, 2004). Measurements were replicated five times for each sample and the coefficient of friction was calculated from the relation;

$$\mu = \tan \alpha \quad (3.8)$$

Where: μ = Coefficient of friction

α = Angle of inclination of the table to the horizontal (^{o})

3.4.2.4*Determination of angle of repose*

A cylindrical container was filled with pods 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 pods formed a conical heap on the floor. The height and diameter of the heap were measured (Maduako and Hannan, 2004). The procedure was repeated 5 times. The same procedure

wasadopted for determining the angles of repose for the crops seeds and the angle of repose was calculated from these measurements as;

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad (3.9)$$

Where: θ = Angle of repose (^{o})

H = Height of the heap (mm)

D = Diameter of the heap (mm)

3.4.2.5 *Determination of bulk and true density*

A container (63.00 mm height and 64.03 mm diameter) was filled with pods and weighed using an electric balance of 0.001g accuracy. The procedurewas repeated five times using different sets of pods and the bulk density was calculated from the weight of the pods divided by the volume of the container. The same procedure was used for the bulk density of crops seeds.

$$\rho_b = \frac{W}{V} \quad (3.10)$$

Where: W = Weight of the pods (kg)

V = Volume of the container (m^3)

The true density was determined using liquid displacement method where a container of known volume was filled with water and 1000 pods were immersed in to it while the amount of water displaced was collected and measured. The procedure was repeated five times and same procedure was used for the true density of crops seeds (Ozturk *et al*, 2009).

$$\rho_t = \frac{Mu}{Vu} \quad (3.11)$$

Where: Mu = Unit mass of the pods (kg)

Vu = Unit Volume of the pods (m^3)

3.4.2.6 ***Determination of moisture content***

The moisture contents ofgroundnut and cowpea seeds were determined using the oven dry method. The initial weights of samples were determined using the electric weighing balance. For groundnut the triplicate samples were dried in an oven set at temperature of 105°C and monitored over a period of 24 hours at 6 - hour intervals until the weights of the samples were found to be constant (Maduako and Hannan, 2004). While that of cowpea, the triplicate samples were dried in an oven set at temperature of 103°C and monitored over a period of 72 hours (ASAE, 1999).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 as;

$$MC\% = \frac{W_1 - W_2}{W_1} * 100 \quad (3.11)$$

Where: $MC\%$ = Moisture content (wet bases) (%)

W_1 = Initial weight of the sample (g)

W_2 = Final weight of the sample (g)

3.4.2.7 *Determination of crushing strength*

The crushing strength of different orientations of the pods was determined using hardness testing machine(Huber *et al.*, 1992);

$$Cs = W/A \tag{3.12}$$

Where: Cs = Crushing strength (kg/mm^2)

W = Weight required for cracking the seeds (kg)

A = Projected area of the seeds under load (mm^2)

3.4.3 Determination of size of the components

The proposed machine design was intended to shell different types and varieties of crops, to optimize power transmission system of the machine for better blower fan and shelling cylinder speeds ratio, to provide a flexible operation conditions such as variable concave clearance, to improve the output capacity and other related performance indices, and to fit operation conditions in terms of operators' performance among others. However, the following design parameters were considered;

3.4.3.1*Power required for shelling*

The power required for shelling groundnut/cowpea pods as reported by Abubakar and Abdulkadir (2012) is expressed as follows;

$$H = WK_k F_C Log \frac{L_1}{L_2} \tag{3.13}$$

Where:H = Power (W)

F_C = Crushing strength of groundnut (N/m^2)

K_k= Kick's constant (1.2)

W= Average weight of unshelled groundnut (kg)

L_1= Average length of unshelled groundnut (m)

L_2 = Average length of shelled groundnut (m)

This was determined as shown in Appendix A;

3.4.3.2*The machine shelling cylinder shaft design*

i) **Determination of cylinder shaft torsional moment**

Hall and Hallowenko, (1982) gave torsional moment as;

$$M_t = \frac{60P}{2\pi N} \qquad (3.14)$$

Where:P=Power required for shelling (Appendix A) = 345.5 W

S= Speed of the cylinder drum (rpm) = 160 rpm

$$M_t = \frac{60(345.5)}{2\pi(160)}$$

M_t = 20.62 Nm

The bending moment (M_b) was calculated based on the lateral loadings on the shaft. The loads were weight of the pulleys, weight of the shelling drum and belt tensions. The determination of bending moment is shown in Appendices G_1 and G_2. The bending moment for the vertical and horizontal component is 27.47 Nm and 150.43 Nm

Total bending moment, M_b = 150.43 + 27.47 = 177.90 Nm

ii) **Cylinder shaft diameter:**

The shaft size was selected using the relationship given by Hall and Hallowenko, (1982). As;

$$d_s = \frac{16}{\pi \tau_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (3.15)$$

Where: d_s = Shaft diameter (mm)

K_b = Shock andfatigue factor applied to bending moment = 1.5

K_t = Shock and fatigue factor applied to torsional moment = 1.0

M_t= Torsional moments = 20.62 Nm

τ_s= Allowablestress of the steel shaft = 40 N/mm^2

Hence,$d_{sc} = \frac{16}{\pi \tau_s}\sqrt{(1.5\ x\ 177.9)^2 + (1\ x\ 20.62)^2}$

d_{sc} = 32.42 mm

3.4.3.3*The machine fan shaft design*

i) **Determination of fan shaft torsional moment**

Based on equation 3.14, thepower required to produce the maximum air flow rate at a speed of 1500 rpm is 4.403 kW, henceM_t = 28.03 Nm

But the loads on the cylinder shaft are shared with the fan shaft, therefore;

Total torsional moment = 28.03 + 20.62 = 48.65 Nm

The bending moment (M_b) was calculated based on the lateral loadings on the shaft. The loads were weight of the pulleys, weight of the fan blades and belt tensions. The determination of bending moment is shown in Appendices $G_3$and G_4.

The bending moment for the vertical and horizontal component is 19.68 Nm and 55.43 Nm respectively

Total bending moment, M_b = 19.68 +55.43 = 75.11 Nm

ii) **Fan shaft diameter:**

The shaft size was selected using the relationship given by Hall and Hallowenko, (1982). From equation 3.14

Similarly, $d_{sf} = \frac{16}{\pi \tau_s}\sqrt{(1.5\ x\ 75.11)^2 + (1\ x\ 48.65)^2}$

d_{sf} = 25.00 mm

3.4.3.4*Power transmission parameters*

i) **Pulley diameters and speed ratio relationship:**

The pulleys diameter was determined using the expression outlined by Sanjay (2010) as;

$$N_1 D_1 = N_2 D_2 \qquad (3.16)$$

Where: N_1= Speed of driving pulley (rpm)

N_2 = Speed of driven pulley (rpm)

D_1 = Diameter of driving pulley (cm)

D_2 = Diameter of driven pulley (cm)

The sizes and speeds of 4 pulleys were determined as prime mover pulley (D_p = 8cm and N_p = 1200 rpm), fan shaft pulleys (D_{f1} = 8cm and N_{f1} = 1200 rpm, D_{f2} = 4cm and N_{f2} = 1200 rpm) and cylinder shaft pulley (D_c = 38cm and N_c = 130 rpm).

ii) **Belt length:**

The effective belts length was selected using the relationship outlined by Sanjay (2010) as;

$$L_b = \frac{\pi}{2}(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4x} + 2x \quad (3.17)$$

Where: D_1= Diameter of driver pulley (cm)

D_2 = Diameter of driven pulley (cm)

x = Center distance between the driver and driven pulley (cm)

The machine design required a set of 4 pulleys as prime mover pulley (D_P = 8cm), fan shaft pulleys (D_{f1} = 8cm, D_{f2} = 4cm) and cylinder shaft pulley (D_c = 38cm).

$$L_{bf} = \frac{\pi}{2}(8 + 8) + \frac{(8 - 8)^2}{4(48)} + 2(48)$$

= 142.10 cm

$$L_{bc} = \frac{\pi}{2}(4 + 38) + \frac{(4 - 38)^2}{4(54)} + 2(54)$$

= 112.44 cm

Hence, the fan belt length (L_{bf})was determined to be 142.10cm while the cylinder belt length (L_{bc})was 112.44cm

iii) **Centre distance:**

The center to center distance between the driver and driven pulley was estimated using the expression given by Khurmi and Gupta (2007) as;

$$D_2 < x < 3(D_1 + D_2) \quad (3.18)$$

The prime mover to fan pulleys center distance

$$8 < x < 3(8 + 8)$$

$8\text{ cm} < x < 48\text{ cm}$

The fan to cylinder pulleys center distance

$$38 < x < 3(4 + 38)$$

$38\text{ cm} < x < 126\text{ cm}$

The prime mover to fan pulleys center distance was determined as $8\text{ cm} < x < 48$ cm but 48 cm was chosen as appropriate while the fan to cylinder pulleys center distance was determined as $38\text{ cm} < x <$ 126 cm and 54 cm was chosen as appropriate.

iv) **Belt tension:**

The following expressions were used to determine the belt tension (Sharma and Kamlesh 2006;Sanjay 2010);

$$M_t = (T_t - T_s)R \tag{3.19}$$

$$\frac{T_t}{T_s} = e^{\mu\theta Cosec\beta} \tag{3.20}$$

Where: T_t and T_s = Tension in tight and slack side of belt respectively (N)

R = Radius of the shaft pulley (m)

μ = coefficient of friction between the pulley and belt

θ = angle of contact between the pulley and belt (^{o})

β = half angle of groove of the pulley (^{o})

when μ = 0.25, $2\beta = 34^o$, and $\theta = 170^o$

Therefore, the tensions in the tight and slack side of the fan belt were determined 877.5 N and $6.5\text{x}10^{-61}$ N respectively while those of cylinder belt were 1755 N and $1.6\text{x}10^{-60}$ N respectively.

v) **Angle of contact of the belt:**

The angle of contact of the belt with the smaller pulley was determined using the expression outlined by Sanjay (2010) as;

$$\theta = 180 - 2sin^{-1}\frac{(r_1 - r_2)}{x} \quad (3.21)$$

Where: θ = Angle of contact (^{o})

r_1= Radius of driver pulley (cm)

r_2= Radius of driven pulley (cm)

The angle of contact of the fan belt with the smaller pulley

$$\theta = 180 - 2sin^{-1}\frac{(4-4)}{48}$$

$= 180^o$

The angle of contact of the cylinderbelt with the smaller pulley

$$\theta = 180 - 2sin^{-1}\frac{(2-19)}{54}$$

$= 216.7^o$

However, the angle of contact of the fan belt with the smaller pulley was determinedto be 180^o and that of the cylinder belt was 216.7^o

vi) **Belt speed:**

Belt speed was estimated using the expression given by Khurmi and Gupta (2007) as;

$$V = \frac{\pi DN}{60} \quad (3.22)$$

Where: V = Belt speed (m/s)

N = Drive speed (rpm)

D = Diameter of drive pulley (m)

The fan belt speed

$$V = \frac{\pi(0.08\ x\ 1200)}{60}$$

= 5.03 m/s

The fan belt speed

$$V = \frac{\pi(0.04\ x\ 1200)}{60}$$

= 2.51 m/s

Based on equation 3.21, the fan belt speed was determined to be 5.03 m/s and that of cylinder belt was 2.51 m/s.

3.4.3.5*Blower design parameters*

i) **Air discharge through the blower:**

The air discharge through the blower was determined from the expression below(Joshua, 1981);

$$Q = VD_aW_a \qquad (3.28)$$

Where: Q = Air discharge rate (m^3/s)

V= Velocity of air required for cleaning= 19.48 m/s

D_a= Depth of air stream = 0.08 m

W_a= Width over which the air is required = 0.12 m

$Q = 19.48\ x\ 0.08\ x\ 0.12$

Q = 0.187 m^3/s

ii) **Number of blades required:**

The terminal velocity of the seeds was determined from the expression given below

$$V_t = 3dg\left(\frac{\rho_s - \rho_f}{\rho_f}\right)^{1/2} \quad (3.23)$$

Where: V_t = Theoretical terminal velocity (m /s)

g= Gravitational acceleration = 9.81 m/s^2

d= Geometric mean of kernel physical dimensions = 0.0107 m

ρ_s= Particle density = 746 kg/m^3

ρ_f= Fluid (air) density = 1.275 kg/m^3

$$V_t = 3(0.0107\ x\ 9.81)\left(\frac{746 - 1.275}{1.275}\right)^{1/2}$$

V_t = 7.59 m/s^2

The following relations were used to determine the number of blades required as reported by Mohammed, (2009).

$$D = 1.265 * \left(\frac{(AB)^2}{(A+B)}\right)^{1/5} \quad (3.25)$$

Where: D = Chaffs outlet dimensional parameter

A = Length of the chaffs outlet frame = 0.76 m

B= Width of the chaffs outlet frame = 0.53 m

$$D = 1.265 * \left(\frac{(0.76\ x\ 0.53)^2}{(0.76 + 0.53)}\right)^{1/5}$$

D = 0.836 m

Therefore,

$$N_b = \frac{4WDV_t}{\pi L d^2} \quad (3.26)$$

Where: N_b = Number of blades required

d = Diameter of air flow rate channel = 0.08 m

W = Width over which air is required = 0.12 m

L = Width of the inlet duct minus the clearance = 0.187 m

V_t = Terminal velocity of the seed = 7.59 m/s

$$N_b = \frac{4\ x\ 0.12\ x\ 0.836\ x\ 7.59}{\pi\ x\ 0.187\ x\ (0.08)^2}$$

N_b = 4 blades

iii) **Weight of the fan blades:**

The weight of the fan blades was determined using the relation(Mohammed, 2009);

$$W_f = \delta g v \quad (3.27)$$

Where: W_f = Weight of the fan blade (N)

δ= Density of the fan galvanized steel blade = 7850 kg/m^3

g= Acceleration due to gravity = 9.81 m/s^2

v= Volume of the fan blades = 8.453x10^{-5}m^3

$W_f = 7850\ x\ 9.81\ x\ 0.0000845$

W_f = 6.51 N

3.4.3.6*Concave radius*

The radius of curvature was determined using the expression given by Dangora*et al*. (2006) as;

$$r_c = r_d + h_p + c_c \quad (3.29)$$

Where: r_c = Concave radius (mm)

r_d = Radius of cylinder drum = 180 mm

h_p = Peg height above the drum = 7 mm

c_c = Concave clearance = 23 mm

$r_c = 180 + 7 + 23$

r_c = 210 mm

3.4.3.7*Cylinder drum*

The cylinder drum was designed to have 6 bars made of cast iron. Each bar, supported by plates, has 33 conical projections at the bottom face arranged in staggered fashion as a shelling tooth.

Equation 3.27 was used to determine the weight of its components as;

i) Weight of the shelling bar:

Where: δ = Density of the cast iron bar = 7874 kg/m^3

g = Acceleration due to gravity = 9.81 m/s^2

v = Volume of the shelling bar = 3.56x10^{-4} m^3

Hence, W_b = 27.50 N

ii) Weight of the shelling tooth:

Where: δ = Density of the cast iron = 7874 kg/m^3

g = Acceleration due to gravity = 9.81 m/s^2

v = Volume of the shelling tooth7.956x10^{-7} m^3

Hence, W_t = 0.061 N

iii) Weight of the supporting plate:

Where: δ = Density of the galvanized steel = 7850 kg/m^3

g = Acceleration due to gravity = 9.81 m/s^2

v = Volume of the supporting plate = 4.637x10^{-6} m^3

Hence, W_p = 0.357 N

3.4.3.8*Concave grates (holes)*

The concave grates wereof different openings for different varieties based on their determined properties.The sieve holes were designed as rectangular openings with rounded corners in a staggered arrangement for groundnut. It has a length of 40 mm and curved at both ends with 8 mm diameter. Round openings were used for cowpea with 13 mm diameter. However, the sieves were fitted in the frame as a concave.

3.4.3.9*Grain delivery chute*

The grain outletwas designed and positioned beneath the shelling chamber but across the length and covered the width of the machine. It has a rectangular shape inclined at an angle of 11.98^o.

3.4.3.10*Mode of concave clearance adjustment*

The shelling machine was designed to have a variable concave clearance to facilitate shelling different types of crops. Therefore, this research work considered a system of drum adjustment by incorporating a lever to carry the drum as load. The lever was pivoted at one end and fixed at the other end as fulcrum. The fulcrum was made adjustable with aid of bolt and nut. When loosening the nut, the drum could be lifted up or lowered down; hence, the required concave to cylinder clearance could be achieved.

i) **Determination of bolt diameter:**

The moment of inertiaand bolt diameter are expressed below(Chakraborti, 2010);

$$I = \frac{l^2 P}{2\pi^2 E} \tag{3.30}$$

And $$D = \left(\frac{64I}{\pi}\right)^{1/4} \tag{3.31}$$

Where:P = Loads on the shaft = 1050.7 N

I = Moment of inertia (mm^4)

E = Modulus of elasticity for a steel material = $2.1x10^5$ N/mm^2

l= Rod length = 340 mm

$$I = \frac{(340)^2 \, x \, 1050.7}{2\pi^2(0.000021)}$$

$= 29.36 \ mm^4$

$$D = \left(\frac{64 \, x \, 29.36}{\pi}\right)^{1/4}$$

$= 5$ mm

However, 10 mm diameter rod was selected for more rigidity

3.4.3.11 *Feed hopper design*

The feed hopper and its orientation were designed based on the angle of repose of the pods for the selected crops. It was designed at a height of 300 mm and width of 450 mm. The bottom faces of front and back were inclined at an angle of 38^o and 43^o respectively. The hopper has a volume of $3.33x10^{-2}$ m^3.

3.4.4 Machines performance evaluation

The performance of the proposed pulse sheller was evaluated based on the following indices; shelling efficiency, cleaning efficiency, damaged grains, scattered loss, and output capacity. These were achieved using the procedure outline by Abubakar and Abdulkadir (2012).

i) Shelling efficiency, S_e (%):

$$S_e = \frac{(Q_T - Q_U)}{Q_T} x100 \quad (3.32)$$

ii) Cleaning efficiency, C_e (%):

$$C_e = \frac{Q_G}{W_C} x100 \quad (3.33)$$

iii) Grains split, G_s (%):

$$G_s = \frac{Q_D}{100} x100 \quad (3.34)$$

iv) Scattered loss, S_L (%):

$$S_L = \frac{W_S}{Q_T} x\ 100 \quad (3.35)$$

v) Output capacity, C_P (kg/hr):

$$C_P = \frac{Q_g}{T} \quad (3.36)$$

Where: Q_D = Quantity of damaged groundnut in sample (kg)

Q_g = Total quantity of grains collected per unit time (kg)

Q_G = Quantity of shelled groundnut (kg)

Q_L = Quantity of scattered, damaged, and unshelled grains (kg)

Q_T = Total quantity of groundnut sample (kg)

Q_U = Quantity of unshelled groundnut (kg)

T = total time of shelling (hr)

W_C = Weight of whole materials collected at the outlet (kg)

W_S = Weight of scattered groundnut (kg)

3.4.5 Experimental design and analysis

The experimental resultswere analyzed graphically and statistically based on Randomized Complete Block Design (RCBD).Four different levels of cylinder peripheral speeds; 2.59, 2.79, 2.98 and 3.18 m/s (130, 140, 150 and 160 rpm) while three levels each of feed rates (8, 10, and 12 kg/min)and concave to cylinder clearances (19, 21and 23 mm) with three replications were considered for the evaluation of developed machine using groundnut. Three different levels each of feed rates (12, 15 and 18 kg/min)and cylinder peripheral speeds; 2.39, 2.59 and 2.79 m/s (120, 130 and 140 rpm) with three replications were considered for the evaluation of developed machine using cowpea. Three different levels each of feed rates (4, 5 and 6 kg/min)and cylinder peripheral speeds; 2.59, 2.79 and 2.98 m/s (130, 140 and 150 rpm) with three replications were considered for the evaluation

of the existing machine. Analysis of Variance (ANOVA) and Least Significant Difference (LSD) methods were used to assess the effect of the variables, their interactions, their significant differences, and to determine the most appropriate concave clearance among the selected clearances. An independent and paired t-test was employed for comparison of the results obtained for evaluation of the existing and modified machines. The layout of the factorial experiment and the outline of the ANOVA are shown in Appendices B_1, B_2, C_1 and C_2.A Pictorial View of the Modified and IAR Groundnut shelling Machines during Test are shown on Plate VI and VII



Plate VI: A Pictorial View of the Modified Machine during Test



Plate VII: A Pictorial View of the IAR Groundnut Sheller during Test

4.0 RESULTS AND DISCUSSION

4.1 Design Related Properties

4.1.1 Basic geometric properties of the crops

Table 4.1: Basic Geometric Properties of the Crops Pods

Crop/Variety	Length (mm)	Thickness (mm)	Width (mm)	Mass (1000) (g)	Arithmetic Diameter D_a (mm)	Geometric Diameter D_g (mm)	Volume (1000) (cm^3)	Unit Volume (cm^3)
GROUNDNUT								
SAMNUT 23	25.17	12.31	12.10	683.9	16.52	15.53	2364	2.000
SAMNUT 24	28.21	13.25	12.73	893.3	18.06	16.81	3191	2.920
BAHAUSHIYA	29.12	11.92	13.83	814.0	18.29	16.86	3359	3.160
FARAR HAUSA	29.02	11.71	13.00	830.3	17.91	16.40	2901	2.600
COWPEA								
SAMPEA 7	166.0	6.170	9.020	1745	60.39	20.98	13122	7.400
SAMPEA 8	138.8	6.290	8.580	1660	51.21	19.56	11828	6.400
KANANNADO	117.0	7.400	9.500	2475	44.63	20.18	18042	8.800
IRONBEAN	148.0	8.200	10.54	3387	55.58	23.38	23280	10.00

Table 4.2: **Basic Geometric Properties of the Crops Seeds**

Crop/Variety	Length (mm)	Thickness (mm)	Width (mm)	Mass (1000) (g)	Arithmetic Diameter D_a (mm)	Geometric Diameter D_g (mm)	Volume (1000) (cm^3)	Unit Volume (cm^3)
GROUNDNUT								
SAMNUT 23	11.55	8.380	7.460	331.5	9.130	8.971	563.9	0.480
SAMNUT 24	13.82	9.080	8.120	429.6	10.34	10.06	751.9	0.600
BAHAUSHIYA	15.60	8.150	8.250	432.6	10.67	10.16	709.2	0.580
FARAR HAUSA	14.53	8.620	8.520	456.1	10.56	10.22	778.3	0.680
COWPEA								
SAMPEA 7	8.910	4.560	7.080	223.8	6.850	6.601	322.2	0.300
SAMPEA 8	8.020	4.550	6.670	201.5	6.413	6.244	268.5	0.250
KANANNADO	10.33	5.930	7.370	252.8	7.877	7.671	383.0	0.360
IRONBEAN	12.55	6.440	8.550	350.0	9.180	8.841	534.2	0.460

4.1.1.1 *Crops sizes and classification*

i) Crop sizes:

The basic geometric properties of the crops were determined as presented in Tables 4.1 and 4.2. The mean length, thickness, and width of the groundnut pods ranged from 25.17 – 29.12 mm, 11.71 – 13.25 mm, and 12.10 – 13.83 mm respectively. The arithmetic and geometric mean diameters ranged from 16.52 – 18.29 mm and 15.53 – 16.86 mm respectively. An improved variety, SAMNUT 23, comparatively has the lowest mean diameter while a local variety, Bahaushiya, is larger in size having the largest mean diameter but exhibit similar properties with SAMNUT 24; the two varieties were found to have merely equal mean diameters. While, the mean length, thickness, and width of the groundnut seeds ranged 11.55 – 15.60 mm, 8.15 – 9.08 mm, and 7.46 – 8.52 mm respectively. The arithmetic and

geometric mean diameters were 9.13 – 10.67 mm and 8.97 – 10.22 mm respectively. These agreed with the findings of Davies (2009), likewise Alonge and Adegbulugbe (2005). An improved variety, SAMNUT 23, comparatively has the lowest mean diameter while a local variety, Fararhausa, is larger in size having the largest mean diameter but SAMNUT 24 and Bahaushiya exhibit similar properties; the two varieties were found to have merely equal mean diameters.

