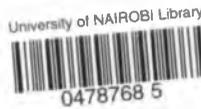


**Optimizing the Performance of a Manually Operated
Groundnut (*Arachis hypogaea*) Decorticator**

OTIENO PAUL MBOYA
[B.Sc. (Hons) EBE UoN, 2005]

A thesis submitted in partial fulfillment of the requirement for the
Degree of Master of Science in Environmental and Biosystems Engineering of
University of Nairobi.

2009



Optimizing the Performance of a Manually Operated Groundnut (*Arachis hypogaea*) Decorticator "

OTIENO PAUL MBOYA
[B.Sc. (Hons) EBE UoN, 2005]

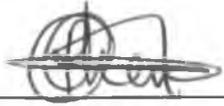
A thesis submitted in partial fulfillment of the requirement for the
Degree of Master of Science in Environmental and Biosystems Engineering of
University of Nairobi.

2009



DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree in any other university.

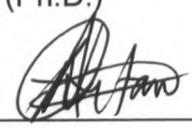
Signature:  _____

Date: 13/08/09

Name: Otieno Paul Mboya

This thesis has been submitted to the board of postgraduate studies of the University of Nairobi with the approval of university supervisor.

Ayub N. Gitau (Ph.D.)

Signature:  _____

Date: 13/8/09

DEDICATION

This thesis is dedicated to my parents Mr. Robert Ondutto and Mary Otieno.

ACKNOWLEDGEMENT

Grateful acknowledgement is made to the University of Nairobi for the second year scholarship and the International Center for Crops Research Institute for Semi Arid Tropics (ICRISAT) for providing financial support for this project.

Thanks are also due to Eng. Dr. Ayub N. Gitau, Eng. Gichuki Muchiri and Dr. Mary Mburu for their inspiration and technical guidance throughout the research period. I also acknowledge the assistance of the Department of Environmental and Biosystems Engineering staff members for their cooperation during the study period and special thanks goes to Mr. Fredrick K. Wanguhu and Mr. Wilfred M. Wamutitu for their assistance during experimental work and also during fabrication of the prototype in the workshop.

May God bless you all.

TABLE OF CONTENTS

DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	v
LIST OF APPENDICES	vii
LIST OF TABLES	vii
LIST OF PLATES.....	vii
LIST OF FIGURES.....	viii
ABBREVIATIONS AND SYMBOLS	viii
ABSTRACT.....	x
1. INTRODUCTION.....	1
1.1 Background	1
1.2 Statement of Research Problem	3
1.3 Justification.....	4
1.4 Objectives.....	5
2. LITERATURE REVIEW	6
2.1 Groundnut production.....	6
2.1.1. Cultivation of Groundnuts	7
2.1.2. Moisture Reduction for the Pods.....	9
2.1.3. Groundnut Production in Kenya.....	10
2.2 Groundnut Decorticators	12
2.2.1 Manually operated Decorticators	12
2.2.2 Motorized Decorticators	20
2.3 Machine design	24
2.4 Multiple objective programming.....	26
2.5 Economic Analysis	28
2.6 Summary of Literature Review	30
3. MATERIALS AND METHODS.....	31
3.1 Identification of the pertinent parameters	31

3.2	Determination of Physical Properties of the Nuts	31
3.3	Description of the decorticators	33
3.3.1.	Rod beater decorticator	33
3.3.2.	Wooden beater decorticator.....	36
3.4	Testing of decorticators performance	37
3.5	Modifications done on the decorticator	39
3.6	Optimizing the Performance of the Decorticator	40
3.7	Economic Analysis	40
3.8	Statistical Analysis.....	40
4.	RESULTS AND DISCUSSION.....	42
4.1	Physical Properties of the Nuts	42
4.2	Machine performance.....	44
4.2.1.	Wooden Beater Decorticator.....	44
4.2.2.	Rod Beater Decorticator	45
4.3	Results for Modified Decorticator	47
4.4	Optimization of performance of decorticator.....	50
4.4.1.	Relationship of shelling efficiency to sieve size and clearance	50
4.4.2.	Relationship of percent damage to sieve size and clearance	52
4.5	Optimization of shelling efficiency and percent damage.....	52
4.6	Economic analysis results	53
5.	CONCLUSION AND RECOMMENDATIONS	54
5.1	Conclusion.....	54
5.2	Recommendations	55
6.	REFERENCES.....	56
7.	APPENDICES	62