The mean length, thickness, and width of the cowpea pods ranged from 117 – 166 mm, 6.17 – 8.20 mm, and 8.58 – 10.54 mm respectively. The arithmetic and geometric mean diameters were 44.63 – 60.39 mm and 19.56 – 23.38 mm respectively. A variety, SAMPEA 8, comparatively has the lowest mean diameter while Ironbean, is larger in size having the largest mean diameter. However, Kanannado and SAMPEA 7 exhibit similar properties; the two varieties were found to have merely equal mean diameters. The mean length, thickness, and width of the cowpea seeds ranged from 8.02 – 12.55 mm, 4.55 – 6.44 mm, and 6.67 – 8.55 mm respectively. The arithmetic and geometric mean diameters were 6.41 – 9.18 mm and 6.24 – 8.84 mm respectively hence, these are similar to the findings of Mazhar *et al*, (2013) and Ozturk *et al* (2009). An improved variety, SAMPEA 8, comparatively has the lowest mean diameter while Ironbean, is larger in size having the largest mean diameter.

ii) **Classification of crop sizes:**

Both the pods and seeds of all varieties of groundnut and cowpea were classified based on small, medium and large sizes. For the groundnut and cowpea pods, the percentage distribution of the classes indicated a range of 40 – 55 % and 45 – 60 % for small and large sizes respectively while the medium class covers only 0 – 5 % in rare cases (Table 4.3). For the groundnut and cowpea seeds, the percentage distribution of the classes indicated a range of 40 – 55 % and 45 – 55 % for small and large sizes respectively while the medium class covers only 0 – 5 % in rare cases (Table 4.4). However, these results do not agree with the findings of Hossain and Haque (1999) which could be due to the difference in their dimensional properties particularly the length.

Table 4.3: Groundnut and Cowpea Pods Classification to Small (S), Medium (M),and Large (L) sizes

Groundnut/cowpea Varieties	Dimension (length)	% Distribution of Classes S (%)	M (%)	L (%)	Min-Max Values	Mean±SD
SAMNUT23	Groundnut	50	0	50	20.80-30.21	25.17±1.36
SAMNUT 24		45	0	55	25.26-33.25	28.21±0.17
BAHAUSHIYA		45	0	55	21.27-32.69	29.12±0.62
FARAR HAUSA		50	5	45	23.93-36.44	29.02±0.57
SAMPEA 7	Cowpea	45	5	50	123.0-196.0	166.0±13.6
SAMPEA 8		55	0	45	98.00-165.0	139.0±2.02
KANANNADO		40	0	60	76.00-155.0	117.0±14.7
IRONBEAN		50	0	50	109.0-165.0	148.0±3.18

Table 4.4: Groundnut and Cowpea Seeds Classification to Small (S), Medium (M), and Large (L) sizes

Variety	Dimension	% Distribution of Classes	Min-Max	Mean±SD

	(length)	S (%)	M (%)	L (%)	Values	
SAMNUT23	Groundnut	50	0	50	10.05-13.75	11.55±1.17
SAMNUT 24		40	5	55	11.69-14.88	13.82±0.03
BAHAUSHIYA		45	0	55	11.52-17.21	15.60±0.86
FARAR HAUSA		50	0	50	11.90-16.73	14.53±0.33
SAMPEA 7	Cowpea	45	0	55	7.550-10.67	8.910±0.60
SAMPEA 8		50	0	50	6.660-9.250	8.020±1.11
KANANNADO		55	0	45	9.220-12.24	10.33±0.22
IRONBEAN		50	0	50	10.63-14.30	12.55±1.50

4.1.1.2 *Mass and volume of the crops*

i) **Mass and volume of the pods**

The mass and volume of 1000 pods of groundnut varieties were found to have a range of 683.9 – 893.3 g and 2364 – 3359 cm^3 respectively which is similar to findings of Alonge and Adegbulugbe (2005) while that of cowpea varieties were found to be 1660 – 3387 g and 11828 – 23280 cm^3 respectively (Table 4.1).These indicated that groundnut varieties are smaller and lighter than those of cowpea which could be attributed to the difference in their pods shapes.

ii) **Mass and volume of the seeds**

The mass and volume of 1000 seeds of groundnut varieties were found to have a range of 331.5 – 456.1 g and 563.9 – 778.3 cm^3 respectively while that of cowpea varieties were found to be 201.5 – 350.0 g and 268.5 – 534.2 cm^3 respectively (Table 4.2). However, the results of groundnut seeds are in closed range with the findings of Davies (2009) as well as Alonge and Adegbulugbe (2005) while that of cowpea seeds are similar to the findings of Mazhar *et al*, (2013). These indicated that cowpea seeds are smaller and lighter than those of groundnut which could be attributed to the difference in their seeds shapes.

4.1.2Complex geometric properties of the crops

Table 4.5: Complex Geometric Properties of the Crops Pods

Crop/Variety	Sphericity Ø (%)	Roundness R (%)	Bulk Density ρ_b (g/cm^3)	True Density ρ_t (g/cm^3)	Porosity Ɛ (%)	Surface Area (mm^2)
			GROUNDNUT			
SAMNUT 23	61.71	66.23	0.289	0.342	15.39	758.3
SAMNUT 24	59.62	65.39	0.280	0.306	8.498	888.9
BAHAUSHIYA	57.93	58.20	0.242	0.258	5.929	894.1
FARAR HAUSA	56.54	58.41	0.286	0.319	10.38	845.9
			COWPEA			
SAMPEA 7	12.64	25.85	0.133	0.236	43.60	1383.4
SAMPEA 8	14.10	28.01	0.140	0.259	45.89	1202.6
KANANNADO	17.25	30.78	0.137	0.281	51.23	1280.3
IRONBEAN	15.80	30.15	0.145	0.339	57.05	1718.5

Table 4.6: **Complex Geometric Properties of the Crops Seeds**

Crop/Variety	Sphericity Ø (%)	Roundness R (%)	Bulk Density ρ_b (g/cm^3)	True Density ρ_t (g/cm^3)	Porosity Ɛ (%)	Surface Area (mm^2)
			GROUNDNUT			
SAMNUT 23	77.67	83.16	0.588	0.691	14.88	252.9
SAMNUT 24	72.81	78.76	0.571	0.716	20.20	318.2
BAHAUSHIYA	65.13	67.97	0.610	0.746	18.21	324.4
FARAR HAUSA	70.33	73.05	0.586	0.671	12.63	328.1
			COWPEA			
SAMPEA 7	74.09	65.02	0.695	0.746	6.897	136.9
SAMPEA 8	77.85	69.37	0.750	0.806	6.890	122.5
KANANNADO	74.26	69.74	0.660	0.702	6.010	184.9
IRONBEAN	70.45	64.92	0.655	0.761	13.89	245.6

4.1.2.1 *Crops shapes and classification*

i) Sphericity and roundness of crops pods and seeds:

The sphericity and roundness of the pods of groundnut varieties show a range of 56.54 – 61.71 % and 58.20 – 66. 23 % respectively while that of cowpea varieties were found to be 12.64 – 17.25 % and 25.85 – 30.78 % respectively (Table 4.5). It could be clarified from Figure 4.1 that groundnut varieties are more of round than spherical in shape because all varieties indicated higher percentage in terms of roundness than sphericity. Cowpea varieties exhibit similar pattern but their percentages in terms of both sphericity and roundness is very low that are less than

31 %. This could be attributed to the fact that the pods of cowpea varieties are lengthy in nature hence could not be classified either spherical or round in shape.

The sphericity and roundness of the seeds of groundnut varieties show a range of 65.13 – 77.67 % and 67.97 – 83.16 % respectively while that of cowpea varieties were found to be 70.45 – 77.85 % and 64.92 – 69.74 % respectively (Table 4.6). These results are similar to the findings of Davies (2009), Alonge and Adegbulugbe (2005), Saeeid *et al* (2009) and Mazhar *et al*, (2013). It could also be clarified from Figure 4.2 that groundnut varieties are more of round than spherical in shape because all varieties indicated higher percentage in terms of roundness than sphericity. However, cowpea varieties exhibit otherwise with the fact of characterizing more of spherical than round in shape because all varieties indicated higher percentage in terms of sphericity than roundness. Both groundnut and cowpea varieties indicated similar properties in terms of sphericity and roundness, hence; other methods were employed for further classifications.

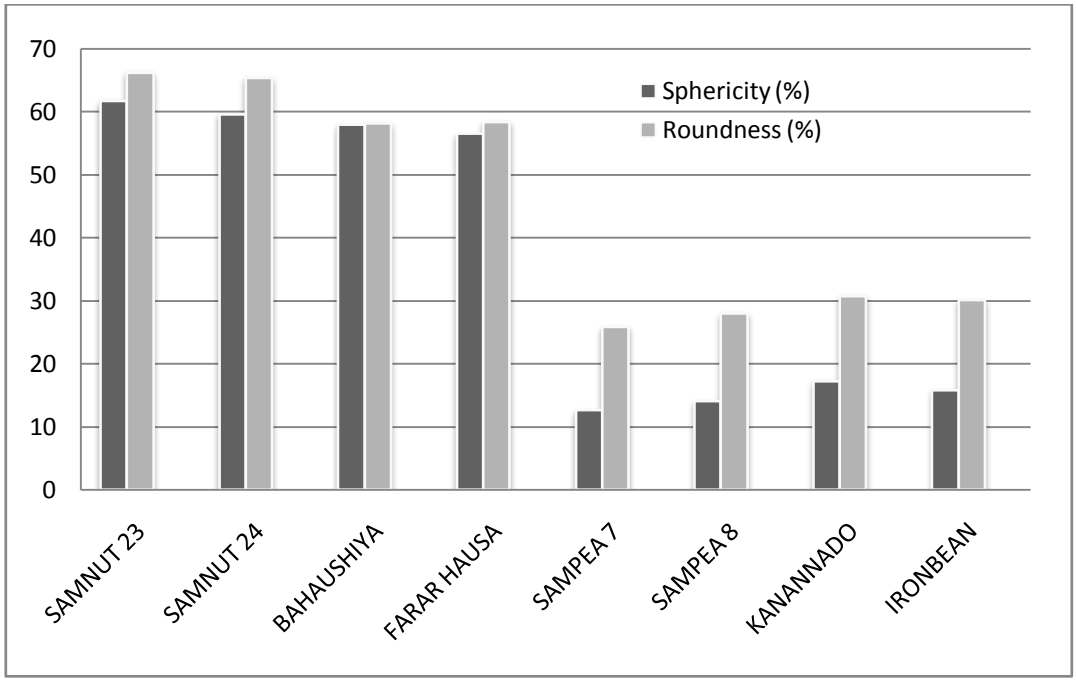


Fig.4.1:Variation of the Sphericity and Roundness of Pods for the Crops Varieties

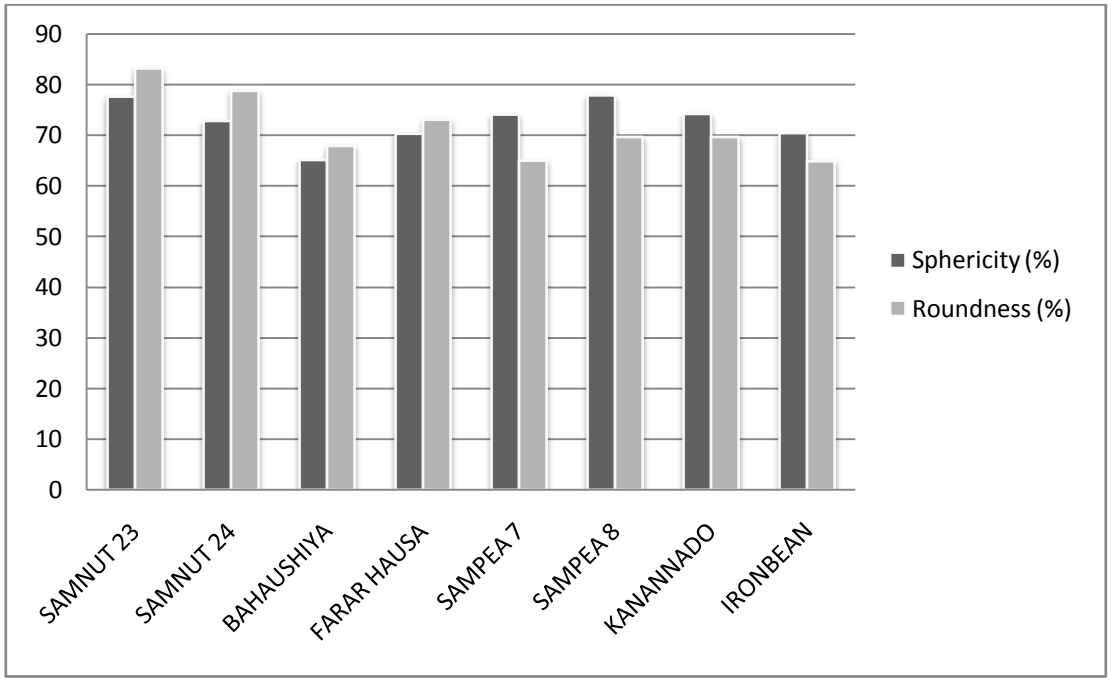


Fig.4.2:Variation of the Sphericity and Roundness of Seeds for the Crops Varieties

ii) Seeds shape classification:

The seeds of groundnut varieties were further classified according to Mazhar *et al* (2013). The varieties SAMNUT 23, SAMNUT 24 and Fararhausa were classified *Ellipticus* which is ellipsoid in shape, because the ratio of their length to width (L/W) fall within the range of 1.51 – 1.71 while Bahaushiya, was classified *Oblongus* which is long cylindroids in shape because the ratio of its length to width (L/W) fall within the range of 1.85 – 2.31. However, these were found similar to the findings of Mazhar *et al* (2013).

The seeds of cowpea varieties do not conform to the basis of Mazhar *et al* (2013) but were further subjected to the USDA (2009) classification. The shapes of cowpea varieties used were compared with the diagrammatic illustrations provided by USDA (2009) and classified according to the terms used to describe the corresponding shape. However, the varieties SAMPEA 7 and SAMPEA 8were found to be *Rhomboid* while Kanannado and Ironbean were *Ovoid*and *Kidney* in shape respectively (Table 4.7).

4.1.2.2 Bulk and true density of the crops

The bulk and true densities of the pods of groundnut varieties show a range of 0.242 – 0.289 g/cm^3 and 0.258 – 0.342 g/cm^3 respectively while that of cowpea varieties were found to be 0.133 – 0.145 g/cm^3 and 0.236 – 0.339 g/cm^3 respectively (Table 4.5).

The groundnut varieties were found to have the ranges of seeds bulk and true densities of 0.571 – 0.610 g/cm^3 and 0.671 – 0.746 g/cm^3 respectively. These are similar to the findings of Davies (2009), likewise Alonge and Adegbulugbe (2005). However, those of cowpea varieties were found to be 0.655 – 0.750 g/cm^3 and 0.702 – 0.806 g/cm^3 respectively. These do not agreed with the findings of Mazhar et al (2013) which could be due to difference in sizes of the seeds (Table 4.6).

Table 4.7: **Seeds Classification Based on their Shapes**

Crop/Variety	Length (mm)	Thickness (mm)	Width (mm)	L/W	(W/T)L	Class
		GROUNDNUT				
SAMNUT23	11.55	8.380	7.460	1.548	10.28	Ellipticus
SAMNUT 24	13.82	9.080	8.120	1.702	12.36	Ellipticus
BAHAUSHIYA	15.60	8.150	8.250	1.891	15.79	Oblongus

FARARHAUSA	14.53	8.620	8.520	1.705	14.36	Ellipticus
			COWPEA			
SAMPEA 7	8.910	4.560	7.080	1.258	13.83	Rhomboid
SAMPEA 8	8.020	4.550	6.670	1.202	11.76	Rhomboid
KANANNADO	10.33	5.930	7.370	1.402	12.84	Ovoid
IRONBEAN	12.55	6.440	8.550	1.468	16.66	Kidney

Table 4.8: **Some Mechanical Properties of the Crops**

Crop/Variety	**Pods coefficient of friction (μ)/Surfaces**			**Seeds coefficient of friction (μ)/Surfaces**			**Angle of Repose Θ (°)**	**Angle of Repose Θ (°)**	**Crushing strength (kg/mm^2)**
				GROUNDNUT					
	Wood	Glass	Iron	Wood	Glass	Iron	(Seeds)	(Pods)	(Pods)
SAMNUT 23	0.37	0.38	0.33	0.26	0.25	0.27	23.97	37.80	0.1180
SAMNUT 24	0.38	0.44	0.34	0.23	0.20	0.27	26.23	34.99	0.1180
BAHAUSHIYA	0.36	0.38	0.30	0.26	0.23	0.28	30.61	37.07	0.1330
FARARHAUSA	0.37	0.39	0.32	0.28	0.25	0.29	27.45	35.72	0.1200
				COWPEA					
SAMPEA 7	0.43	0.38	0.43	0.32	0.26	0.30	24.57	--	0.0076
SAMPEA 8	0.45	0.47	0.47	0.29	0.29	0.31	24.93	--	0.0121
KANANNADO	0.38	0.40	0.38	0.33	0.27	0.27	30.26	--	0.0126
IRONBEAN	0.42	0.39	0.47	0.27	0.25	0.25	27.55	--	0.0086

4.1.3Some mechanical properties of the crops

4.1.3.1 *Coefficient of friction of the crops*

The coefficient of friction of groundnut pods with the wooden, glass, and galvanized iron surfaces were found to have a range of 0.36 – 0.38, 0.38 – 0.44, and 0.30 – 0.34 respectively while that of cowpea pods were 0.38 – 0.45, 0.38 – 0.47 and 0.38 – 0.47 respectively (Table 4.8). However, these were not similar to the findings of Davies (2009), likewise Alonge and Adegbulugbe (2005) which could be due to some differences in geometric properties of the crops. Among groundnut varieties, the pods of SAMNUT 24 have higher coefficient of friction with all surfaces while other varieties are relatively similar. On the other hand a cowpea variety, Kanannado, has the lowest coefficient of friction with most of the surfaces while other varieties were relatively similar. These could be related to the differences in varietal basic geometric properties. In general; both groundnut and cowpea varieties have similar coefficient of friction on the glass surface. In addition, cowpea varieties were found to have higher coefficient of friction on the wooden and galvanized iron surfaces; hence, cowpea varieties could be regarded with high coefficient of friction compared to groundnut varieties (Fig. 4.3).

The coefficient of friction of groundnut seeds on the wooden, glass, and galvanized iron surfaces were found to have a range of 0.23 – 0.28, 0.20 – 0.25, and 0.27 – 0.29 respectively while that of cowpea seeds were 0.27 – 0.33, 0.25 – 0.29 and 0.25 – 0.31 respectively (Table 4.8). However, these were not similar to the findings of Davies (2009), Saeeid *et al* (2009), as well as Alonge and Adegbulugbe

(2005)which could be due to some differences in geometric properties of the crops. Among the groundnut varieties, the seeds of SAMNUT 24 were found to have the least coefficient of friction on all surfaces while other varieties were relatively similar. Similarly, for the cowpea varieties, the seeds of Ironbean have the lowest coefficient of friction on all the surfaces while other varieties were relatively similar. These could also be related to the differences in varietal geometric properties. In general; both seeds of groundnut and cowpea varieties were found to have similar coefficient of friction on the glass surface. In addition, the seeds of cowpea varieties were found to have higher coefficient of friction on the wooden and galvanized iron surfaces; hence, cowpea varieties could be regarded with high coefficient of friction compared to that of groundnut (Fig. 4.4).

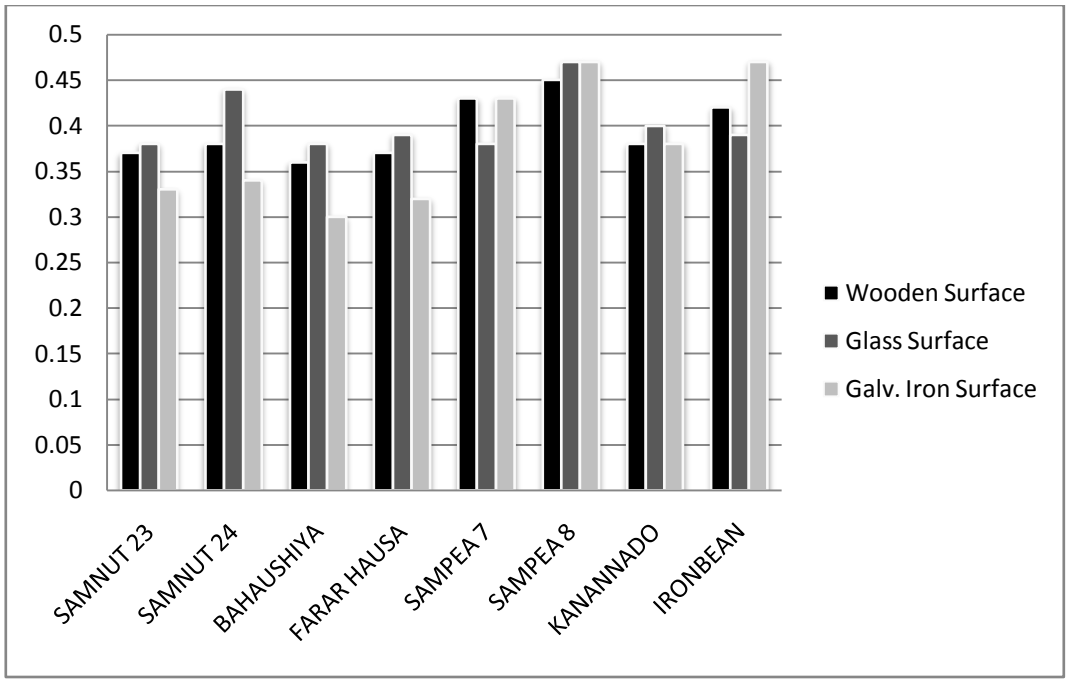


Fig.4.3:Variation of the Coefficient of Friction for the Pods of Crops Varieties

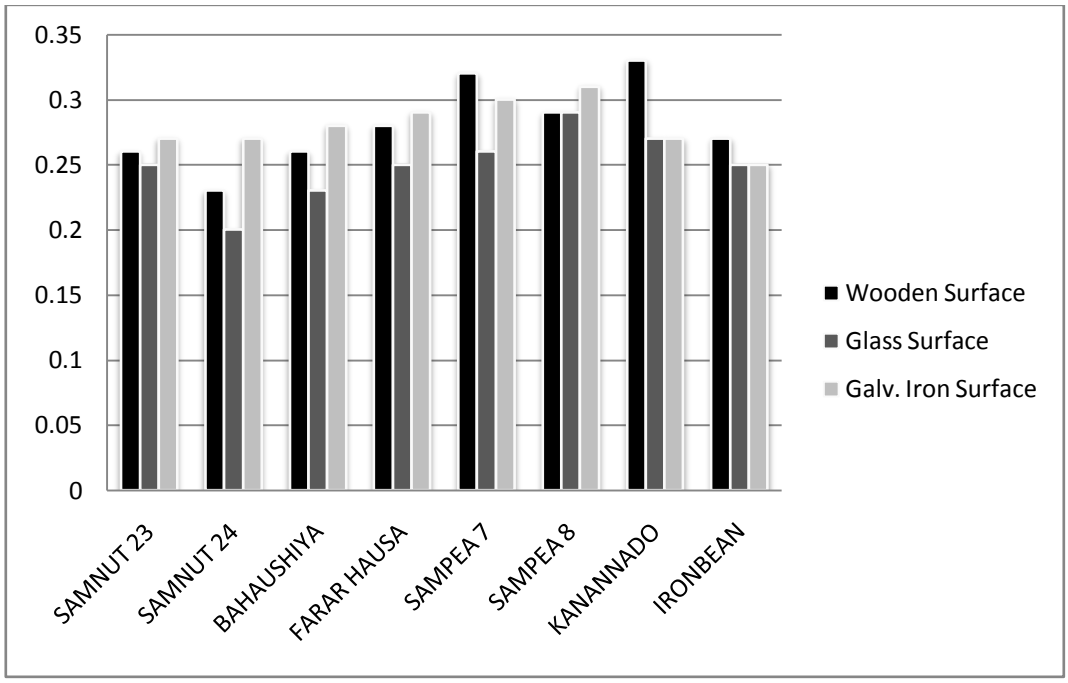


Fig.4.4:Variation of the Coefficient of Friction of the Seeds of Crops Varieties

4.1.3.2 *Angle of repose of the crops*

The angle of repose of unshelled groundnut varieties were found to fall within the range of 35 – 40^{o} while that of the groundnut and cowpea seeds were found to fall within the range of 23 – 31^{o} (Table 4.8)and these were similar to the findings of Davies (2009), Saeeid *et al* (2009), as well as Alonge and Adegbulugbe (2005) but differ from that of Ozturk *et al* (2009) which could be due to differences in basic geometric properties of the crops. However, Figure 4.5 shows that among the groundnut varieties, the seeds of Bahaushiya were found to have the highest angle of repose while that of SAMNUT 23 were characterized with the least angle of repose. For the cowpea varieties, the seeds of Kanannado were found to have the highest angle of repose while that of SAMPEA 7 were characterized with the least angle of repose.

4.1.3.3 *Crushing strength of the crops*

The crushing strength of both unshelled (pod) groundnut and cowpea varieties were found to be less than 1 kg/mm^2 but that of cowpea were closer to zero.This indicated that cowpea varieties have lower crushing strength compared to that of groundnut. The ranges were 0.118 – 0.133 kg/mm^2 and 0.0076 – 0.0126 kg/mm^2 for groundnut and cowpea varieties respectively (Table 4.8).

4.1.3.4 *Moisture content of the crops*

The groundnut and cowpea seeds moisture content (wet basis) were found to be 8.89 % and 11.11 % respectively.

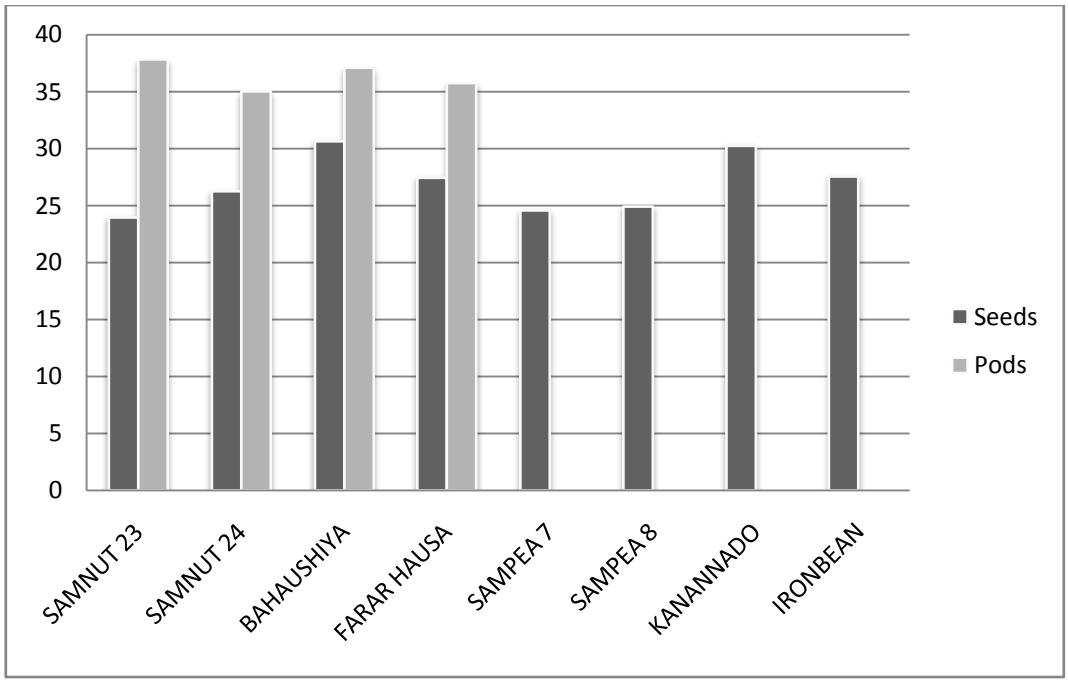


Fig. 4.5:Variation of the Angle of Repose of the Seeds and Pods for the Crops Varieties

4.2 Effect of Cylinder Speed, Feed Rate and Concave to Cylinder Clearance on the Machine Performance

4.2.1 Effects of cylinder speed on shelling efficiency at various feed rates

The shelling efficiency using groundnut ranges from 91.67 % to 96.00 %. The minimum efficiency was obtained at a speed of 2.98 m/s (150 rpm) and a feed rate of 8 kg/min while the maximum was at a speed of 2.98 m/s (150 rpm) and a feed rate of 12 kg/min (Appendix E_2). The trend of cylinder speed and shelling efficiency at various feed rates shows a positive linear relationship (Fig. 4.6). This implies thatthe shelling efficiency increased with increase in cylinder speed at different feed rates which was due to increased in impact force on the pods. The trend at a feed rate of 10 kg/min is more symmetrical compared to other feed rate levels, having indicating higher coefficient of determination ($R^2 = 0.895$). The feed rate level has the least gradient (a = 1.98) which is indicating the least degree of increased in shelling efficiency with the increased in cylinder speed. However, the degree of increased in shelling efficiency with the increase in cylinder speed is more pronounced with a feed rate of 12 kg/min, having the higher gradient (a = 4.241). The results of the analysis of variance shows that the effect of speeds, feed rates and their interactions were highly significant on shelling efficiency at 1% level of confidence (Table 4.9). A further analysis to assess of the effects of these variables and their interactions using LSD method indicated that the speeds level; 3.18 m/s and 2.98 m/swere statistically at par, likewise 2.98 m/s and 2.79 m/s though the effect of 3.18 m/s was greater than that of 2.79 m/s. Similarly, the feed rates level; 12 kg/min and 10 kg/minwere statistically at par, likewise 10 kg/min and 8 kg/min though the effect of 12 kg/min was greater than that of 8 kg/min. A

combination of speed level of 3.18 m/s and 12 kg/min feed rate were ranked the best interaction (Appendix F_1), hence could be the best treatment combination for the shelling process.

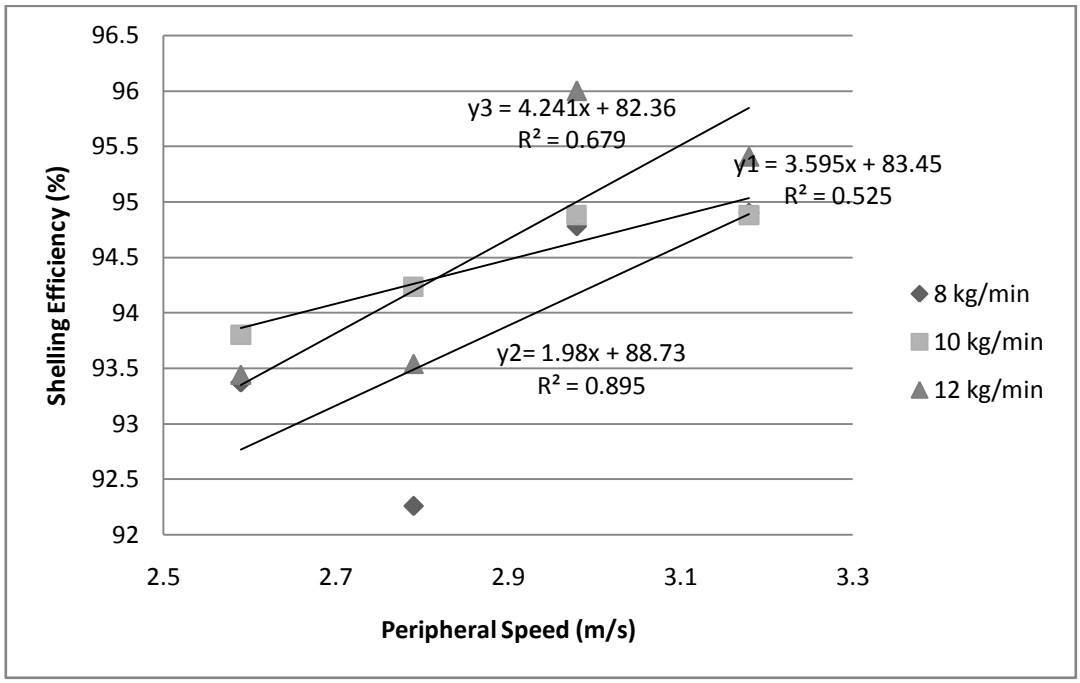


Fig. 4.6: Variation of Groundnut Shelling Efficiency with the Cylinder Speeds at VariousFeed Rates

Table 4.9:Analysis of Variance for Groundnut Shelling Efficiency

Source of Variance	DF	SS	MS	Fcal	Ftab 5%	Ftab 1%
Replication	2	0.66	0.33	2.83^{NS}	3.13	4.92
Speed	3	9.77	3.26	28.02**	2.74	4.08
Feed rate	2	8.71	4.35	37.47^{**}	3.13	4.92
Clearance	2	0.62	0.31	2.67^{NS}	3.13	4.92
S x F	6	10.45	1.74	14.98^{**}	2.23	3.07
S x C	6	3.40	0.57	4.87^{**}	2.23	3.07
F x C	4	0.63	0.16	1.36^{NS}	2.50	3.60
S x F x C	12	20.03	1.67	14.36^{**}	1.89	2.45
Error	70	8.14	0.12			
Total	107	62.40				

The shelling efficiency using cowpea ranges from 92.29 % to 95.75 % at a speed of 2.39 m/s (120 rpm) and 2.79

m/s (140 rpm) respectively. The minimum efficiency was obtained at a feed rate of 12 kg/min while maximum was at 18 kg/min (Appendix E_3).The shelling efficiency increased with increase in cylinder speed at different feed rates which was due to increased in impact force on the pods as shown in Figure 4.7. It could be seen from the figure that the shelling efficiency increased with the increase in feed rates at all speed levels except 2.39 m/s. This is because the feed rates do not chock up the shelling chamber and the cowpea pods were not hard; hence, could easily be shelled.The results of the analysis of variance shows that the effect of speeds, feed rates and their interactions were not significant on shelling efficiency at 5% level of confidence (Table 4.10).

On comparison with the groundnut shelling, the two set of results indicated a closed range of shelling efficiencies and yielded a similar trends graphically though the efficiencies are higher with cowpea than groundnut crop for all speed levels (Fig. 4.8).This implies that the machine is having similar characteristics in shelling processes with both crops.The trend for cowpea shelling is symmetrically better than that of groundnut, having the higher coefficient of determination ($R^2 = 0.892$) likewise the degree of increased in shelling efficiency is more pronounced with cowpea shelling than groundnut, having higher gradient (a = 1.758). Generally, the relationship between cylinder speed and shelling efficiency shows positive linear trend for both groundnut and cowpea.

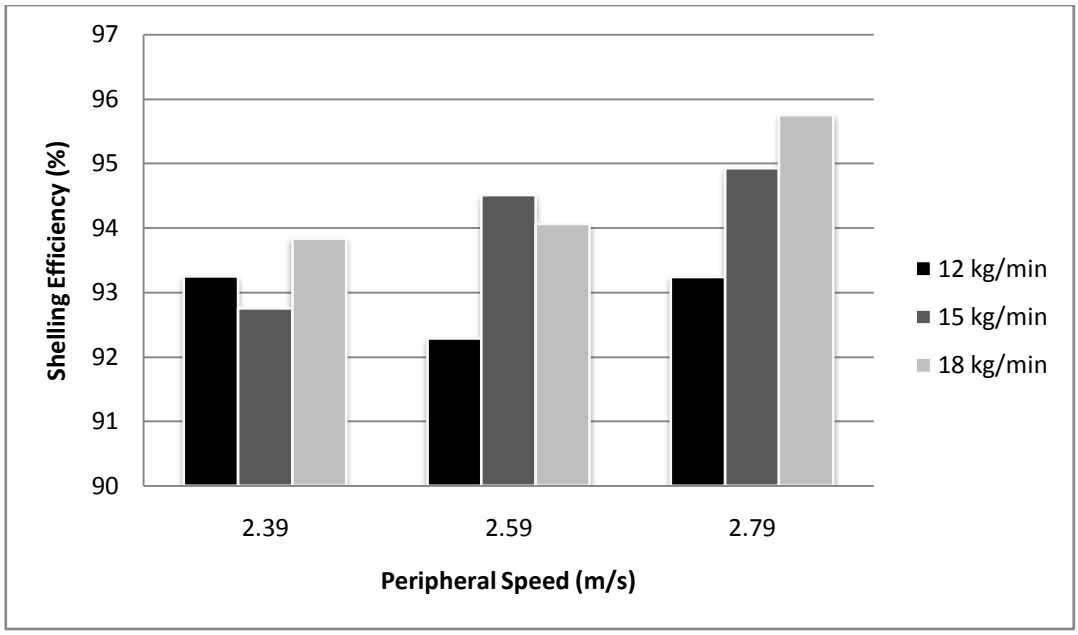


Fig. 4.7: Variation of Cowpea Shelling Efficiency with the Cylinder Speeds at Various Feed Rates

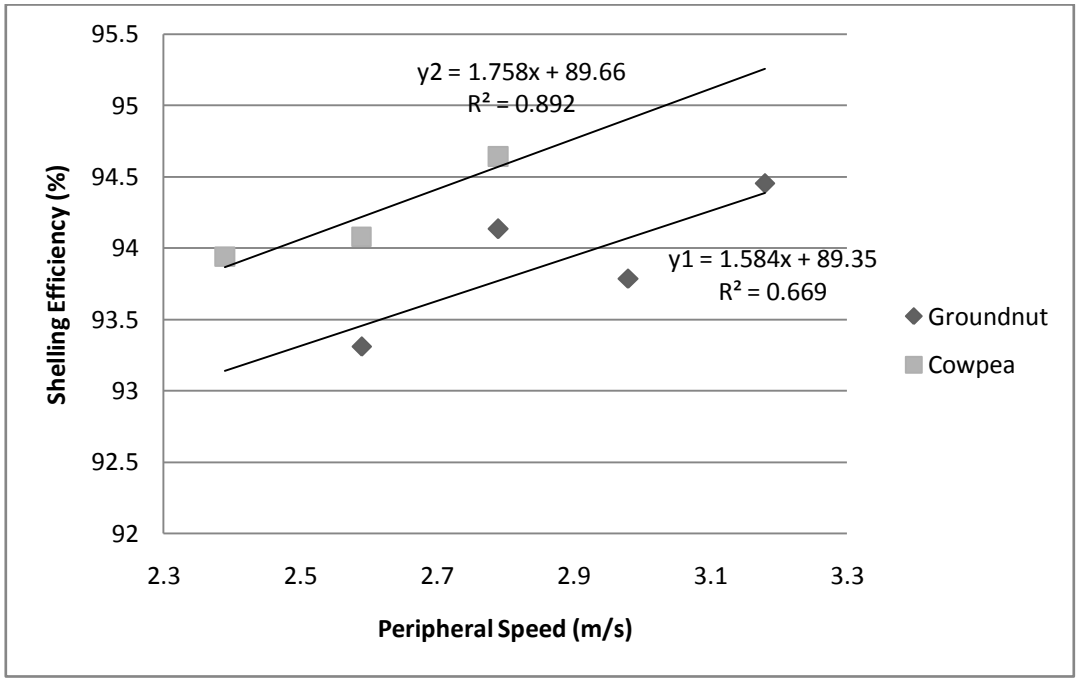


Fig. 4.8: Shelling Performance of the Modified Machine on Groundnut and Cowpea

4.2.2 Effects of cylinder speed on shelling efficiency at various concave clearances

The shelling efficiency shows no specific pattern with increase in concave clearance but the performance was relatively in closed range for all clearances at the lower speed levels and tends to be higher with 21 mm concave clearance as the speed level increased (Fig. 4.9). However, the shelling efficiency increased linearly with the increase in cylinder speed for all concave clearances. The trend at a concave clearance of 19 mm is more proportionate, having indicating higher coefficient of determination (R^2 = 0.906) but the degree of increase in shelling efficiency with the increase in cylinder speed is more pronounced with the 21 mm concave clearance, having the higher gradient (a = 3.372). The results of the analysis of variance shows that the effect of concave to cylinder clearance on the shelling efficiency was not significant at 5% level of confidence while the effects of its interactions with the cylinder speed were highly significant on shelling efficiency at 1% level (Table 4.9). A further analysis to assess the effects interactions using LSD method indicated that a combination of speed level of 2.59 m/s and 19 mm concave clearance were ranked the best interaction though the effects of all the interactions were found statistically atpar (Appendix F_1).

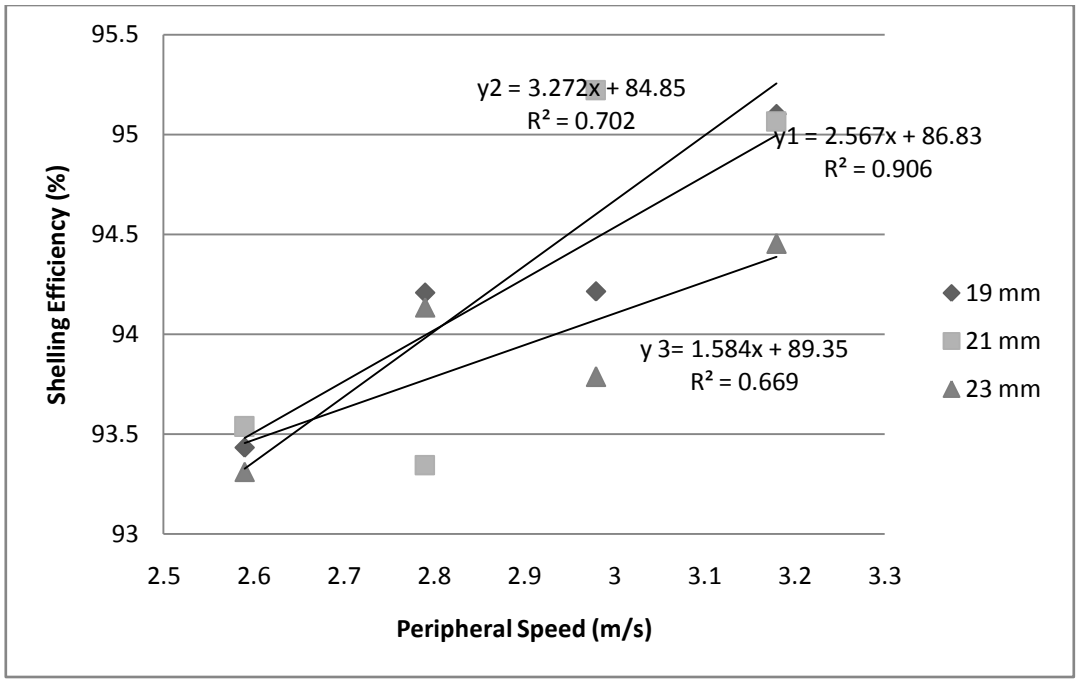


Fig. 4.9: Variation of Groundnut Shelling Efficiency with the Cylinder Speeds at Various Concave Clearances

Table 4.10: **Analysis of Variance for Cowpea Shelling Efficiency**

Source of Variance	DF	SS	MS	Fcal	Ftab 5%	1%
Replication	2	1.385	0.693	1.997^{NS}	3.63	6.23
Speed	2	1.824	0.912	2.630^{NS}	3.63	6.23
Feed rate	2	0.148	0.074	0.213^{NS}	3.63	6.23
S x F	4	2.155	0.539	1.553^{NS}	3.01	4.77
Error	16	5.549	0.347			
Total	26	11.061				

4.2.3Effects of cylinderspeed on cleaning efficiency at various feed rates

The cleaning efficiency for groundnut shelling ranges from 90.94 % to 97.44 %. The minimum efficiency was obtained at a cylinder speed of 2.59 m/s (130 rpm) and a feed rate of 12 kg/min while the maximum was at 3.18 m/s (160 rpm) and 8 kg/min (Appendix E_2).The trend of cylinder speed and cleaning efficiency at various feed rates shows a positive linear relationship (Fig. 4.10). This mean, it increased with increase in cylinder speed at different feed rateslevels which was due to increase in fan speed. As the fan speed increased there was more stream of air flowing across the fallen objects thereby blowing off the materials other than grains. The trend lines for all the feed rate level symmetrically indicated closed coefficient of determination (R^2 = 0.934 – 0.983) with the highest at 10 kg/min while the lowest at 12 kg/min. The degree of increased in cleaning efficiency with the increase in cylinder speed is more pronounced with a feed rate of 8 kg/min, having the higher gradient (a = 6.727).The results of the analysis of variance shows that the effects of speeds and feed rates were highly significant on cleaning efficiency at 1% level of confidence while the effects of their interactions were not significant at 5% level (Table 4.11). When assessing the effects of these variables using LSD method, it was found that the effects of the speed levels were not statistically the same but 3.18 m/s was ranked the best. However, the feed rates levels exhibit otherwise that; 8 kg/min and 10 kg/minwere statistically at par, likewise 10 kg/min and 12 kg/min though the effect of 8 kg/min was greater than that of 12 kg/min (Appendix F_1).

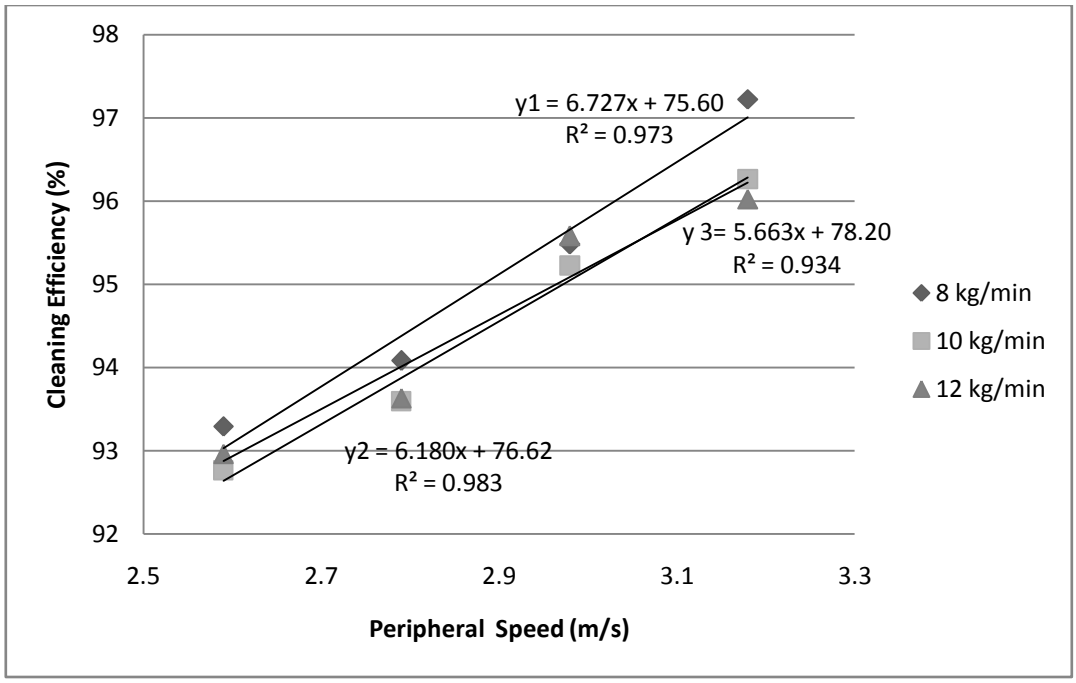


Fig. 4.10:Variation of Groundnut Cleaning Efficiency with the Cylinder Speeds at Various Feed Rates

Table 4.11:Analysis of Variance for Groundnut Cleaning Efficiency

Source of Variance	DF	SS	MS	Fcal	Ftab 5%	1%
Replication	2	0.14	0.07	0.12^{NS}	3.13	4.92
Speed	3	240.721	80.240	141.6^{**}	2.74	4.08
Feedrate	2	18.035	9.018	15.92^{**}	3.13	4.92
Clearance	2	6.469	3.235	5.71^{**}	3.13	4.92
S x F	6	7.416	1.236	2.18^{NS}	2.23	3.07
S x C	6	11.710	1.952	3.45^{**}	2.23	3.07
F x C	4	4.015	1.004	1.77^{NS}	2.50	3.60
S x F x C	12	40.585	3.382	5.97^{**}	1.89	2.45
Error	70	39.650	0.566			
Total	107	368.739				

The cleaning efficiency of cowpea ranges from 96.90 % to 98.32 %. The minimum efficiency was obtained at a speed of 2.79 m/s (140 rpm) and a feed rate of 15 kg/min while the maximum was at a speed of 2.79 m/s (140 rpm) and a feed rate of 18 kg/min (Appendix E_3).The cleaning efficiency increased with increase in cylinder speed at different feed rates (Fig. 4.11) which was due to the fact that the aerodynamic properties of the cowpea pods makes its chaffs sensitive to the change in air speed and liable to be blow off as the cylinder speed increased. It could be seen from the figure that the cleaning efficiency decreased with the increase in feed rates at all speed levels except 2.79 m/s. This could be because of the inadequate volume of air required to separate the materials in bulk at a lower speed level. The results of the analysis of variance shows that the effects of speeds, feed rates and their interactions were not significant on cleaning efficiency at 5% level of confidence (Table 4.12).