LIST OF APPENDICES

Appendix A: Goal Programming	62
Appendix B: Table of results for analysis.....	65
Appendix C: Questionnaire.....	66
Appendix D: Survey Results	68
Appendix E: Modification Drawings of Decorticator	69

LIST OF TABLES

Table 2.1: Maximum moisture content for pulses and oilseeds:	10
Table 2.2: Comparative study of groundnut decorticators in India.....	23
Table 3.1: Pertinent parameters affecting groundnut decorticators	31
Table 3.2: Results recording table	38
Table 4.1: Physical properties of the groundnut pods.....	43
Table 7.1: ANOVA results for shelling efficiency	65
Table 7.2: Coefficients of the model	65
Table 7.3: ANOVA table	65
Table 7.4: Model summary for prediction of percent damage.....	65

LIST OF PLATES

Plate 1.1: Groundnut, <i>Arachis hypogaea</i>	2
Plate 2.1: Mechanical Groundnut Harvesting	8
Plate 2.2: Modified Motorized Decorticator for Shelling Seed.....	21
Plate 3.1: Rod beater decorticator	35
Plate 3.2: Rod beater decorticator shelling unit.....	35
Plate 3.3: Wooden bar decorticator	36

LIST OF FIGURES

Figure 2.1: Schematic of a Bamboo groundnut crusher.	13
Figure 2.2: Schematic sketch of rubber tire decorticator	15
Figure 2.3: CIAE model manual groundnut decorticator	18
Figure 2.4: CIAE manual groundnut decorticator.	19
Figure 2.5: Motorized rubber tire – decorticator.....	22
Figure 2.7: Schematic of machine design.....	25
Figure 3.1: Schematic layout of a tray drier	33
Figure 4.1: Effect of moisture content on shelling efficiency.	45
Figure 4.2: Effect of decorticator clearance on shelling efficiency	46
Figure 4.3: Effect of sieve size on shelling efficiency for modified decorticator ..	48
Figure 4.4: Effect of clearance on shelling efficiency for modified decorticator ..	49
Figure 4.5: Graph of damage versus clearance for modified decorticator.....	49

ABBREVIATIONS AND SYMBOLS

AOAC	Association of Official Analytical Chemists
CGIAR	Consultative group on international Agricultural Research
CIAE	Central Institute of Agricultural Engineering
FAO	Food and Agriculture Organization of the United Nations
Ha	Hectare
Hp	Horse Power
Hr	Hour
ICAR	Indian Council of Agricultural Research
ICGV	ICRISAT Groundnut Variety
ICRISAT	International Crop Research Institute for Semi-Arid Tropics
IDRC	International Development Research Center
KAPP	Kenya Agricultural Productivity Project
Kg	Kilogram
KSAE	Kenya Society of Agricultural Engineers

Kshs	Kenya Shillings
m	Metre
mm	Millimetre
Psi	Pounds per square inch
rpm	Revolutions per Minute
Sec	Second
TNAU	Tamil Nadu Agricultural University
VOPS	Vegetable Oil/Protein System Programmes
Wb	Wet Basis
TORA	Software for Optimization
WBS	Wooden Beater Decorticator
RBS	Rod Beater Decorticator
%	Percentage
R ²	Coefficient of determination

ABSTRACT

Shelling of groundnut pods using manual decorticators in Kenya is characterized by high kernel breakages and low shelling efficiencies. As a result farmers get low income due to low cost of broken kernels and a lot of time is lost in the tedious shelling operation. To overcome this problem, pertinent parameters that influence shelling efficiency of manually operated groundnut decorticators were identified. Two manually operated decorticators were tested and modifications done on one (WBS) because it was affordable and locally fabricated.

Results of machine performance tests showed that for WBS (Wooden beater sheller) at a feed rate of 30 kg/hr and 22.6 mm clearance (used by the farmers in the field), shelling efficiency increased with decrease in moisture content for all the groundnut varieties. The highest shelling efficiency was 55.3% for ICGV 99568, 39.2% for ICGV 90704 and 29% for ICGV 12991 at moisture content of 5.92% wb. For RBS (Rod beater sheller) at a feed rate of 30 kg/hr and 22.6 mm clearance, the highest shelling efficiency was 58.3% for ICGV 99568, 42.7% for ICGV 90704 and 35% for ICGV 12991 at moisture content of 7% wb. Identification of the pertinent parameters showed that pod moisture content, feeding rate, groundnut variety, rotations per minute, percentage of matured nuts, drying method, clearance and sieve size influence performance of manually operated groundnut decorticators.

Theoretical equations developed were optimized which showed that a maximum shelling efficiency of 88.73% can be achieved with percent damage of 4% when the sieve size is 11 mm and clearance is 16 mm. With the modifications done on the WBS decorticator, the highest shelling efficiency of 87% was obtained at a clearance of 10 mm for ICGV 99568 varieties. The results of optimization of the manually operated groundnut decorticator implies that farmers who shell for seeds can now obtain more seeds shelled with low breakage and therefore will get more income.

1. INTRODUCTION

1.1 Background

In Kenya, consumption of proteins is higher relative to production (Koguta and Kosambo, 1999). High demand for proteins creates the need for increased efficiency in production of proteins. Efficient Production of proteins goes along way in ensuring good health and economic development (Yao, 2004). One of the crops which is a good source of proteins and is produced below the potential in Kenya is Groundnut (*Arachis hypogaea*). Groundnut is a species in the legume family *Fabaceae* native to South America (Nautiyal, 2007). It is an annual herbaceous plant growing to 30 to 50 cm tall. The leaves are opposite, pinnate with four leaflets (two opposite pairs; no terminal leaflet), each leaflet 1 to 7 cm long and 1 to 3 cm broad. The flowers are a typical pea flower in shape, 2 to 4 cm across, yellow with reddish veining. After pollination, the fruit develops into a legume 3 to 7 cm long containing 1 to 4 seeds, which forces its way underground to mature (Nautiyal, 2007). Its seed contains about 63% carbohydrate, 19% protein and 6.5% oil (Goli, 1997). As the groundnut seed is contained in pod, which is usually developed underground, the pod is harvested by pulling or lifting the plant manually or by using a hoe. The pod is then dried and shelled or stored in sacks.

Production of groundnut in developing countries account for nearly 95 percent of world production. Asia accounts for about 70 percent of this amount where the major producers including India and China together represent over two-thirds of global output. Other important producers are Nigeria, Senegal, Sudan and Argentina (Nautiyal, 2007). In most of the developing countries kernels are used for oil extraction, food and as an ingredient in confectionery products. Following extraction, the residual cake is processed largely for animal feed, but is also used for human consumption.



Plate 1.1: Groundnut, *Arachis hypogaea*

Source: Thomas Schoepe (2007): www.plant-pictures.de

Groundnut production in Kenya is mainly done in the western parts of the country. The farmers are vulnerable to losses due to the low prices paid for pods and kernels. It is, therefore, imperative for farmers to diversify their production and create added value through post harvest handling including processing thereby reducing risks and opening new local and export markets. There is a necessity to investigate new opportunities for improving efficiency in post production system. One of the major factors that affect agricultural output is the level of mechanization (Lagat *et al.*, 2007). Level of mechanization influences the level of efficiency in the production system such that high level mechanization

goes with high efficiencies. In Kenya, the shelling equipment available are inefficient and limited resulting in a lot of time wastage in shelling. Under these inefficient shelling conditions, the farmers are not timely to the market demand and also compromise other beneficial activities including education and socialization.

Shelling is a fundamental step in groundnut processing and is necessary as the activity allows the kernels and hull to be used as well as other post harvesting technologies to take place such as oil extraction or in hull briquetting (Nyaanga *et al.*, 2003). Shelling can generally be done by hand or machines. Hand shelling is the process in which the pod is pressed between the thumb and first finger so that the kernel is released. It is the most predominantly used method in Kenya's smallholder agriculture. While hand shelling keeps the rate of Kernel breakage low, it is labour intensive and leads to "sore thumb syndrome" when large quantities are handled.

Optimizing the performance of a manually operated groundnut decorticator is important so that the shelling efficiency is set at maximum possible and kernel breakage set at minimum possible. The purpose of this study was to partly establish the factors that influence the performance of a manually operated groundnut decorticator. Factors influencing performance of decorticator were then evaluated to determine the optimum conditions to be set.

1.2 Statement of Research Problem

Manual shelling of groundnut is a time-consuming and tedious operation. The few existing manual decorticators in Kenyan farms are imported and out of reach of the rural peasant farmers who are characterized by small holdings and low income. The power requirement of such decorticators is high and hence, the prime mover is very expensive. Despite the many studies done on evaluation and modification of groundnut decorticators, farmers still have problems of high kernel breakages and low shelling and winnowing efficiencies from the existing

the shelling efficiency of the decorticator. This is also true according to the study done by Jha *et al.*, (2008) who found out that bulk density is an indicator of savings in storage and transportation space and not shelling efficiency. However, bulk density of groundnut pods can determine the speed in which the pods fall on the shelling chamber. Groundnuts with high bulk density will fall with greater force into the shelling chamber, thus cracking the pods.