Comparatively, the two set of results are not closely similar since the cleaning efficiencies obtained for the cowpea shelling are higher than those of groundnut shelling as indicated in Figure (Fig. 4.12). The trend for groundnut cleaning is symmetrically better than that of cowpea, though, the two trend lines yielded closed coefficient of determination of 0.987 and 0.980 for groundnut and cowpea respectively. However, the degree of increased in cleaning efficiency with the increase in cylinder speed is more with the groundnut cleaning than cowpea as indicated by the wide margin in their gradients, 8.53 and 3.375, for groundnut and

cowpea trends respectively. Generally, the relationship between cylinder speed and cleaning efficiency shows positive linear trend for both groundnut and cowpea.

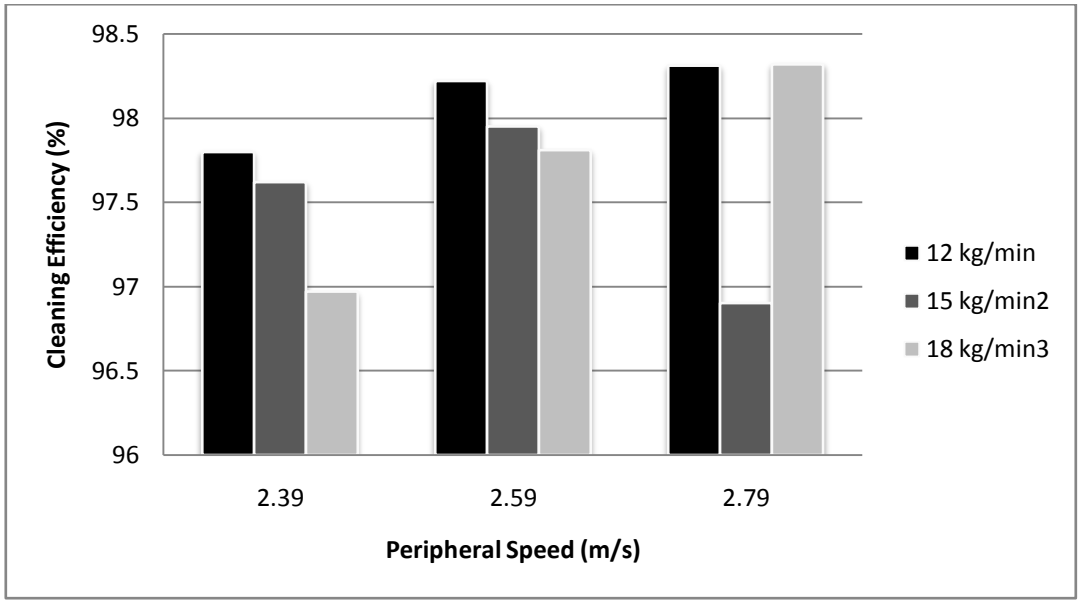


Fig. 4.11: Variation of Cowpea Cleaning Efficiency with the Cylinder Speeds at Various Feed Rates

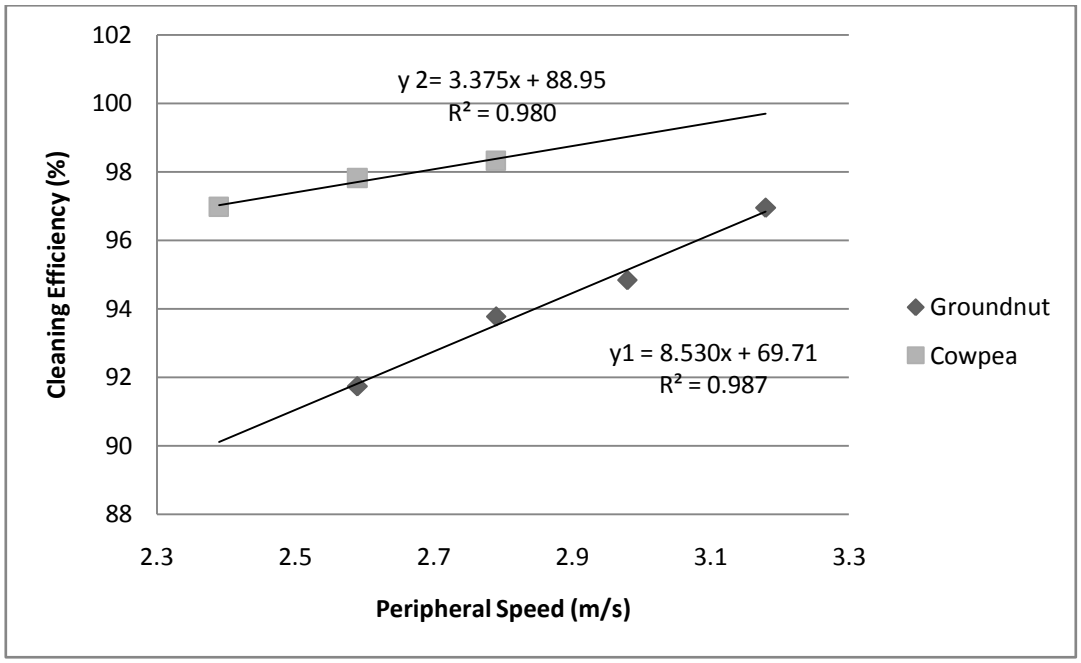


Fig. 4.12: Cleaning Performance of the Modified Machine on Groundnut and Cowpea

4.2.4 Effects of cylinder speed on cleaning efficiency at various concave clearances

Figure 4.13 shows that the cleaning efficiency is directly proportional to the increase in cylinder speed at various concave clearances. The cleaning efficiency decreased with the increase in concave to cylinder clearance. This could be attributed to the fact that with the increase in clearance at the lower speed level there would be more materials to crush at a time. This could results in clogging which is power demanding and could reduce the speed of the machine which might reduce the cleaning efficiency. The trend at a 23 mm concave clearance is more proportionate, having the highest coefficient of determination (R^2 = 0.987), compared to those of other clearance levels. The extent to which the cleaning efficiency increased with the increase in cylinder speed at various clearances reflected more with a clearance of 23 mm which has the highest gradient (a = 8.53). The result of the analysis of variance shows that, both the effect of concave clearance and its interactions with the cylinder speed were highly significant on cleaning efficiency at 1% level (Table 4.11). When assessing the effects of concave clearance and its interactions using LSD method, it was found that a clearance of 19 mm was ranked the best. A combination of speed level of 3.18 m/s and 23 mm concave clearance were ranked the best interaction (Appendix F_1).

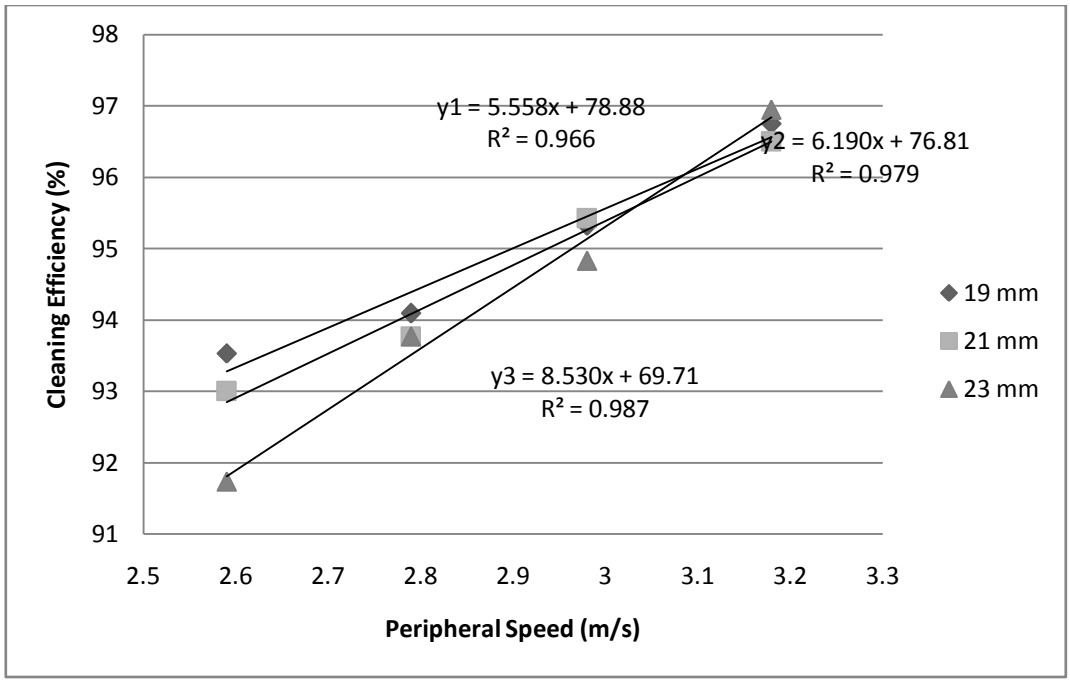


Fig. 4.13: Variation of Groundnut Cleaning Efficiency with the Cylinder Speeds at Various Concave Clearances

Table 4.12: **Analysis of Variance for Cowpea Cleaning Efficiency**

Source of Variance	DF	SS	MS	Fcal	Ftab 5%	1%
Replication	2	0.611	0.306	0.220^{NS}	3.63	6.23
Speed	2	1.298	0.649	0.468^{NS}	3.63	6.23
Feed rat	2	1.826	0.913	0.658^{NS}	3.63	6.23
S x F	4	3.613	0.903	0.651^{NS}	3.01	4.77
Error	16	22.195	1.387			
Total	26	29.544				

4.2.5Effect of cylinder speed on grain damage at various feed rates

A range of 12.00 % to 26.67 % groundnut grain damage was obtained at the cylinder speed 2.79 m/s (140 rpm) and 2.98 m/s (150 rpm) respectively (Appendix E_2). The percentages exceeded the expected limit. This could be attributed to the assertion that the shelling teeth were having sharp edges that could easily shear off the grains. In addition, the orientation of the larger seeds, that might requirea guiding force to pass, aligned along the length of the sharp edged rectangular sieve openings and instead of passing, would be shared by the robbing action of the shelling bars. The change in grain damage with increase in cylinder speed at feed rates of 10 and 12 kg/min best fitteda negative polynomial function while that of 8 kg/min gave a positive polynomial function (Fig. 4.14). The grain damage was the maximum and tends to decrease at a cylinder speed level of 2.98 m/s. This could be attributed to the non uniformity of the split distribution across the treatments or to the fact that when the cylinder speed exceed 2.98 m/s, the centrifugal force due to cylinder rotation increases thereby reducing the grain dwelling time in the cylinder and increasing their tendency to passed out thus reducing the level of breakage. The effects of cylinder speeds, feed rates and their interactions on grains damage were highly significant at 1% level (Table 4.13). When these effects were further analyzed, the speed levels were statistically unequal while the speed level of 2.98 m/s was ranked the most affecting. For the feed rate, the levels were also unequal and the highest level of 12 kg/min was ranked the most affecting and down the group to the lower level. When assessing the interactions of these variables both levels of 2.98 m/s and 12 kg/min formed the highest combination in terms of grain

damage (Appendix F_1). Hence, the best levels in terms of minimum grain damage are 2.79 m/s and 8 kg/min cylinder speed and feed rate respectively.

The mechanically damaged grains for cowpea shelling were found to be 0.00 % for all the treatment of the cowpea shelling (Appendix E_3); however, it does not agree with the findings of Irtwange (2009) and Maunde (2011). This implies that the machine was not associated with mechanical grains damage at the selected speed and feed rate levels as far as cowpea shelling is concerned. This is attributed to the nature of the crop variety used that it is hard and the impact force exerted while shelling at all speed levels do not exceed its crushing strength. Hence, the grains might not break at all instances.

The two set of result implies that the performance of the machine with regards to grain damage is incomparable for the different crop types. The notable difference could be related to the difference in physical and mechanical properties of the crops; the groundnut seeds are soft with low crushing strength which makes it liable to break by the impact and rubbing action in the shelling chamber, cowpea seeds could be seen otherwise. However, the level of grain damage (0.00 %) was highly impressive and acceptable for cowpea shelling while that of the groundnut supersedes the expected limit.

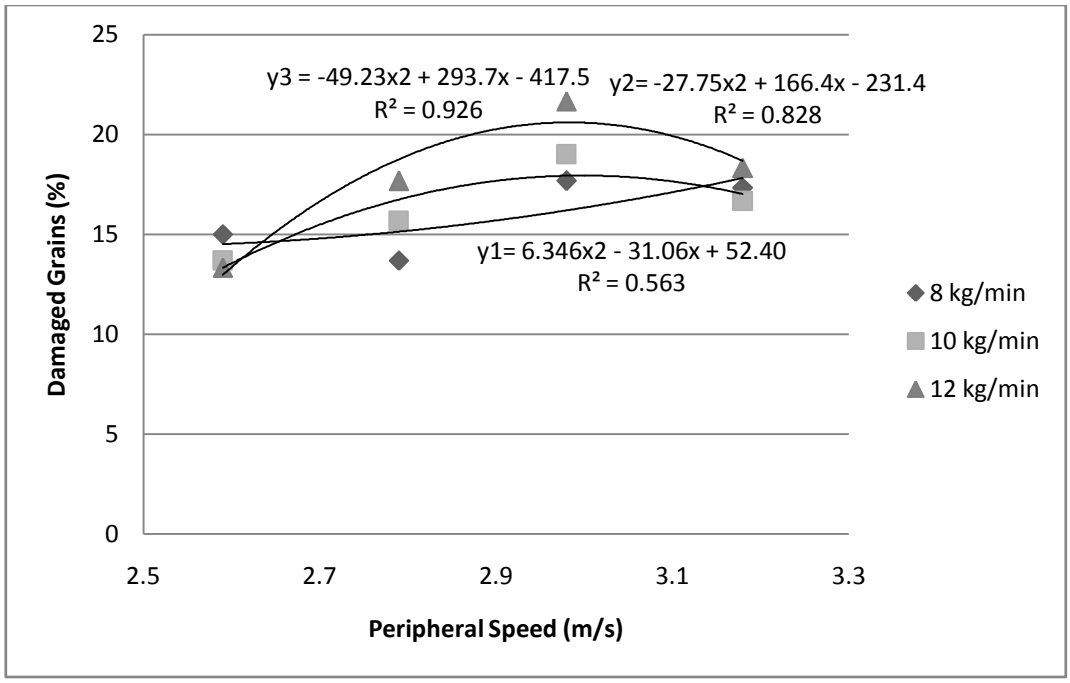


Fig. 4.14:Variation of Groundnut Grains Damage with the Cylinder Speeds at Various Feed Rates

Table 4.13:Analysis of Variance for Groundnut Grains Damage

Source of Variance	DF	SS	MS	Fcal	Ftab 5%	1%
Replication	2	13.722	6.861	57.89**	3.13	4.92
Speed	3	307.037	102.346	863.54**	2.74	4.08
Feedrate	2	143.056	71.528	603.51**	3.13	4.92
Clearance	2	101.167	50.583	426.80**	3.13	4.92
S x F	6	65.241	10.873	91.74**	2.23	3.07
S x C	6	227.130	37.855	319.40**	2.23	3.07
F x C	4	18.944	4.736	39.96**	2.50	3.60
S x F x C	12	522.074	43.506	367.08**	1.89	2.45
Error	70	8.296	0.119			
Total	107	1406.667				

4.2.6 Effect of cylinder speed on grain damage at various concave clearances

The change in grain damage for groundnut with increase in concave clearance at all speed levels does not indicate a definite pattern (Fig. 4.15). These could be attributed to the non uniformity of the damage levels across the treatments. The effects of concave clearances and their interactions with the other variables on grains damages were highly significant at 1% level (Table 4.13). When these effects were further analyzed, the clearance levels of 19 mm and 21 mm were statistically equal but 23 mm clearance was the best level in terms of minimum grain damage. For the interactions of concave clearance with other variables, it was found that clearance level of 19 mm part take in forming the worst interactions with 2.98 m/s and 12 kg/min (AppendixF_1). Hence, clearance level of 23 mm was found to have the best interactions in terms of minimum grain damage with 2.59 m/s and 8 kg/min speed and feed rate levels respectively.

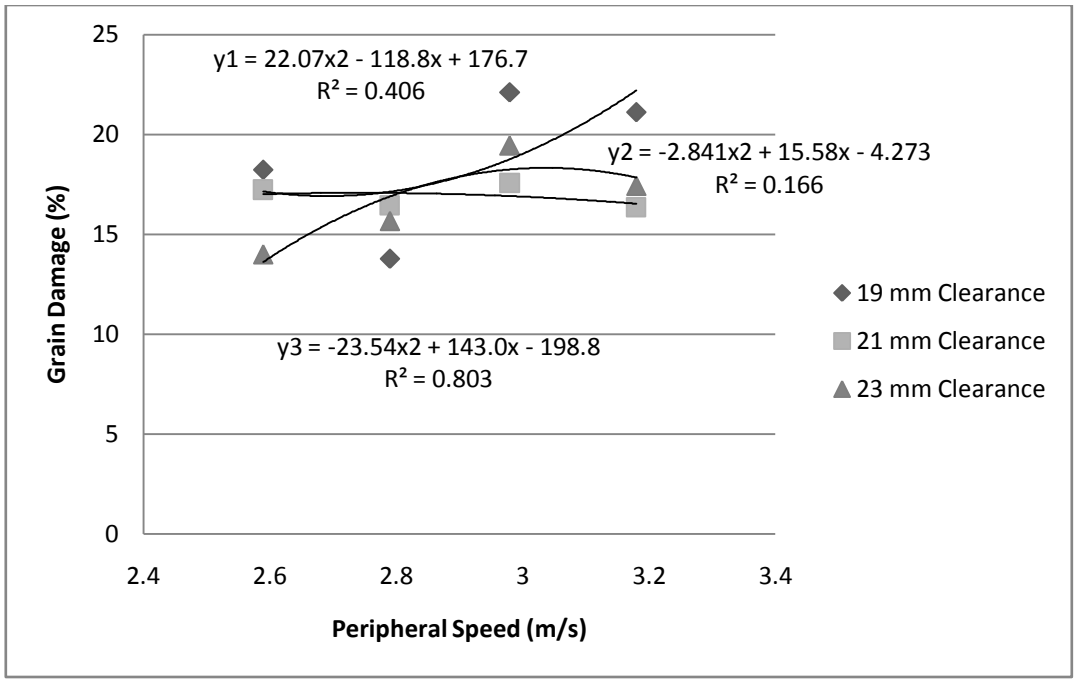


Fig. 4.15: Variation of Groundnut Grains Damage with the Cylinder Speeds at Various Concave Clearances

4.2.7Effect of cylinder speed on scatter loss at various feed rates

For groundnut, a maximum scattered loss of 7.58 % was obtained at a speed of 3.18 m/s (160 rpm) with a feed rate of 8 kg/min while a minimum of 0.50 % was obtained at a speed of 2.59 m/s (130 rpm) and feed rate of 12 kg/min (Appendix E_2). The scattered losses of the machine increased with the increase in cylinder speed at various feed rates but decreased with the increase in feed rates at the higher speed levels (Fig. 4.16). These were because of the reduction in speed when there were more materials in the shelling chamber resulting in the reduction in the volume of air stream required to blow off the chaffs at the lower speed level. With the little materials in the chamber at higher speed level there were tendency of the split and premature grains to be blown off; being their aerodynamic requirement might have been exceeded. The trend at a feed rate of 12 kg/min is symmetrically better than others, having the higher coefficient of determination (R^2 = 0.952) but least gradient (a = 8.02) which is indicating the least degree of increased in scatter loss with the increased in cylinder speed. However, the degree of increased in scatter loss with the increase in cylinder speed is more pronounced with a feed rate of 8 kg/min, having the higher gradient value (a = 9.124).The analysis of variance shows that the effects of speeds and feed rates were highly significant at 1% level on the scattered losses but their interactions were not significant at 5% level (Table 4.14). Further analysis shows that the effects of the speed levels were statistically unequal while the highest speed level of 3.18 m/s was ranked the waste and down the group to the lower level. However, the feed rates levels exhibit otherwise that; 8 kg/min and 12 kg/minwere statistically having the same effect, likewise 12

kg/minand 10 kg/min though the effect of 8 kg/min was less than that of 10 kg/min (AppendixF_1). However, this signifies that a speed level of 2.59 m/s and feed rate of 10 kg/min could be the best in terms of minimum scattered losses.

For cowpea shelling, a maximum scattered loss of 0.625 % was obtained at a speed of 2.79 m/s (140 rpm) with a feed rate of 12 kg/min while a minimum of 0.175 % was obtained at a speed of 2.39 m/s (120 rpm) with a feed rate of 15 kg/min (Appendix E_3). The scattered losses of the machine increased with the increase in cylinder speed at various feed rates but adapted a pattern of decreased then increased with the increase in feed rates at all speed levels (Fig. 4.17). These were because at the higher speeds there could be more volume of air stream required to blow off the chaffs hence increasing the tendency of the premature grains to be blown. The analysis of variance shows that the effect of speeds was highly significant at 1% level while that of feed rates was significant at 5% level on the scattered losses but their interactions were not significant at 5% level (Table 4.15). Further analysis of cylinder speed levels using LSD method shows that the effect of 2.79 m/s was greater than that of 2.59 m/s but 2.59 m/s and 2.39 m/s were statistically having the same effects in terms of scattered losses. For the feed rate levels, 12 kg/min and 18 kg/min were statistically at par but their effects were higher than that of 15 kg/min (Appendix F_2). Therefore, a speed level of 2.59 m/s or 2.39 m/s in combination with a feed rate level of 15 kg/min could be the best in terms of minimum losses.

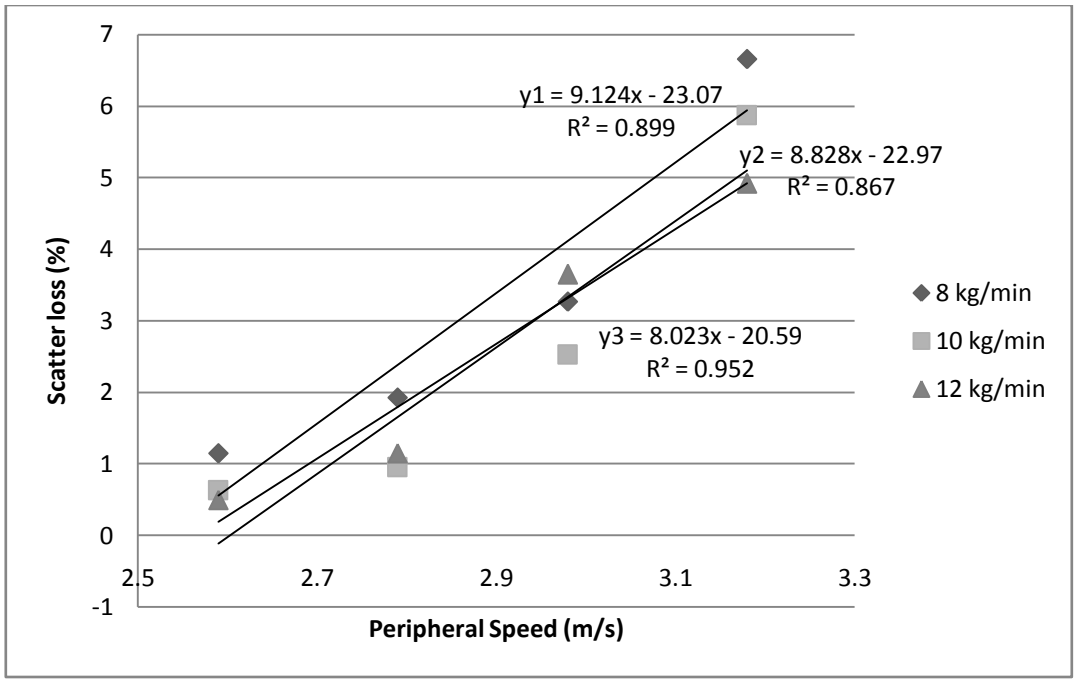


Fig. 4.16: Variation of Groundnut Grains Scatter Loss with the Cylinder Speeds at Various Feed Rates

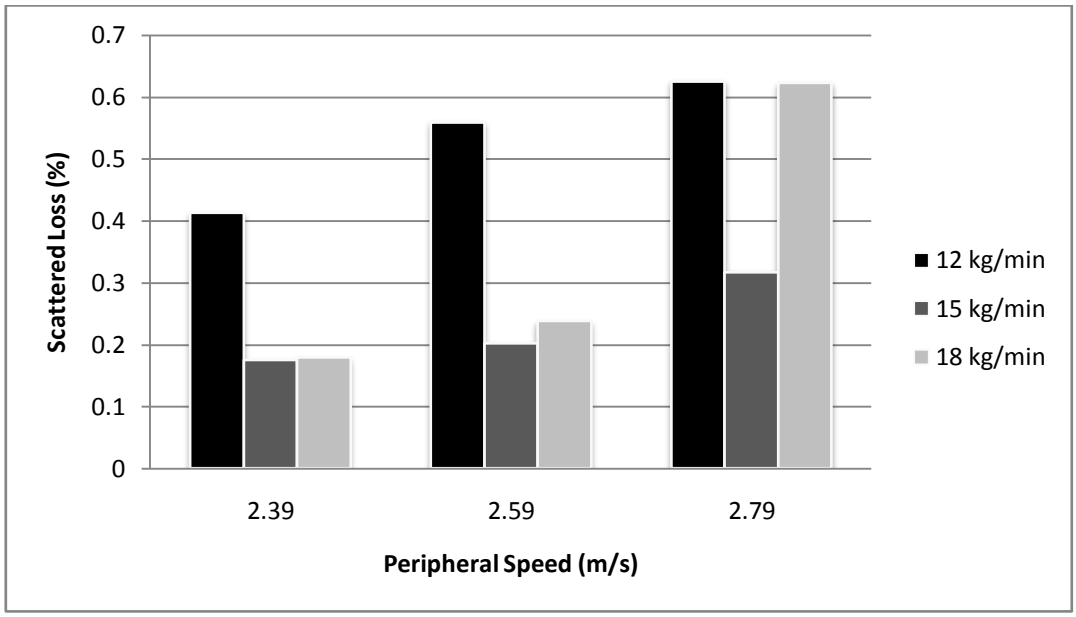


Fig. 4.17: Variation of Cowpea Grains Scatter Loss with the Cylinder Speeds at Various Feed Rates

The machine performance with the two crops does not indicate similar characteristics with regards to scattered losses. The percentages for cowpea shelling, often less than unity, are far better and more reliable than those obtained for groundnut shelling. Figure 4.18 shows to some extent that the machine exhibit similar characteristics at lower speed levels. The difference in the losses obtained could be attributed to the difference in mechanical and aerodynamic requirements of the crops. For instance, the loss in groundnut shelling was influenced by percentage split. It was observed during a preliminary investigation that 75 – 80 % of the losses were split grains. The trend for groundnut scatter loss is more symmetrical compared to that of cowpea, though, the two trend lines yielded closed coefficient of determination(0.929 and 0.911 for groundnut and cowpea respectively). However, the degree of increased in scatter loss with the increase in cylinder speed was more with the groundnut than cowpea because of the wide margin in their gradients as 8.658 and 0.146 for groundnut and cowpea trends respectively. Generally, the relationship between cylinder speed and scatter loss shows positive linear trend for both groundnut and cowpea.

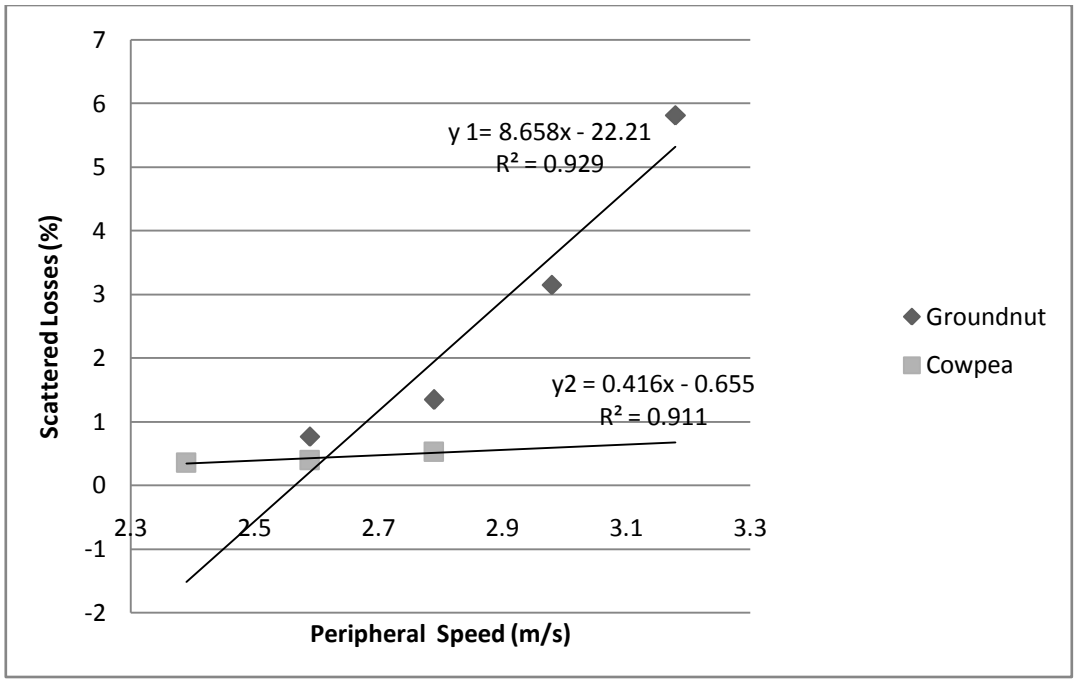


Fig. 4.18: Variation of Scatter loss with the Cylinder Speed for Groundnut and Cowpea

Table 4.14:Analysis of Variance for Groundnut Grain Scatter Loss

Source of Variance	DF	SS	MS	Fcal	Ftab 5%	1%
Replication	2	1.165	0.582	1.88^{NS}	3.13	4.92
Speed	3	130.856	43.62	141.2^{**}	2.74	4.08
Feedrate	2	4.240	2.120	6.86^{**}	3.13	4.92
Clearance	2	3.088	1.544	5.00^{**}	3.13	4.92
S x F	6	3.351	0.558	1.81^{NS}	2.23	3.07
S x C	6	0.458	0.076	0.25^{NS}	2.23	3.07
F x C	4	0.300	0.075	0.24^{NS}	2.50	3.60
S x F x C	12	6.473	0.539	1.75^{NS}	1.89	2.45
Error	70	21.623	0.309			
Total	107	171.553				

4.2.8Effect of cylinder speed on scatter loss at various concave clearances

The scatter loss of the machine decreased with the increasing concave clearance at lower speedlevels but the pattern changes at the higher speed levels (Fig. 4.19). It could also be seen that the losses were more with concave clearance level of 19 mm. These could be attributed to fact that the tendency of the materials to be crushed was more with clearance of 19 mm than 21 and 23 mm. This could render the grains liable to split and blown off, thereby increasing the percentage losses. The analysis shows that the effects of concave clearance levels were highly significant at 1% level on the scattered losses but its interactions with other variables were not significant at 5% level (Table 4.14). Further analysis shows that the effects of the clearance levels; 19 mm and 21mmwere statistically of the same effects, likewise 21 mm and 23 mm though the effect of 19 mm was greater than that of 23 mm in terms of higher losses (Appendix F_1). However, it implies that 23 mm clearance could be the best in terms of minimum scatter loss

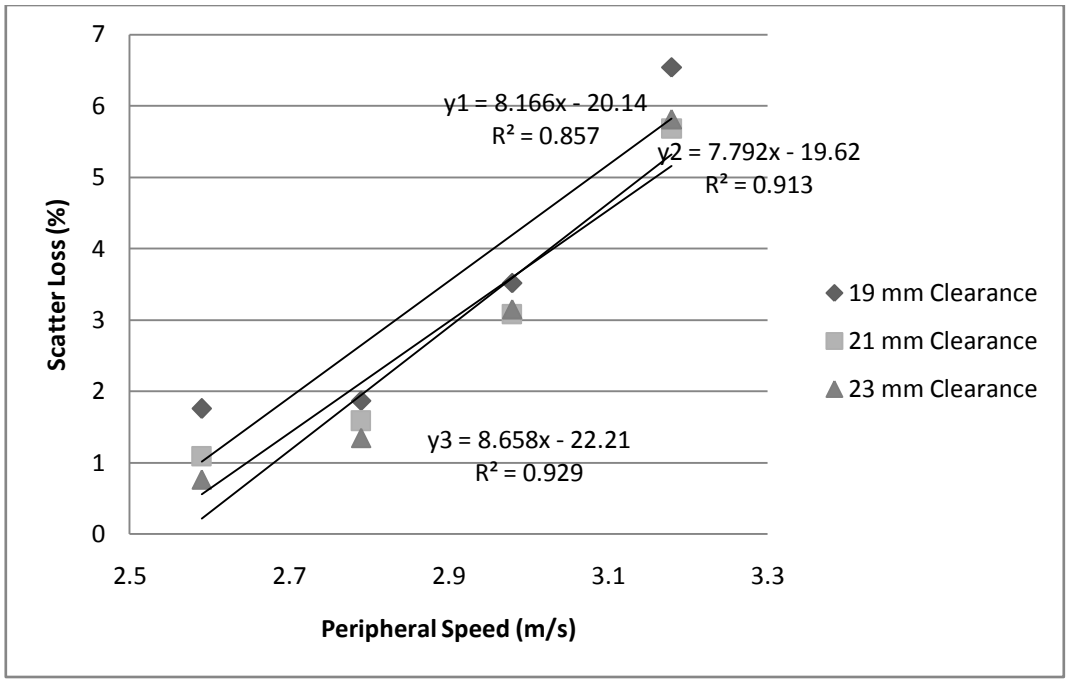


Fig. 4.19: Variation of Groundnut Grains Scatter Loss with the Cylinder Speeds at Various Concave Clearances

Table 4.15: **Analysis of Variance for Cowpea Grain Scatter Loss**

Source of Variance	DF	SS	MS	Fcal	Ftab 5%	1%
Replication	2	0.107	0.054	7.724**	3.63	6.23
Speed	2	0.117	0.058	8.403**	3.63	6.23
Feed rat	2	0.064	0.032	4.581*	3.63	6.23
S x F	4	0.042	0.010	1.497NS	3.01	4.77
Error	16	0.111	0.007			
Total	26	0.441				

4.2.9Effect of cylinder speed on output capacity at various feed rates

For groundnut, amaximum output capacity of 254.99 kg/h was obtained at a speed of 3.18 m/s (160 rpm) and a feed rate of 8 kg/min while a minimum of 211.05 kg/hr was obtained at a speed of 2.98 m/s (150 rpm) with a feed rate of 12 kg/min (Appendix E_2). The output capacity does not indicate a specific pattern with the increase in cylinder speed at various feed rates but decreased with increase in feed rates which could be attributed to clogging effect when large feed rates were fed (Fig. 4.20). The output capacity at a feed rate of 8 kg/min indicated a positive trend and is symmetrically better than others having the higher coefficient of determination ($R^2 = 0.989$) but that of 10 kg/min indicated a negative trend with the coefficient of determination of 0.564. However, the trend at a feed rate of 12 kg/min, which is positive, is symmetrically poor having the least and very low coefficient of determination ($R^2 = 0.194$). The effect of cylinder speeds was not significant at 5% level while that of feed rates was highly significant at 1% level and their interactions were also highly significant at 1% level (Table 4.16). When these effects were further analyzed, the feed rate levels; 8 and 10 kg/min, 10 and 12 kg/min were statistically equal though 8 kg/min was greater than 12 kg/min. However, when assessing the interactions of these variables a feed rate level of 8 kg/min and speed of 3.18 m/s gave the best interaction (Appendix F_1).

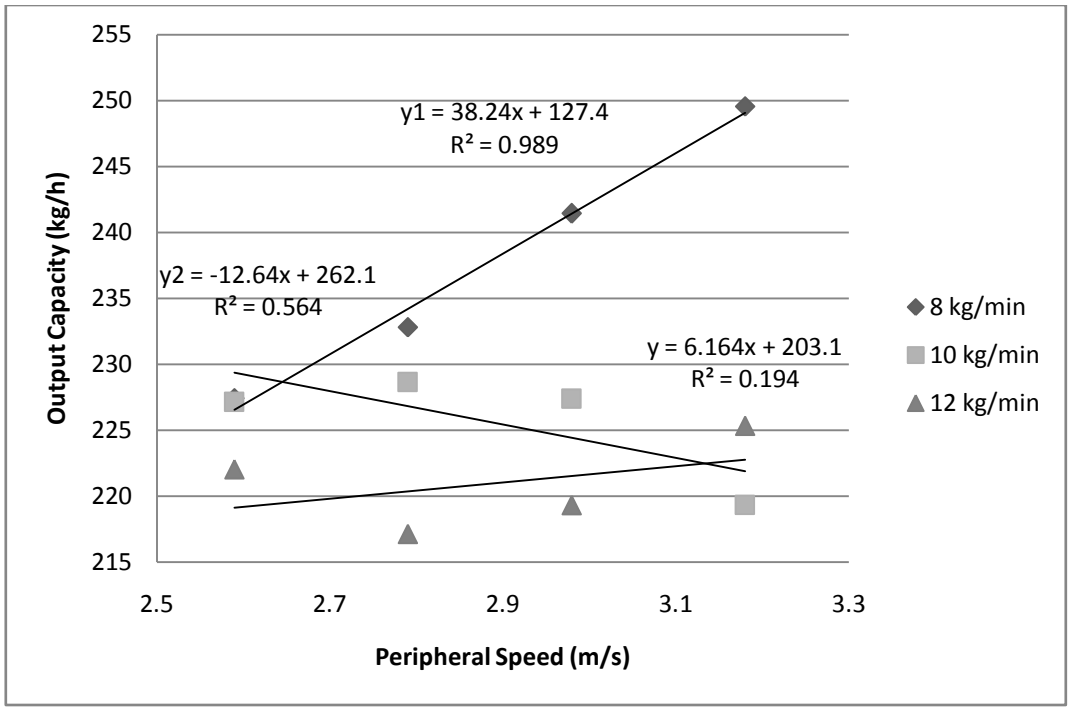


Fig. 4.20: Variation of Groundnut Output Capacity with the Cylinder Speeds at Various Feed Rates

Table 4.16:Analysis of Variance for the Output Capacity of Groundnut Shelling

Source of Variance	DF	SS	MS	Fcal	Ftab 5%	1%
Replication	2	1337.75	668.87	4.774*	3.13	4.92
Speed	3	651.02	217.01	1.549NS	2.74	4.08
Feedrat	2	5440.55	2720.28	19.417**	3.13	4.92
Clearance	2	287.64	143.82	1.027NS	3.13	4.92
S x F	6	2745.55	457.59	3.266**	2.23	3.07
S x C	6	440.75	73.46	0.524NS	2.23	3.07
F x C	4	376.83	94.21	0.672NS	2.50	3.60
S x F x C	12	5636.15	469.68	3.352**	1.89	2.45
Error	70	9806.93	140.10			
Total	107	26723.17				

The output capacity, when evaluated with a cowpea, increased with increase in cylinder speed at various feed rates but does not have specific pattern with the increase in feed rate at various speed levels(Fig. 4.21). A maximum output capacity of 546.65 kg/h was obtained at a speed of 2.79 m/s (140 rpm) with feed rate of 12 kg/min. A minimum of 276.76 kg/hr was obtained at a speed of 2.39 m/s(120 rpm) with feed rate of 18 kg/min (Appendix E_3). Both the effects of the speeds and feed rates were highly significant at 1% on the output capacity, likewise their interactions (Table 4.17). When the effects of both the speed and feed rate levels were further analyzed, a speed level of 2.79 m/s was the best while that of the feed rates, 15 kg/min was the best. For their interactions, a speed level of 2.59 m/s and a feed rate of 18 kg/min formed the best interaction (Appendix F_1).

It could be seen from the results obtained that the output of the machine with the cowpea crop is far better than that of the groundnut as shown by Figure 4.22; hence, the machine gave higher output with the cowpea. This is because the cowpea pods required less shelling force resulting in less shelling time that would eventually gave higher output per unit quantity than groundnut.

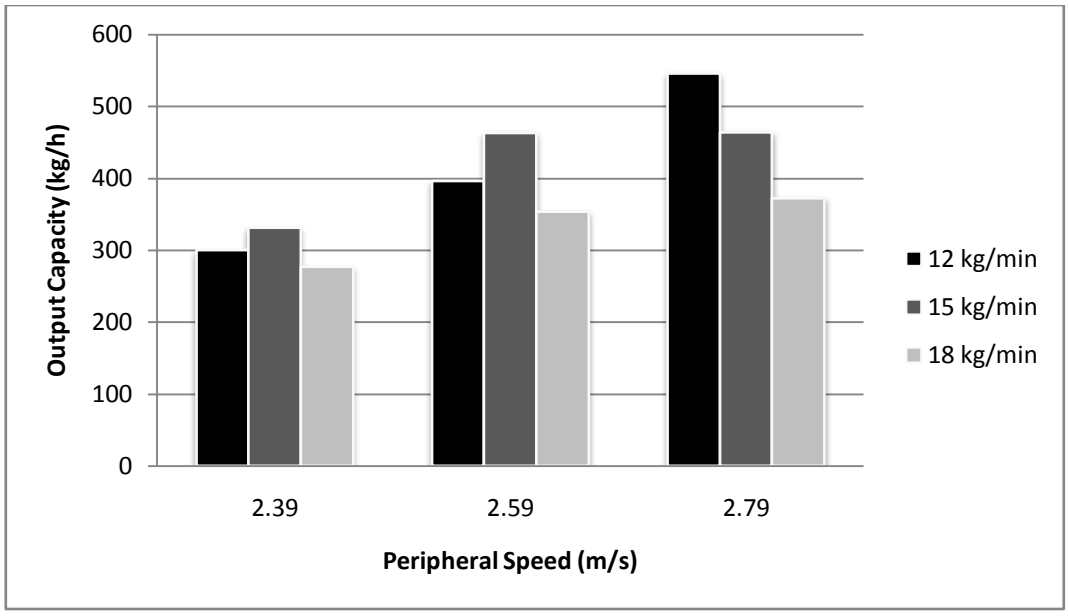


Fig. 4.21: Variation of Cowpea Output Capacity with the Cylinder Speeds at Various Feed Rates

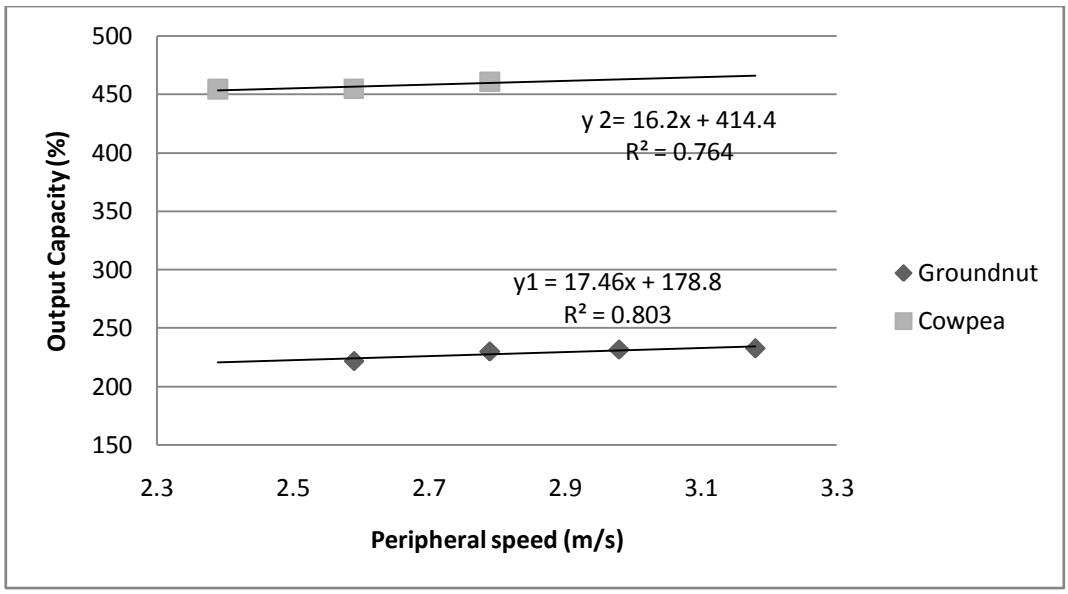


Fig. 4.22: Output Performance of Modified Machine for Groundnut and Cowpea

4.2.10 Effect of cylinder speed on output capacity at various concave clearances

The output shows an increased with increase in concave clearance. This could be related to the actual crop clearance requirement that the 23 mm clearance may best fit the size of the crop variety used. The trend of cylinder speed and output capacity at various concave clearances shows a positive linear relationship (Fig. 4.23). This implies thatthe output capacity increased with increase in cylinder speed at different concave clearance. The trend at a concave clearance of 23 mm is symmetrically better than others, having the higher coefficient of determination (R^2 = 0.803) with highest gradient (a = 17.46) which is indicating the highest degree of increased in output capacity with the increase in cylinder speed. The trend at a concave clearance of 20 mm is symmetrically poor having least and very low coefficient of determination (R^2 = 0.218) which also has the least gradient (a = 4.631), indicating the least degree of increased in output capacity with the increase in cylinder speed. Both the effects of concave clearance and its interactions with the other variables were not significant at 5% level of confidence (Table 4.16). Therefore, any of the clearance level or their interactions can yield an impressive output.

4.2.11 Best performance parameters for the modified machine

The best performance of the machine, when evaluated with groundnut, was obtained when operated at a speed of 3.18 m/s (160 rpm, S_4) with feed rate of 8 kg/min (F_1) and 21 mm (C_2) concave clearance because this combination revealed a maximum output capacity of 254.99 kg/h, moderate shelling of 94.90%,

maximumcleaning efficiency of 97.22 %, moderate visually grain damage of 14.00 %, and moderate scatter loss of 6.29 %. However, when cowpea was used, the best performance of the machine was obtained when operated at a speed of 2.79 m/s (140 rpm, S_3) with a feed rate of 12 kg/min (F_1) because this combination revealed a maximum output capacity of 546.18 kg/h, moderate shelling efficiency of 93.24 %, maximum cleaning efficiency of 98.31 %, minimum visually damaged grains of 0.00% and maximum scatter loss of 0.625 %.

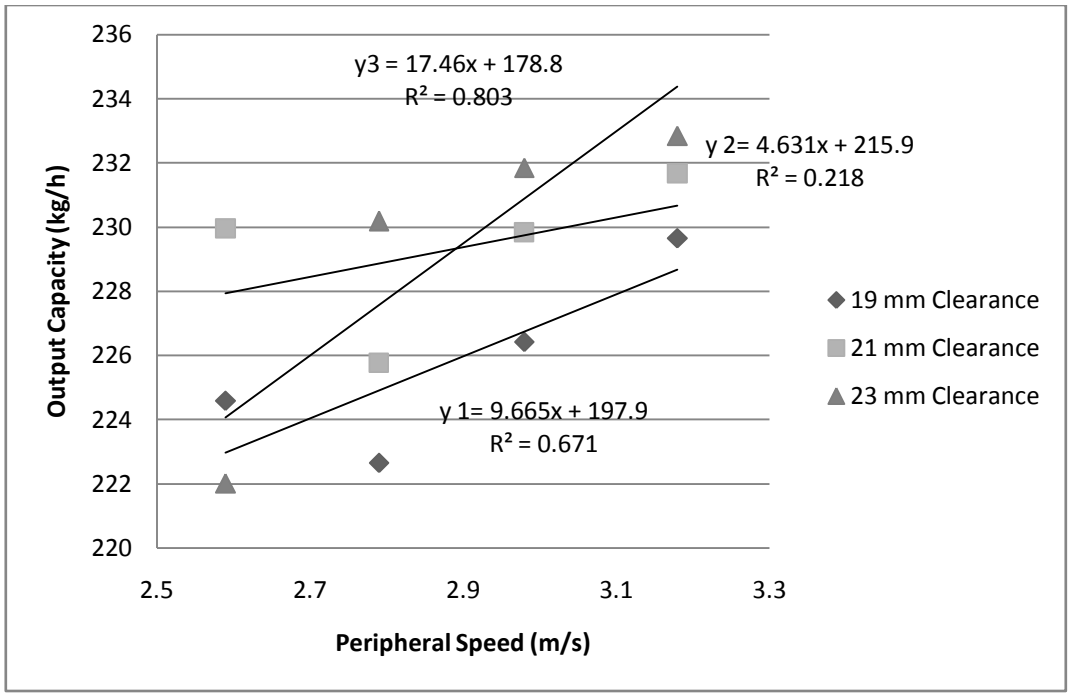


Fig. 4.23: Variation of Groundnut Output Capacity with the Cylinder Speeds at Various Concave Clearances

Table 4.17: **Analysis of Variance for the Output Capacity of Cowpea Shelling**

Source of Variance	DF	SS	MSS	Fcal	Ftab	
					5%	1%
Replication	2	259.45	129.72	0.90^{NS}	3.63	6.23
Speed	2	58728.53	29364.27	203.60^{**}	3.63	6.23
Feed rat	2	15618.05	7809.03	54.14^{**}	3.63	6.23
S x F	4	8333.70	2083.42	14.45^{**}	3.01	4.77
Error	16	2307.66	144.23			
Total	26	85247.38				

4.3 Comparative Performance of Modified and IAR Groundnut Shelling Machines

The performance of the modified and IAR Groundnut shelling machines using groundnut crop (Bahaushiya) were compared based on the results obtained for each performance index. Both machines were evaluated with a sieve of rectangular openings. An independent t-test was employed on the basis that there were unequal number of observations for different experimental materials and the same treatments were imposed. The results compared for each performance index are shown in Appendices E_2 and E_4 for modified and IAR Groundnut shelling machines respectively.

4.3.1 Comparative shelling performance of the machines

For the groundnut shelling using modified sheller, the shelling efficiency ranges from 91.67 % to 96.00 %. However, when IAR groundnut sheller was used, the shelling efficiency ranges from 96.59 % to 98.10 %. The two set of results do not indicated a similar range and the efficiencies of the IAR groundnut shelling machine were far better than those of modified shelling machine (Fig. 4.24). The trend for IAR groundnut sheller ismore symmetrical than that of modified sheller, having the higher coefficient of determination (R^2 = 0.892) likewise the degree of increase in shelling efficiency is more pronounced with IAR groundnut sheller than modified sheller, having indicating higher gradient value (a = 1.758). An independent t-test shows that there is highly significant difference between the shelling performance of the modified machine and that of the existing one meanwhile the negative sign of the t-calculated value indicated that the performance of IAR groundnut sheller was superior (Table 4.18).Generally, the

relationship between cylinder speed and shelling efficiency shows positive linear trend for both machines.

4.3.2 Comparative cleaning performance of the machines

The cleaning efficiency of modified shelling machine using groundnut ranges from 90.94 % to 97.44 % while using IAR groundnut shelling machine, the cleaning efficiency ranges from 93.69 % to 97.19 %. The two set of results are in closed range. This signifies that both of the machines have similar cleaning performance and trends (Fig. 4.25). To justify these points, an independent t-test analysis shows that there is no significant difference between the two set of results (Table 4.18). The trend for modified sheller is more symmetrical than that of IAR groundnut sheller, though, the two trend lines yielded closed coefficient of determination of 0.987 and 0.980 for IAR and modified sheller respectively. However, the degree of increase in cleaning efficiency with the increase in cylinder speed is more pronounced with the modified sheller than IAR groundnut sheller as indicated by the difference in their gradients. Generally, the relationship between cylinder speed and cleaning efficiency shows positive linear trend for both machines.

4.3.3 Comparative machinery grain damages

The mechanically grain damage for modified shelling machine using groundnut shows a range of 12.00 % to 26.67 %. However, for groundnut shelling using IAR Groundnut sheller a range of 10.16 % to 11.93 % grain damagewas obtained. The two set of results do not indicated a similar range of percentage grains damage

likewise the trends. It could also be seen that the percentagegrains damage of the modified shelling machine were far beyond those of IAR groundnut shelling machine (Fig. 4.26). This could be due to the effects of sharp and pointed shelling teeth of the modified machine.The trend for IAR groundnut sheller is more symmetrical than that of the modified sheller, having the higher coefficient of determination (R^2 = 0.991). However, the grain damage is directly proportional to the increase in cylinder speed for modified sheller, hence a positive linear relationship with a gradient of 7.155 whilethe grain damage is inversely proportional to the increase in cylinder speed for IAR groundnut sheller, thus a negative linear relationship with a gradient of -1.275. An independent t-test shows that there is highly significant difference between the results of the machines performances meanwhile the positive sign of the t-calculated value indicated that the result favors the performance of IAR groundnut sheller (Table 4.18).

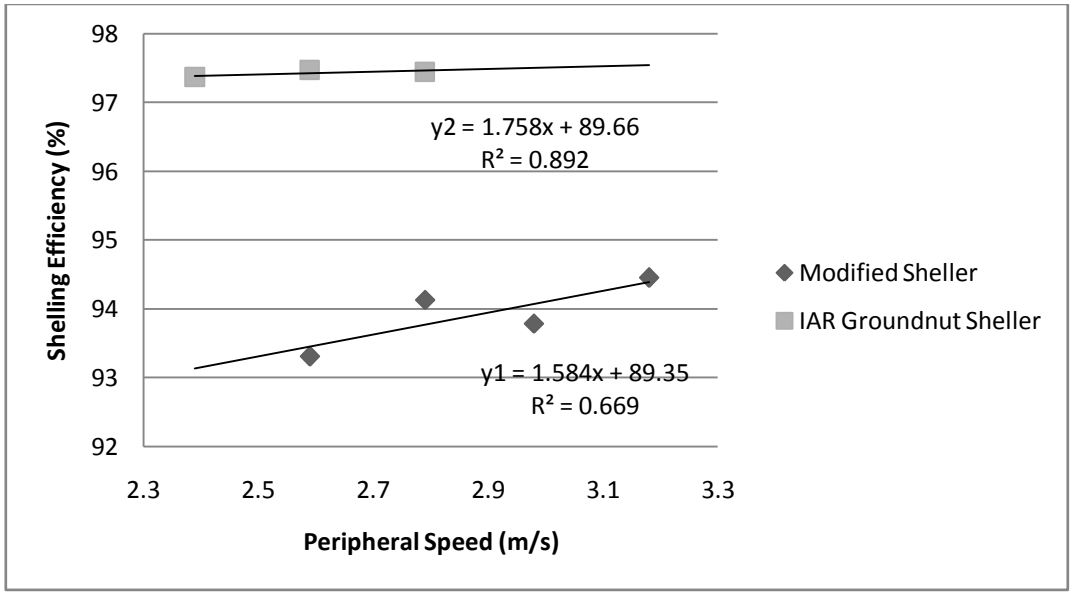


Fig. 4.24: Variation of the Shelling Efficiency with the Cylinder Speeds for the Performance of Modified and IAR Groundnut Shelling Machines

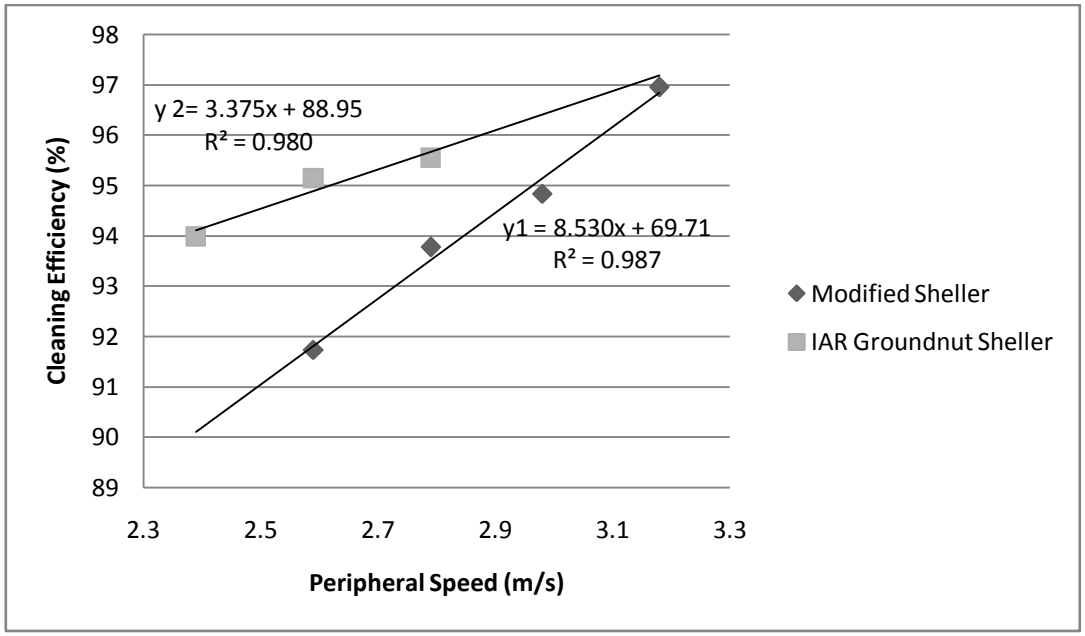


Fig. 4.25: Variation of the Cleaning Efficiency with Cylinder Speeds for the Performance of Modified and IAR Groundnut ShellingMachines

4.3.4 Comparative machinery scattered loss

The scatter loss for modified shelling machine using groundnut shows a range of 0.50 % to 7.58 %. However, for groundnut shelling using IAR Groundnut sheller a range of 0.714 % to 4.85 % grain damagewas obtained. The two set of results are in closed ranges and signifies that both of the machines have similar characteristics and trends in terms of losses (Fig. 4.27). The Figure showed that the performance of modified shelling machine is better in terms of minimum losses. The trend for modified sheller is more symmetrical than that of IAR groundnut sheller, though,

the two trend lines yielded closed coefficient of determination of 0.929 and 0.911 for modified and IAR groundnut sheller respectively. However, the degree of increase in scatter loss with the increase in cylinder speed is more with the modified than IAR groundnut sheller because of the wide margin in their gradients as 8.658 and 0.416 for the trends of modified and IAR groundnut sheller respectively. Generally, the relationship between cylinder speed and scatter loss shows positive linear trend for both machines.An independent t-test analysis shows that there is no significant difference between the two set of results (Table 4.18).

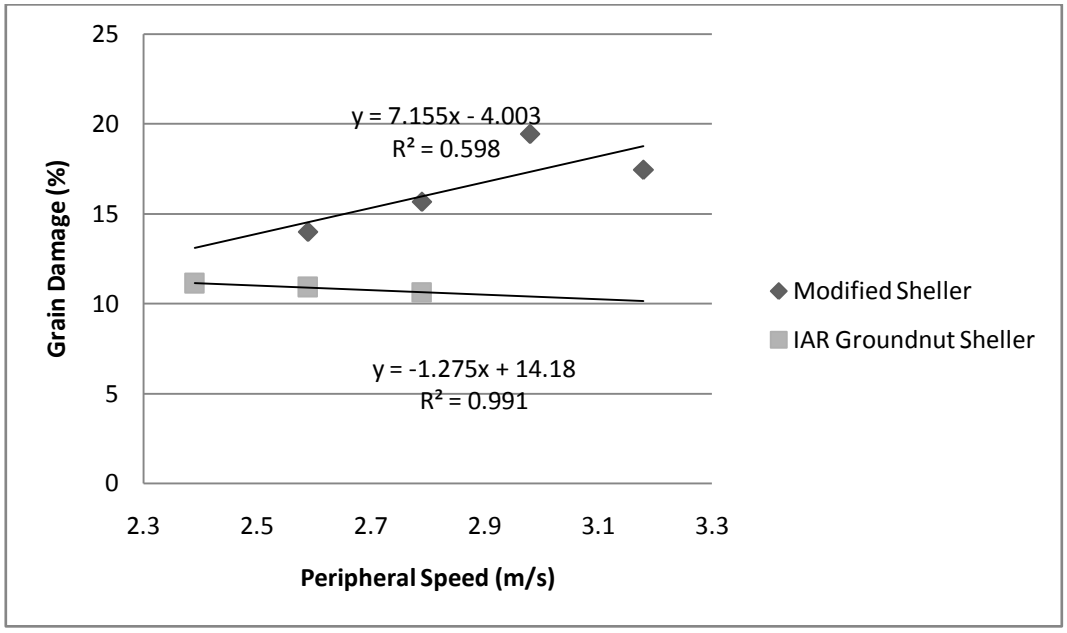


Fig. 4.26: Variation of the Grain Damage with Cylinder Speeds for the Performance of Modified and IAR GroundnutShelling Machines

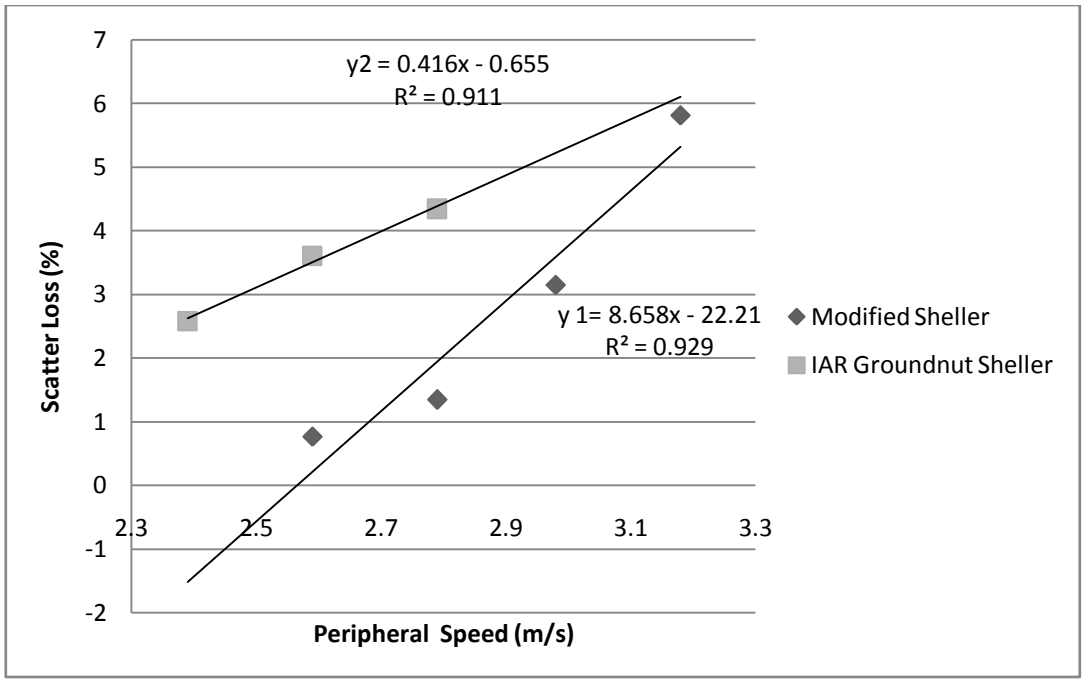


Fig. 4.27: Variation of the Scatter Loss with Cylinder Speeds for the Performance of Modified and IAR GroundnutShelling Machines

4.3.5 Comparative output capacity of the machines

The output capacity for modified shelling machine using groundnut shows a range of 211.05 kg/h to 254.99 kg/h. However, for groundnut shelling using IAR Groundnut sheller a range of 102.42 kg/hr to 154.07 kg/h output capacitywas obtained. This implies that the performance of modified shelling machine with regards to output capacity is far beyond that of IAR groundnut shelling machine (Fig. 4.28). The notable difference could be attributed to the size of the shelling chamber of the modified machine which is more than twice that of the existing IAR groundnut shelling machine. The trend for modified sheller is more symmetrical than that of IAR groundnut sheller, having the higher coefficient of determination (R^2 = 0.803). However, the output capacity is directly proportional to the increase

in cylinder speed for both machines, hence a positive linear relationship. An independent t-test shows that there is highly significant difference between the results of the machines performances (Table 4.18).

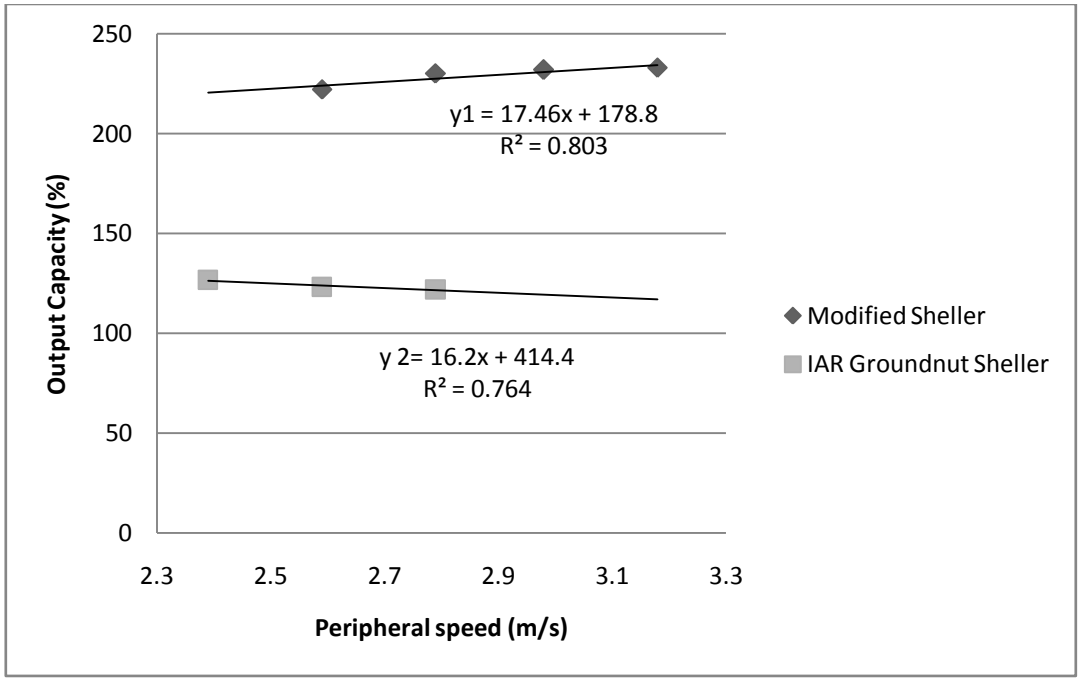


Fig. 4.28: Variation of the Output Capacity with Cylinder Speeds for the Performance of Modified and IARGroundnut Shelling Machines

Table 4.18: **An Independent t-test for the Comparison of the Performance of Modifiedand IAR Groundnut Shelling Machinery**

Indices	Machine	CF	CSS	SS	PSE	t_{ical}	t_{itab} 5%	1%
Shelling Efficiency	Modified Sheller	105853.5	105864.6	11.14	0.349	-10.46^{**}	2.093	2.861
	IAR Groundnut Sheller	85700.61	85703.35	2.737				
Cleaning Efficiency	Modified Sheller	106762.7	106813	50.30	0.759	-1.348^{NS}		
	IAR Groundnut Sheller	81818.88	81832.91	14.03				
Grain Damage	Modified Sheller	3322.675	3391.229	68.56	0.746	7.310^{**}		
	IAR Groundnut Sheller	1126.028	1128.723	2.695				
Scatter Loss	Modified Sheller	91.90868	141.3545	49.45	0.810	0.567^{NS}		
	IAR Groundnut Sheller	47.96024	68.20673	20.25				
Output Capacity	Modified Sheller	630520.0	631568.8	1048.8	7.107	14.78^{**}		
	IAR Groundnut Sheller	138848.1	141913.3	3065.2				

Where: *CF = Correction factor, CSS = Crude sum of square, SS = Sum of square, PSE = Pooled mean error*

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The basic geometric, complex geometric, and some mechanical properties of four different varieties of groundnut; SAMNUT 23, SAMNUT 24, Bahaushiya and Fararhausa, and four varieties of cowpea; SAMPEA 7, SAMPEA 8, Kanannado and Ironbean, were determined. The average ranges of the geometric mean diameters were found to be 15.53 – 16.86 mm and 20.18 – 23.38 mm for groundnut and cowpea pods respectively while those of groundnut and cowpea seeds were 8.97 – 10.22 mm and 6.60 – 8.84 mm respectively. The crops seeds lengths were classified in to small, medium and large sizes meanwhile the ranges of the classes for all varieties were determined according to the crop types. The crops varieties were also classified based on their seeds shape. The groundnut varieties; SAMNUT 23, SAMNUT 24, and Fararhausa were classified as Ellipticuswhile

Bahaushiya was classified as Oblongusin shape**.** However, the cowpea varieties; SAMPEA 7, Kanannado and Ironbean were classified asRhomboid, Ovoid and Kidney in shape respectively.

The existing IAR groundnut sheller was modified for pulse shelling and the performances of both existing and modified shelling machines were evaluated. The effects of the selected variables on the performance indices were assessed for the developed machine. Most of the performance indices increased with the increase in cylinder speed but indicated no specific pattern with the increase in feed rate and concave clearance for the evaluation of modified machine using groundnut and cowpea except damaged grain. The best performance of the modified machine using groundnut was found at speed of 3.18 m/s (160 rpm) with a feed rate of 8 kg/min and 21 mm concave clearance. These gave out the shelling efficiency, cleaning efficiency, scattered loss, damaged grains and output capacity of 94.90%, 97.22 %, 6.29 %, 14.00 % and 254.99 kg/h respectively. When using cowpea the best performance of the modified machine was found at speed of 2.79 m/s (140 rpm) with a feed rate of 12 kg/min and 10 mm concave to cylinder clearance. These gave out the shelling efficiency, cleaning efficiency, scatter loss, grain damage and output capacity of 93.24 %, 98.31 %, 0.625 %, 0.00 % and 546.18 kg/h respectively.

The comparative performance analysis was carried out for the modified machine using groundnut and cowpea and that of modified and existing machines using

groundnut. An independent t-test was employed to assess the differences between the performance indices of the machines. For the performance of the existing and modified machines, the results shows that the existing machine excel in shelling and minimum grains damage while the modified machine was superior in terms of output capacity.

5.2 Conclusion

The following conclusions were deduced from the results of this research work.

1) The properties of different crop varieties were determined and the varieties were found to have similar properties. However, the similarities in their properties facilitate the design and development of this multi crops shelling machine.

2) A pulse (modified) shelling machine was designed, developed and the performance was evaluated using groundnut and cowpea.The modified machine was able to shell different type of crops. However, the optimum performance of the modified machine using groundnut was found at a speed of 3.18 m/s (160 rpm) with a feed rate of 8 kg/min and 21 mm concave clearance. When using cowpea the optimum performance of the modified machine was found at a

speed of 2.79 m/s (140 rpm) with a feed rate of 12 kg/min and 10 mm concave clearance.

3) Comparatively the performance of the modified machine for cowpea shelling was superior tothat of groundnut shelling. For the performance of the existing and modified machines, it could be concluded that the existing machine excel in shelling efficiency and minimum grain damage while the modified machine was superior in terms of output capacity.

5.3 Recommendations

The following recommendations were drawn;

i) The shelling teeth have conical shapes with the plat, rounded and sharp edge which might increase grain damage. The teeth should rather have a dull shape to minimize grain damage.

ii) The blower fan used to blow out the stream of air with a very high pressure which increases the amount of losses during operation. The height of the fan air outlet should be increased so as to increase the volume and reduce the pressure of air stream passing across the falling materials.

iii) To facilitate mechanized cowpea shelling, the current status of the modified pulse shelling machine should be adopted and the machine should be operated using the best parameters selected.

iv) The modified pulse shelling machine should be used for groundnut shelling meant for oil extraction since it does not matter whether the grains split or not

References:

Abou El-kheir, M. M. and ShoukrA. Z., (1993).Modeling of the Action of MechanicalShellingof Peanut for Different Materials of Beater Drum, *Misr Journal of Agricultural Engineering*, 10(1): 123-135.

Abubakar,M. and Abdulkadir B. H. (2012). Design and Evaluation of Motorized andManually Operated Groundnut Shelling Machine, *International Journalof Emerging Trend inEngineering and Development*, 2(4): 673-682

Adewumi, B.A., Ademosun O.C., and Ogunlowo A.S. (2007). Design, Fabrication, andPreliminary Testing of a Thresher-cleaner for Grain Legume,*Journal of FoodScience Technology*,44(3):276-280

Akcali, I. D. and Onur G., (1990). Physical Properties of Peanut in Turkey, *AgriculturalMechanization in Asia, Africa, and Latin America*, 21(3): 55-60

Alonge, A. F., and Adegbulugbe T. A. (2005). Some Physical Properties of Groundnut,*Journal of Agricultural Engineering and Technology*, 13(1): 35-41

Ani, D. P., Umeh J. C. and WeyeE. A., (2013). Profitability and Economic Efficiency of Groundnut Production in Benue State, Nigeria, *African Journal of Food, Agriculture, Nutrition and Development*, 13(4): 8091 – 8105

ASAE, (1999). The List of Crops for Moisture Measurement- Ungrounded Grains and Seeds, *American Society of Agricultural Engineers Standards*, p: 567

Chakraborti, M., (2010). *Strength of Materials, for Engineering Degree and DiplomaStudents*, S. K. Kataria and Sons, New Delhi, p: 611-616

Chima, O. B., (2013). Factors Militating Against the Global Competitiveness of Manufacturing Firms in Nigeria,*American International Journal of Contemporary Research 3(4):54-63*

Dangora, N. D., Suleiman M. L., Mohammed U. S., (2006). Modification of IAR MaizeDehusker Sheller for Sorghum Threshing, *Proceeding of Nigerian Institution of Agricultural Engineers*, 28: 106-112

Dauda, A (2001). Design, Construction and Performance Evaluation of aManually OperatedCowpea Thresher for Small Scale Farmers in NorthernNigeria, *Agricultural Mechanization in Asia, Africa, Latin America*, 32(4):47-49.

Davies, R. M., (2009). Some Physical Properties of Groundnut Grains, *Research Journal of Applied Sciences, Engineering and Technology*, 1 (2):10 - 13

Delhagen, W., H. Shaheer, M. Rafiq, and A. Yip, (2003). A low-cost Peanut Sheller for Use in Developing Naions, Final Application for IDEAS, pp 1 - 6

Food and Agricultural Organization, (2008). Economics and Social Department: The Statistical Division,*Food and Agriculture Organization (FAO),* United Nations

Food and Agricultural Organization, (2011). Crop Statistics Concepts, Definitions, andClassifications, *Food andAgriculture Organization Statistics(FAO),* United Nations

Greater Access to Trade Expansion, (2008). A Study of the Cowpea Value Chain in Kano State, Nigeria, from a Pro-Poor and Gender Perspective,*Greater Access to TradeExpansion* (GATE)Project under the Women in Development IQC, p: 7

Gore, K. L.; GuptaC. P. and SinghC., (1990).Development of powerOperated GroundnutSheller,*Agricultural Mechanization in Asia, Africa, Latin America,* 21(3): 38-44

Hall, S. A. and Holowenko R. A., (1982), *Machine Design*, Schemes Outline Series, p:112

Helmy, M. A. (2001), Evaluation of a Reciprocating Peanut Sheller, *Agricultural Mechanizationin Asia, Africa, Latin America*, 32(4): 35-24:27

Hossain M. A. and HaqueM. A., (1999). Geometric Properties of Groundnut Kernels, *Tropical Agricultural Research and Extension*, 2 (2): 107 - 110

Huber, J. A., O Dogherty M. J., J. Dyson and C. J. Marshal, (1992), A Study of Physical andMechanical Properties of Wheat Straw, *International Conference onAgricultural Engineering*, Upp Sala

Institute for Agricultural Research, (1987). Report on Agricultural Equipment PrototypesDeveloped byAgricultural Mechanization Research Program, *Institute for Agricultural Research (IAR)*, AhmaduBello University, Zaria

Ibrahim, H. Y., Napoleon D. S., and Hassan I. I., (2010). An Evaluation of Groundnut Processingby Women in Rural Area of North Central Nigeria, *Journal ofAgricultural Science*, 2(1): 206-212

Irtwange, S. V. (2009). Design, Fabrication and Performance of a Motorized CowpeaThresherfor Nigerian Small-scale Farmers,*African Journal of Agricultural Research*, 4(12): 1383-1391

Isiaka, M., (2005). Operation and Maintenance of IAR Groundnut Shellers, *Instituteof Agricultural Research Samara Extension Bulletin*, MechanizationSeries, 1: 4-8

John, O. S. (2010).Growth and Yield Response of Groundnut to Plant Densities andPhosphoruson an Ultisol in Southeastern Nigeria,*Libyan Agriculture Research Center Journal International*, 1(4): 211-214, 2010

Joshua, H. C., (1981). Design and Selection of Threshers Parameter and Components,*Agricultural Mechanization in Asia, Africa, and Latin America*, 11(2):61-63

Karaj, S., Muller, J.,(2010). Determination of Physical, Mechanical and Chemical Properties of Seeds and Kernels of Jatropha Curcas L., *Industrial Crops and Production, ELSEVIER*, pp 1 - 10

Kittichai, T. (1984).Development and Test of a Power-operated Groundnut Sheller,M. Eng Thesis No AE-84-11, *Asian Institute of Technology, Bangkok*

Khurmi, R.S.and J.K.Gupta (2007). *Machine Design*, 14th Edition, Eurasian Ltd, RanNagar, New Delhi, p: 1230

Maduako, J. N. and Hannan M. (2004). Determination of Some Physical Properties of threeGroundnut Varieties, *Nigerian Journal of Technology*, 24(2): 12-18

Maduako J. N., Saidu M., Matthias P., and I. Vanke, (2006). Testing of an Engine PoweredGroundnut Shelling Machine, *Journal of Agricultural Engineering and Technology*, 14: 29-37

Maunde, F.A. (2011). Performance Evaluation of Manual Cowpea Thresher, *African Journal of Agricultural Research*, 6 (30): 6412 – 6415

Mazhar, K., Bahadır, S., Erdal E., I. Ozturk, T. B. Ozmen, (2013). Seed Size and ShapeAnalysis of Registered Common Bean Cultivars in Turkey Using Digital Photography,*Journal of Agricultural Sciences*, 19 (2013): 219 - 234

Mohammed, J. (2009). Development of a Maize Dehusker Thresher, an UnpublishedMaster Degree Thesis Submitted to the Department of Agricultural Engineering,Ahmadu Bello University, Zaria, Nigeria

Mulleriyawa, R. (2008). Multi-grain Threshing Machine Helps Solve ManyFarmer Problems, *Features*, the Island, Monday 11th August. P 4

Olaoye, J. O. (2002). Performance Modeling of a Multipurpose CropThreshing MachineforAssessment of Grain Loss, Being anaspect of the research findings for the1997 senateresearchgrant, at University of Ilorin, Ilorin, Nigeria

Olaoye, J O. (2004). An Analytical Modeling of the Performance ofTooth Peg GrainCrop Thresher, PhD Dissertation, Department of Agricultural Engineering and Biosystems, University of Ilorin, Nigeria

Olaoye, J O. (1998), Evaluation of the Physical Characteristics of a Castor Nut in Nigeria, In:*Proceedings of the 2nd National Engineering conference*, A Conference organized by the School of Engineering, Kaduna Polytechnic, Kaduna, Nigeria, 5(1): 13 –20

Ozturk, I., M. Kara, Elkoca E., and Ercisli S., (2009). Physico-Chemical Grain Properties of New Common Bean cv. 'Elkoca-05', *Scientific Research and Essay*, 4 (2): 88 – 93

Pradhan, R. C., P. P. Said, S. Singh, (2013). Physical Properties of Bottle Gourd Seeds, *Agric Engineering International: CIGR Journal*, 15(1): 106－113

Renuka, B. (2007), Ergonomic Evaluation of Harvest and Post HarvestActivities Performed byFemale Laborers in Sorghum Crop with Agricultural Tools, a PhD Dissertation of the Department of Family Resource Management, College of Rural Home Science, Dharwad University of Agricultural Sciences, Dharwad –580005

Rowland, J. R. J., (1993). Dry Land Farming in Africa, *Macmillan Press LTD*, London and Basingstoke, p: 271 – 275

Saeeid, F., M. Naghi, S. Vishgaei, and B. Kaviani, (2009). Some physical Properties of Groundnut Kernel cv. NC2 as a Function of Moisture Content, *American -Eurasian Journal of Agricultural and Environmental Sciences*, 6 (6):675 - 679

Sanjay, K. (2010). A Numerical Approach in Agricultural Engineering with Objective, NET,GATE, and ARS Digest, Kalyani Publishers, New Delhi, 110002, p: 247-256

Sharma, C. S. and Kamlesh P., (2006), Theory of Mechanisms and Machines, Prentice hall of India private limited, p: 184-241

Singh, G. (1993).Development of a Unique Groundnut Decorticator, *Agricultura l Mechanization in Asia, Africa, and Latin America*,24(1): 55-64.

Smith, D. W., Sims B. G., O'Neill D. H., (1994). *Testing and Evaluation of AgriculturalMachinery and Equipment – Principles and Practices*, Overseas Division, SilsoeResearch Institute, United Kingdom, p 67-74

Taru, V. B., Kyagya I. Z., Mshelia S. I. and AdebayoE. I., (2008). Economic EfficiencyofRecourse Used in Groundnut Production in Adamawa State of Nigeria, *WorldJournal of Agricultural Science,* 4(5):896-900

U.S. Department of Agriculture, (2009). Agricultural Marketing ServiceScience and TechnologyPlant Variety Protection, S.W., Washington, *Exhibit C*, pp 1 - 3

Young, C.T. and Ahmed E. H. (1982). Composition, Nutrition, and Flavors of Peanuts,*Peanut science and technology*,Yoakum,TX, USA: APRES, p: 655–688

Younis, S. M., Abdel-Mawla H. A.and FaragH. A., (1997).Developmentof PeanutSheller, *Misr Journal of Agricultural Engineering,* 14(1): 106-117

Yusuf D. D., (2011). Role and Challenges of Agricultural Mechanization in Meeting theNeeds of Tomorrows Agriculture in Nigeria, *Proceedings of*

the 11th International Conference and Annual General Meeting of Nigerian Institution of Agricultural Engineer, Ilorin, Nigeria, 32: 13 – 42

Appendices:

Appendix A: **Power Requirement for Shelling of Crop Varieties**

Crops/varieties	**Power required**	
	(kW)	**(hp)**
SAMNUT 23	0.3214	0.437
SAMNUT 24	0.3845	0.523
BAHAUSHIYA	0.3455	0.470
FARAR HAUSA	0.3524	0.479
SAMPEA 7	0.1983	0.270
SAMPEA	0.2753	0.369
KANANNADO	0.3870	0.526
IRONBEAN	0.3675	0.500

Appendix B_1: A Layout of 4x3x3 Factorial Experiment Involving Four CylinderSpeeds (S_1, S_2, S_3, S_4), Three Feed Rates (F_1, F_2, F_3) and Three Concave toCylinder Clearances (C_1, C_2, C_3) Arranged in a Randomized CompleteBlock Design (RCBD), with Three Replications for Groundnut Shelling

$C_1S_1F_1$	$C_1S_2F_2$	$C_1S_3F_3$	$C_2S_1F_1$	$C_2S_2F_2$	$C_2S_3F_3$	$C_3S_1F_1$	$C_3S_2F_2$	$C_3S_3F_3$
$C_1S_2F_2$	$C_1S_3F_3$	$C_1S_4F_3$	$C_2S_2F_2$	$C_2S_3F_3$	$C_2S_4F_3$	$C_3S_2F_2$	$C_3S_3F_3$	$C_3S_4F_3$
$C_1S_3F_3$	$C_1S_4F_2$	$C_1S_1F_1$	$C_2S_3F_3$	$C_2S_4F_2$	$C_2S_1F_1$	$C_3S_3F_3$	$C_3S_4F_2$	$C_3S_1F_1$
$C_1S_4F_1$	$C_1S_1F_1$	$C_1S_2F_2$	$C_2S_4F_1$	$C_2S_1F_1$	$C_2S_2F_2$	$C_3S_4F_1$	$C_3S_1F_1$	$C_3S_2F_2$

RI

$C_1S_1F_1$	$C_1S_2F_2$	$C_1S_3F_3$	$C_2S_1F_1$	$C_2S_2F_2$	$C_2S_3F_3$	$C_3S_1F_1$	$C_3S_2F_2$	$C_3S_3F_3$
$C_1S_2F_2$	$C_1S_3F_3$	$C_1S_4F_3$	$C_2S_2F_2$	$C_2S_3F_3$	$C_2S_4F_3$	$C_3S_2F_2$	$C_3S_3F_3$	$C_3S_4F_3$
$C_1S_3F_3$	$C_1S_4F_2$	$C_1S_1F_1$	$C_2S_3F_3$	$C_2S_4F_2$	$C_2S_1F_1$	$C_3S_3F_3$	$C_3S_4F_2$	$C_3S_1F_1$
$C_1S_4F_1$	$C_1S_1F_1$	$C_1S_2F_2$	$C_2S_4F_1$	$C_2S_1F_1$	$C_2S_2F_2$	$C_3S_4F_1$	$C_3S_1F_1$	$C_3S_2F_2$

RII

$C_1S_1F_1$	$C_1S_2F_2$	$C_1S_3F_3$	$C_2S_1F_1$	$C_2S_2F_2$	$C_2S_3F_3$	$C_3S_1F_1$	$C_3S_2F_2$	$C_3S_3F_3$
$C_1S_2F_2$	$C_1S_3F_3$	$C_1S_4F_3$	$C_2S_2F_2$	$C_2S_3F_3$	$C_2S_4F_3$	$C_3S_2F_2$	$C_3S_3F_3$	$C_3S_4F_3$
$C_1S_3F_3$	$C_1S_4F_2$	$C_1S_1F_1$	$C_2S_3F_3$	$C_2S_4F_2$	$C_2S_1F_1$	$C_3S_3F_3$	$C_3S_4F_2$	$C_3S_1F_1$
$C_1S_4F_1$	$C_1S_1F_1$	$C_1S_2F_2$	$C_2S_4F_1$	$C_2S_1F_1$	$C_2S_2F_2$	$C_3S_4F_1$	$C_3S_1F_1$	$C_3S_2F_2$

RIII

Appendix B_2:A Layout of 3x3 Factorial Experiment Involving Three Cylinder Speeds (S_1, S_2, S_3) and Three Feed Rates (F_1, F_2, F_3) Arranged in a Randomized Complete Block Design (RCBD), with Three Replications for Cowpea Shelling

$R_1S_1F_1$	$R_1S_2F_3$	$R_1S_3F_2$	$R_2S_1F_1$	$R_2S_2F_3$	$R_2S_3F_2$	$R_3S_1F_1$	$R_3S_2F_3$	$R_3S_3F_2$
$R_1S_2F_2$	$R_1S_3F_1$	$R_1S_1F_3$	$R_2S_2F_2$	$R_2S_3F_1$	$R_2S_1F_3$	$R_3S_2F_2$	$R_3S_3F_1$	$R_3S_1F_3$
$R_1S_3F_3$	$R_1S_1F_2$	$R_1S_2F_1$	$R_2S_3F_3$	$R_2S_1F_2$	$R_2S_2F_1$	$R_3S_3F_3$	$R_3S_1F_2$	$R_3S_2F_1$

Appendix C_1: An Outline of the Analysis of Variance (ANOVA) for 4x3x3 Factorial Experiments in Randomized Complete Block Design (RCBD) for Groundnut Shelling

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	Computed F	Tabulated F	
					5%	1%
Replication (R)	(r-1) = 2					
Feed rate (F)	(f-1) = 2					
Cylinder speed (S)	(s-1) = 3					
Concave clearance (C)	(c-1) = 2					

F*S	(f-1)(s-1) = 6					
F*C	(f-1)(c-1) = 4					
S*C	(s-1) (c-1) = 6					
F*S*C	(f-1)(s-1)(c-1) = 12					
Error	(r-1)(fsc-1) = 70					
Total	(rfsc-1) = 107					

Appendix C_2: An Outline of the Analysis of Variance (ANOVA) for 3x3 Factorial Experiments in Randomized Complete Block Design (RCBD) forCowpea Shelling

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	Computed F	Tabulated F	
					5%	1%
Replication (R)	(r-1) = 2					
Feed rate (F)	(f-1) = 2					
Cylinder speed (S)	(s-1) = 2					
F*S	(f-1)(s-1) = 4					
Error	(r-1)(fs-1) = 16					
Total	(rfs-1) = 26					

Appendix D_1: Average Experimental Data for the Evaluation of Modified Pulse ShellerusingGroundnut

S/N	TRTM	CRC	SPD	FDRT (kg/min)	T (s)	W_C (kg)	Q_G (kg)	Q_U (kg)	W_S (kg)	Q_D (g)	Q_{CF} (kg)	Q_g (kg)
1	S1F1C1	19	2.59	8	35.33	2.687	2.107	0.136	0.048	18.00	0.167	2.291
2	S1F2C1	19	2.59	10	45.67	3.086	2.650	0.202	0.041	16.67	0.184	2.893
3	S1F3C1	19	2.59	12	58.67	3.600	3.190	0.215	0.054	20.00	0.261	3.459
4	S2F1C1	19	2.79	8	35.67	2.439	1.967	0.170	0.061	12.00	0.111	2.198
5	S2F2C1	19	2.79	10	46.67	2.856	2.737	0.144	0.036	15.00	0.197	2.916
6	S2F3C1	19	2.79	12	56.00	3.640	3.247	0.144	0.050	14.33	0.228	3.440
7	S3F1C1	19	2.98	8	35.33	2.153	2.047	0.170	0.083	18.67	0.084	2.300
8	S3F2C1	19	2.98	10	45.33	2.802	2.510	0.130	0.110	21.00	0.117	2.750
9	S3F3C1	19	2.98	12	59.00	3.843	3.410	0.194	0.109	26.67	0.229	3.713
10	S4F1C1	19	3.18	8	34.33	2.151	2.057	0.124	0.178	18.33	0.077	2.358
11	S4F2C1	19	3.18	10	45.67	2.768	2.457	0.137	0.157	22.67	0.075	2.751
12	S4F3C1	19	3.18	12	58.33	3.647	3.260	0.157	0.226	22.33	0.126	3.643
13	S1F1C2	21	2.59	8	36.33	2.426	2.100	0.148	0.041	14.67	0.163	2.290
14	S1F2C2	21	2.59	10	47.00	3.046	2.767	0.196	0.023	20.33	0.221	2.985
15	S1F3C2	21	2.59	12	56.67	4.080	3.430	0.234	0.025	16.67	0.287	3.689
16	S2F1C2	21	2.79	8	35.33	2.257	2.133	0.184	0.042	16.33	0.134	2.359
17	S2F2C2	21	2.79	10	45.67	2.956	2.643	0.168	0.034	12.00	0.189	2.845
18	S2F3C2	21	2.79	12	53.67	3.880	2.937	0.182	0.052	21.00	0.247	3.170
19	S3F1C2	21	2.98	8	35.33	2.439	2.233	0.130	0.055	18.67	0.110	2.418
20	S3F2C2	21	2.98	10	45.33	2.965	2.672	0.155	0.096	15.67	0.142	2.923

21	S3F3C2	21	2.98	12	56.00	3.377	3.029	0.129	0.124	18.33	0.149	3.283
22	S4F1C2	21	3.18	8	33.67	2.294	2.093	0.130	0.161	14.00	0.064	2.385
23	S4F2C2	21	3.18	10	45.67	2.718	2.491	0.142	0.144	17.67	0.102	2.777
24	S4F3C2	21	3.18	12	57.00	3.497	3.143	0.162	0.195	17.33	0.139	3.500
25	S1F1C3	23	2.59	8	36.67	2.438	2.097	0.139	0.025	15.00	0.194	2.261
26	S1F2C3	23	2.59	10	47.33	3.202	2.738	0.197	0.019	13.67	0.249	2.954
27	S1F3C3	23	2.59	12	57.33	3.833	3.237	0.241	0.017	13.33	0.347	3.494
28	S2F1C3	23	2.79	8	34.33	2.353	2.067	0.144	0.043	13.67	0.146	2.253
29	S2F2C3	23	2.79	10	47.67	3.362	2.949	0.156	0.029	15.67	0.216	3.134
30	S2F3C3	23	2.79	12	55.33	3.747	3.110	0.197	0.038	17.67	0.227	3.344
31	S3F1C3	23	2.98	8	32.67	2.104	1.947	0.189	0.074	17.67	0.069	2.210
32	S3F2C3	23	2.98	10	45.33	2.923	2.693	0.149	0.075	19.00	0.157	2.917
33	S3F3C3	23	2.98	12	56.00	3.719	3.130	0.175	0.122	21.67	0.254	3.427
34	S4F1C3	23	3.18	8	32.00	2.124	1.920	0.124	0.146	17.33	0.054	2.190
35	S4F2C3	23	3.18	10	45.67	2.784	2.487	0.170	0.160	16.67	0.084	2.817
36	S4F3C3	23	3.18	12	54.67	3.583	3.163	0.163	0.168	18.33	0.128	3.494

Appendix D_2: Average Experimental Data for the Evaluation of Modified Pulse Sheller using Cowpea

S/N	TRTM	CRC (mm)	SPD (m/s)	FDRT (kg/min)	T (s)	W_C (kg)	Q_G (kg)	Q_U (kg)	W_S (kg)	Q_D (kg)	Q_{CF} (kg)	Q_g (kg)
1	S_1F_1	10	2.39	12	21.33	1.820	1.650	0.120	0.0073	0.000	0.040	1.777
2	S_1F_2	10	2.39	15	29.33	2.800	2.500	0.193	0.0047	0.000	0.067	2.698
3	S_1F_3	10	2.39	18	44.00	3.520	3.170	0.207	0.0060	0.000	0.107	3.383
4	S2F1	10	2.59	12	15.33	1.690	1.547	0.133	0.0097	0.000	0.030	1.690
5	S2F2	10	2.59	15	23.33	3.090	2.833	0.163	0.0060	0.000	0.063	3.003
6	S2F3	10	2.59	18	34.33	3.497	3.160	0.200	0.0080	0.000	0.077	3.368
7	S3F1	10	2.79	12	13.00	1.977	1.827	0.133	0.0123	0.000	0.033	1.972
8	S3F2	10	2.79	15	20.67	2.793	2.520	0.133	0.0083	0.000	0.087	2.662
9	S3F3	10	2.79	18	34.00	3.567	3.343	0.150	0.0220	0.000	0.060	3.515

Where: *Q_D = Quantity of damaged groundnut in sample (kg), Q_g = Total quantity of grains collected per unit time (kg), Q_G = Quantity of shelled groundnut (kg), Q_L = Quantity of scattered, damaged, andunshelled grains (kg), Q_T = Total quantity of groundnut sample (kg), Q_U = Quantity of unshelled groundnut (kg), T = total time of shelling (hr), W_C = Weight of whole materials collected at the outlet (kg), W_S = Weight of scattered groundnut (kg), Q_{CF} = Quantity chaffs collected at the grains outlet (kg*

Appendix D_3: Average Experimental Data for the Evaluation of IAR Groundnut Sheller

S/N	TRTM	CRC (mm)	SPD (m/s)	FDRT (kg/min)	T (s)	W_C (kg)	Q_G (kg)	Q_U (kg)	W_S (kg)	Q_D (g)	Q_{CF} (kg)	Q_g (kg)
1	S1F1R3	23	2.59	4	71.00	2.140	1.960	0.040	0.0200	11.337	0.133	2.020
2	S1F2R3	23	2.59	5	80.33	3.063	2.700	0.080	0.0200	11.560	0.193	2.800
3	S1F3R3	23	2.59	6	91.00	3.653	3.400	0.067	0.0400	11.933	0.220	3.507
4	S2F1R3	23	2.79	4	64.33	2.047	1.880	0.040	0.0400	10.803	0.080	1.960
5	S2F2R3	23	2.79	5	75.00	2.640	2.420	0.087	0.0333	11.333	0.113	2.540
6	S2F3R3	23	2.79	6	89.33	3.977	3.690	0.073	0.0600	11.870	0.193	3.823
7	S3F1R3	23	2.98	4	71.00	2.007	1.887	0.053	0.1000	10.160	0.060	2.040
8	S3F2R3	23	2.98	5	82.67	3.563	2.373	0.080	0.1133	10.693	0.100	2.567
9	S3F3R3	23	2.98	6	88.67	3.737	3.490	0.073	0.1400	10.980	0.167	3.703

Appendix E_1:Average Calculated Data for the Preliminary Performance Evaluation of the IARGroundnut Shelling Machine

S/N	TRMT	Speed (rpm)	FDRT (kg/min)	C_P (kg/h)	S_e (%)	C_e (%)	M_d (%)	S_L (%)
1	S_1F_1	120	2	51.44	94.75	89.35	1.92	0.44
2	S_1F_2	120	3	64.50	96.94	92.65	2.44	0.58
3	S_1F_3	120	4	56.83	97.70	93.87	2.66	0.40
4	S_2F_1	140	2	64.94	95.57	90.60	1.82	0.90
5	S_2F_2	140	3	70.17	96.84	92.97	1.68	0.83
6	S_2F_3	140	4	76.48	97.32	94.02	1.96	0.73
7	S_3F_1	160	2	63.58	97.05	90.79	1.46	3.04
8	S_3F_2	160	3	76.73	97.33	95.93	1.66	2.21
9	S_3F_3	160	4	75.04	97.92	94.79	1.21	2.06

Where: TRMT = treatment, FDRT = Feed Rate, C_P = Output Capacity, S_e = Shelling efficiency, C_e= Cleaning efficiency, M_d = Damaged grains, S_L = Scatter loss

Appendix E_2: Average Calculated Data for the Evaluation of Modified Pulse Sheller usingGroundnut

S/N	TRTM	CRC (mm)	SPD (m/s)	FDR (kg/min)	Se (%)	Ce (%)	M_d (%)	S_L (%)	C_p (kg/h)
1	S1F1C1	19	2.59	8	93.87	93.77	18.00	2.18	233.42
2	S1F2C1	19	2.59	10	92.84	94.05	16.67	1.47	228.06
3	S1F3C1	19	2.59	12	93.59	92.76	20.00	1.61	212.26
4	S2F1C1	19	2.79	8	92.01	95.44	12.00	2.86	221.85
5	S2F2C1	19	2.79	10	94.69	93.10	15.00	1.32	224.95
6	S2F3C1	19	2.79	12	95.92	93.73	14.33	1.41	221.14
7	S3F1C1	19	2.98	8	92.61	96.11	18.67	3.58	234.31
8	S3F2C1	19	2.98	10	95.17	95.82	21.00	4.06	218.38
9	S3F3C1	19	2.98	12	94.86	94.03	26.67	2.90	226.56
10	S4F1C1	19	3.18	8	94.73	96.42	18.33	7.58	247.28
11	S4F2C1	19	3.18	10	94.87	97.29	22.67	5.87	216.87
12	S4F3C1	19	3.18	12	95.71	96.54	22.33	6.17	224.83
13	S1F1C2	21	2.59	8	93.37	93.29	14.67	1.85	226.87
14	S1F2C2	21	2.59	10	93.80	92.76	20.33	0.72	228.66
15	S1F3C2	21	2.59	12	93.44	92.96	16.67	0.69	234.34
16	S2F1C2	21	2.79	8	92.26	94.08	16.33	1.76	240.32
17	S2F2C2	21	2.79	10	94.23	93.59	12.00	1.15	224.30
18	S2F3C2	21	2.79	12	93.54	93.63	21.00	1.84	212.65
19	S3F1C2	21	2.98	8	94.78	95.48	18.67	2.22	246.36
20	S3F2C2	21	2.98	10	94.88	95.22	15.67	3.16	232.09
21	S3F3C2	21	2.98	12	96.00	95.58	18.33	3.85	211.05
22	S4F1C2	21	3.18	8	94.90	97.22	14.00	6.29	254.99
23	S4F2C2	21	3.18	10	94.88	96.26	17.67	5.22	218.94
24	S4F3C2	21	3.18	12	95.41	96.02	17.33	5.53	221.05
25	S1F1C3	23	2.59	8	93.63	92.06	15.00	1.15	221.96
26	S1F2C3	23	2.59	10	93.44	92.21	13.67	0.63	224.67
27	S1F3C3	23	2.59	12	92.86	90.94	13.33	0.50	219.41
28	S2F1C3	23	2.79	8	93.56	93.81	13.67	1.93	236.27
29	S2F2C3	23	2.79	10	94.83	93.58	15.67	0.95	236.69
30	S2F3C3	23	2.79	12	94.01	93.93	17.67	1.15	217.58
31	S3F1C3	23	2.98	8	91.67	96.70	17.67	3.27	243.59
32	S3F2C3	23	2.98	10	94.94	94.63	19.00	2.53	231.67
33	S3F3C3	23	2.98	12	94.75	93.17	21.67	3.65	220.29
34	S4F1C3	23	3.18	8	94.37	97.44	17.33	6.66	246.38
35	S4F2C3	23	3.18	10	93.76	96.99	16.67	5.87	222.10
36	S4F3C3	23	3.18	12	95.23	96.42	18.33	4.92	230.07

Appendix E_3: Average Calculated Data for the Evaluation of Pulse Sheller using Cowpea

S/N	TRTM	CRC (mm)	SPD (m/s)	FDRT (kg/min)	S_e (%)	C_e (%)	G_s (%)	S_L (%)	C_p (Kg/h)
1	S1F1	10	2.39	12	93.25	97.80	0.000	0.413	299.93
2	S1F2	10	2.39	15	92.75	97.62	0.000	0.175	331.12
3	S1F3	10	2.39	18	93.84	96.97	0.000	0.179	276.76
4	S2F1	10	2.59	12	92.29	98.22	0.000	0.559	396.70
5	S2F2	10	2.59	15	94.51	97.95	0.000	0.202	463.27
6	S2F3	10	2.59	18	94.06	97.81	0.000	0.238	353.15
7	S3F1	10	2.79	12	93.24	98.31	0.000	0.625	546.18
8	S3F2	10	2.79	15	94.93	96.90	0.000	0.317	463.65
9	S3F3	10	2.79	18	95.75	98.32	0.000	0.623	372.21

Appendix E_4:Average Calculated Data for the Performance Evaluation of the IAR Groundnut Shelling Machine

S/N	TRTM	CRC (mm)	SPD (m/s)	FDRT (kg/min)	S_e (%)	C_e (%)	M_d (%)	S_L (%)	C_p (kg/h)
1	S1F1	23	2.59	4	98.02	93.77	11.337	0.990	102.42
2	S1F2	23	2.59	5	97.14	93.69	11.560	0.714	125.48
3	S1F3	23	2.59	6	98.10	93.98	11.933	1.140	138.73
4	S2F1	23	2.79	4	97.96	96.09	10.803	2.041	109.68
5	S2F2	23	2.79	5	96.59	95.71	11.333	1.312	121.92
6	S2F3	23	2.79	6	98.10	95.14	11.870	1.558	154.07
7	S3F1	23	2.98	4	97.41	97.01	10.160	4.854	103.44
8	S3F2	23	2.98	5	96.90	97.19	10.693	4.393	111.77
9	S3F3	23	2.98	6	98.02	95.54	10.980	3.774	150.36

Where: *TRMT = treatment, FDRT = Feed Rate, C_P = Output Capacity, S_e = Shelling efficiency, C_e = Cleaning efficiency, M_d = Damaged grains, S_L = Scatter loss*

Appendix F_1: Operation Parameters Ranks based on Fisher's Least Significant Difference (LSD) Method for the Modified Machine using Groundnut

Machine	Pulse shelling machine											
Operation parameters	S_e(%)		C_e(%)			G_s(%)			S_L (%)			C_P (kg/h)
Performance indices	Speed	FDRT	Speed	FDRT	CRC	Speed	FDRT	CRC	Speed	FDRT	CRC	FDRT
Ranks	S_4^a	F_3^a	S_4^a	F_1^a	C_1^a	S_4^a	F_1^a	C_1^a	S_4^a	F_1^a	C_1^a	F_1^a
	S_3^{ab}	F_2^{ab}	S_3^b	F_2^b	C_2^b	S_3^b	F_2^b	C_2^{ab}	S_3^b	F_3^{ab}	C_2^{ab}	F_3^{ab}
	S_2^{bc}	F_1^b	S_2^c	F_3^c	C_3^c	S_2^c	F_3^c	C_3^c	S_2^c	F_2^{bc}	C_3^{bc}	F_2^{bc}
	S_1^c		S_1^d			S_1^d			S_1^{cd}			

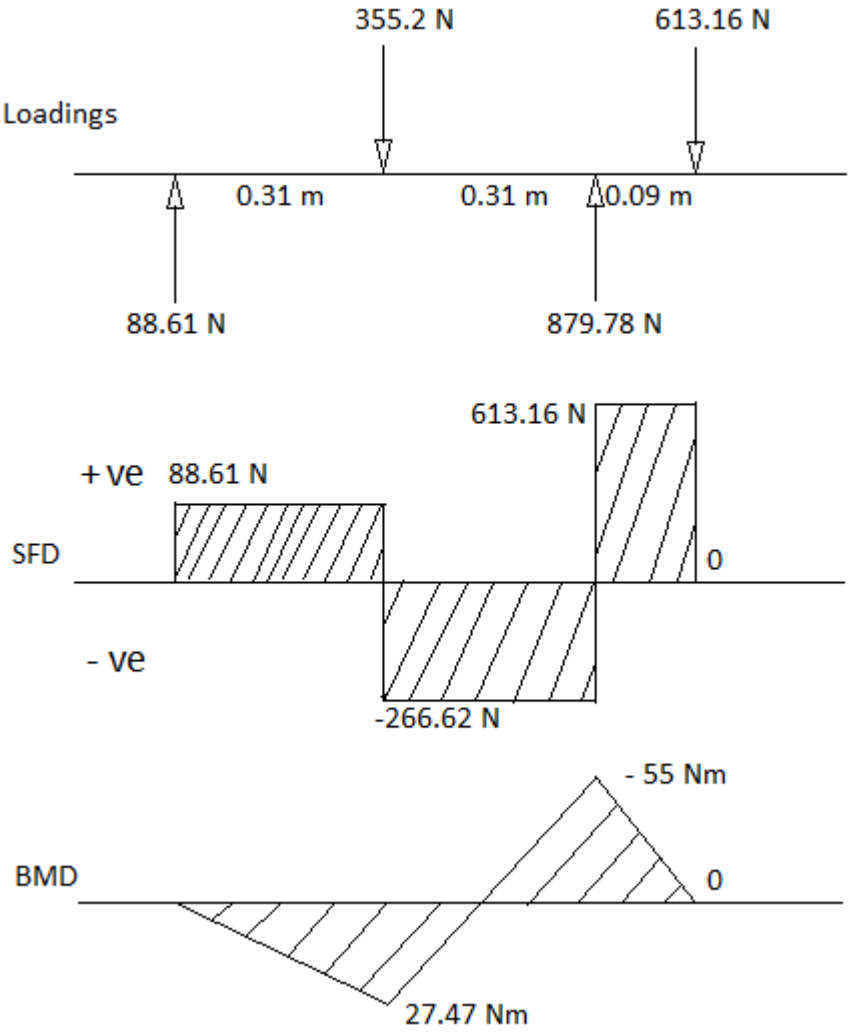
Where: *FDRT = Feed rate, CRC = Concave to cylinder clearance*

Appendix F_2:Operation Parameters Ranks based on Fisher's Least Significant Difference (LSD) Method for Modified and IAR Groundnut Shelling Machines

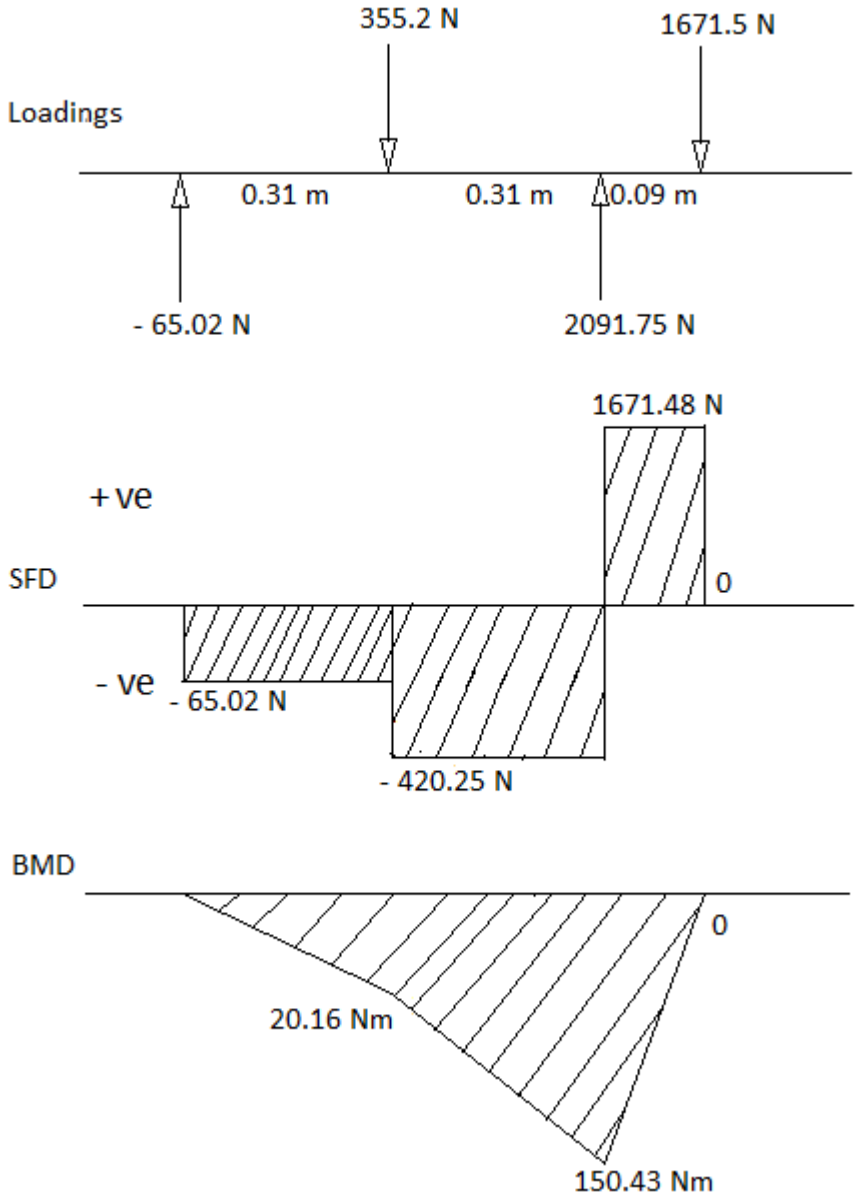
Machine	Pulse shelling machine - Cowpea				IAR groundnut shelling machine - Groundnut					
Operation parameters	S_e(%)		C_p (kg/h)		S_e(%)	C_e (%)		S_L(%)	C_P(kg/h)	
Performance indices	Speed	FDRT	Speed	FDRT	FDRT	Speed	FDRT	Speed	Speed	FDRT
Ranks	S_3^a	F_1^a	S_3^a	F_2^a	F_1^a	S_3^a	F_1^a	S_3^a	S_2^a	F_3^a
	S_2^b	F_3^{ab}	S_2^b	F_1^b	F_3^{ab}	S_2^{ab}	F_2^{ab}	S_2^b	S_1^{ab}	F_2^b
	S_1^{bc}	F_2^b	S_1^c	F_3^c	F_2^c	S_1^c	F_3^{bc}	S_1^{bc}	S_3^{bc}	F_1^c

Where: *FDRT = Feed rate, CRC = Concave to cylinder clearance*

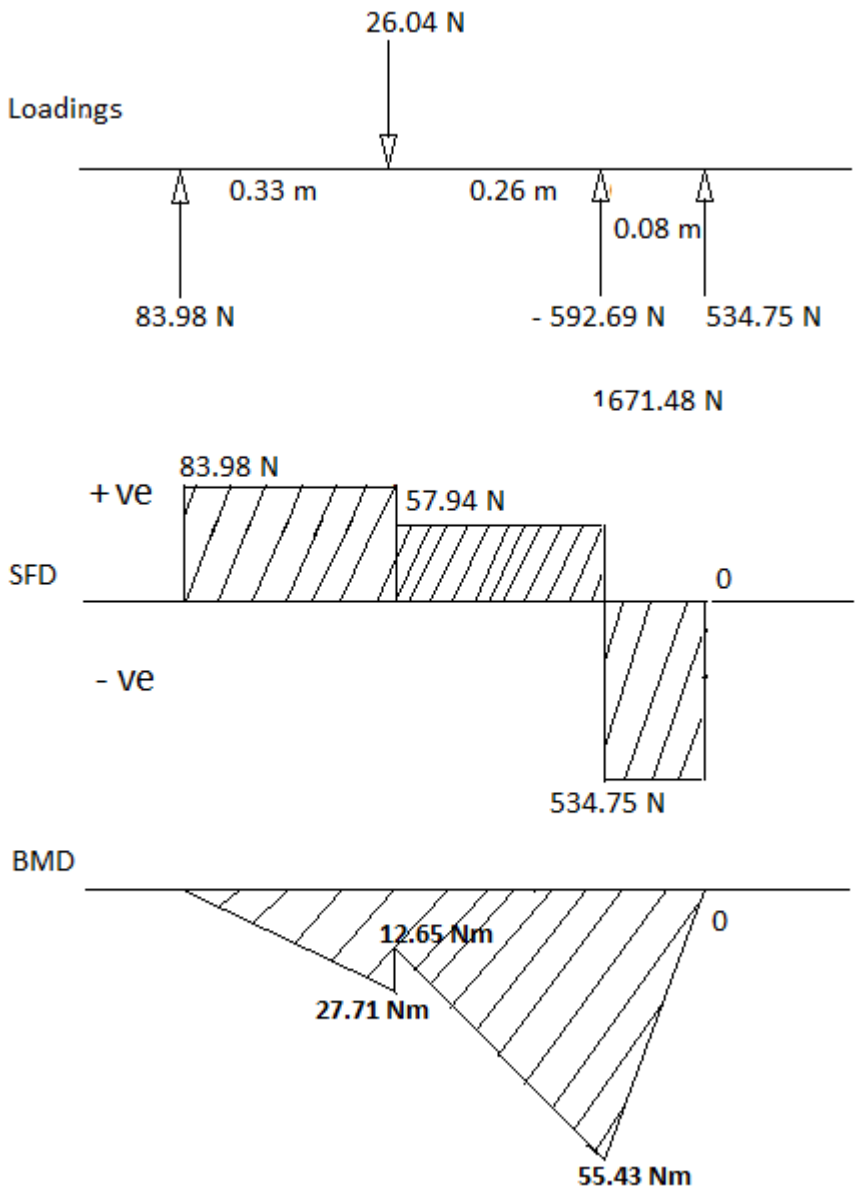
Appendix G_1: Bending Moment and Shear Force Diagram for the Vertical Loadings on the Cylinder Shaft



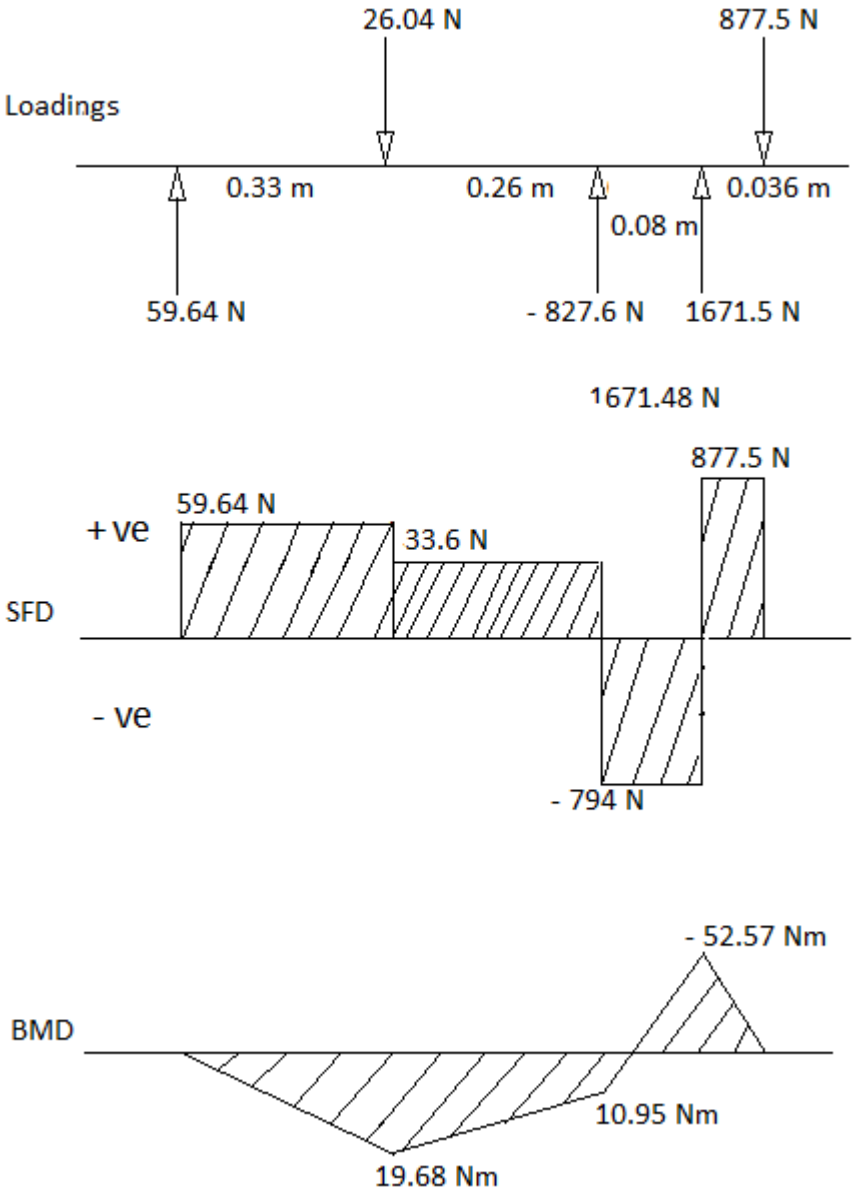
Appendix G_2: Bending Moment and Shear Force Diagram for the Horizontal Loadingson the Cylinder Shaft



Appendix G_3: Bending Moment and Shear Force Diagram for the Vertical Loadings on the Fan Shaft

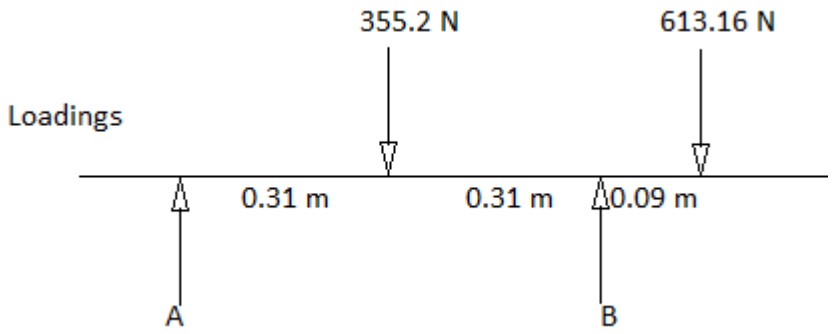


Appendix G_4: Bending Moment and Shear Force Diagram for the Horizontal Loadings on the Cylinder Shaft



Appendix G_5: Some Design Calculations

Calculation of the cylinder shaft bending moment



Calculation of the reactions

Sum of the forces equals to zero

A + B = 355.2 + 613.16

A + B = 968.36 …… (1)

Taking moment about A

0.62B = 355.2 x 0.31 + 613.16 x 0.71 …… (2)

B = 879.76 N

A = 968.36 – 879.76 = 88.59 N

From the diagram when substituting the values of A and B

Shear force calculation

88.59 – 355.2 = - 266.59 N

- 266.59 + 879.76 = 613.17 N

Bending moment calculation

88.59 x 0.31 = 27.46 Nm

27.46 – (266.59 x 031) = - 55.2 Nm

- 55.2 + (613.16 x 0.09) = 0.005 Nm which is approximately zero

Appendix H: Cost Estimate for the Production ofModified Pulse Shelling Machine

S/N	Materials	Quantity	Rate (#)	Amount (#)
1	Sheet metal (5 mm)	1/8 sheet	1,000	1,000
2	Angle iron (2 in)	4 length	2,800	11,200
3	Angle iron (1.5 in)	1 length	1,500	1,500
4	Shaft (30 mm)	1m	5,000	5,000
5	Shaft (25 mm)	1m	3,000	3,000
6	Flat bar (1.5 in)	1 length	1,800	1,800
7	Flat bar (0.5 in)	1 length	750	750
8	Rod (5 mm Ø)	1m	1,500	1,500
9	Bearing (206 flat)	2pcs	3,000	6,000
10	Bearing (205)	2pcs	1,600	3,200
11	Shoes (Shelling bars)	12pcs	700	8,400
12	Sieve (500 mm width, round hole)	1pcs	4,000	4,000
13	Sieve (500 mm width, rectangular hole)	1pcs	4,000	4,000
14	Hinges	4pcs	400	1,600
15	Pulleys	3pcs	2,500	7,500
16	V – Belt	2pcs	400	800
17	Bolts and Nuts			3,000
18	Electrodes	3pct	1,400	4,200
19	Cutting disc	4pcs	500	2,000
20	Grinding disc	2pcs	500	1,000
21	labour			20,000
	Total			**91,450**

Fig. 3.1: An Isometric View of the Developed Machine

Fig 3.2: Views of the Developed Machine