4.2 Machine performance

The data obtained were used to calculate shelling efficiency and percent damage for each of the decorticators. The results include the effect of moisture content, decorticator clearance and sieve size on shelling efficiency and percent kernel damage.

4.2.1. *Wooden Beater Decorticator*

Results of the effect of moisture content on the shelling efficiency of WBS decorticator for the various varieties with a clearance of 22.6 mm and a feed rate of 30 kg/hr are presented in Figure 4.1. The figure showed that shelling efficiency increased with decrease in moisture content for all the varieties. As a result of this trend, the highest shelling efficiency was 55.3% for ICGV 99568, 39.2% for ICGV 90704 and 29% for ICGV 12991 at moisture content of 5.92% wb. To achieve the highest shelling efficiency, the pods should be dried to a moisture content of about 6.0% wb. Husks are weakest at this moisture content when subjected to impact, shear and compressive forces and tangential force provided by wooded bars. The results seem also to agree with the observation by Atiku *et al.*, (2004) that moisture content of groundnut is probably one of the most important crop factor influencing harvesting and post harvest operations for groundnut.

constraint in groundnut production in Kenya is high labour requirements in the processes of planting, weeding and shelling. Therefore, this study is pertinent and timely since a good documentation of the factors influencing decorticator performance would aid in the modification of existing groundnut decorticators to improve on overall performance. Groundnut as a cash crop is a valuable crop which gives relatively high returns for limited land area. Improvement in the efficiency of groundnut decortication will improve farmers' income as more kernels will be sold as seed and this goes a long way to reduce poverty. With the release of labour due to improved efficiencies of the decorticator, time would be created for farmers to be involved in other productive activities such as education and recreation.

Research on groundnut is important because of the crop's important dietary contribution, its use as a cash crop and income generation, its potential in meeting part of the global demand for vegetable oils, its secondary value as animal feed and fodder and its contribution to the sustainability of mixed cropping systems (CGIAR, 2008).

1.4 Objectives

The overall objective of the study was to evaluate and optimize the technical and economic performance of a manually operated groundnut decorticator.

The specific objectives were to;

1. Identify pertinent parameters that influence shelling efficiency of manually operated groundnut decorticators.
2. Test existing manually operated groundnut decorticators
3. Make modifications that optimize the technical performance of the decorticator.
4. Perform cost-benefit analysis towards optimization of performance.

2. LITERATURE REVIEW

2.1 Groundnut production

Groundnut originated between southern Bolivia and northern Argentina from where it spread throughout the New World as Spanish explorers discovered its versatility (CGIAR, 2008). Presently, groundnut is grown in nearly 100 countries. Major groundnut producers in the world are: China, India, Nigeria, USA, Indonesia and Sudan. Developing countries account for 96% of the global groundnut area and 92% of the global production. Asia accounts for 58% of the global groundnut area and 67% of the groundnut production with an annual growth rate of 1.28% for area, 2.00% for production and 0.71% for productivity. It is grown on 26.4 million ha worldwide with a total production of 36.1 million metric Tons and an average productivity of 1.4 metric Tons per ha (FAO, 2008).

The crop does well where average rainfall is from 600 to 1,200 mm and mean daily temperatures are more than 20 degrees Celsius. Groundnut is a valuable cash crop for millions of small-scale farmers in the semi-arid tropics. It generates employment on the farm and in marketing, transportation and processing. According to Okumu (2000), groundnut should not be viewed only as a cash crop but also as an input for improving soil fertility through Nitrogen fixation. This makes Groundnut the 13th most important food crop of the world (CGIAR, 2008). It is the world's 4th most important source of edible oil and 3rd most important source of vegetable protein. Groundnut seeds contain high quality edible oil (50%), easily digestible protein (25%) and carbohydrates (20%). The seeds yield a non-drying, edible oil, used in cooking, margarines, salads, canning, for deep-frying, for shortening in pastry and bread, and for pharmaceuticals, soaps, cold creams, pomades and lubricants, emulsions for insect control and fuel for diesel engines. The oil cake, a high-protein livestock feed, may be used for human consumption. Other products include dyes, ice cream, massage oil, paints and peanut milk. Seeds are eaten raw, whole roasted and salted or chopped in

confectioneries or ground into peanut butter. Young pods may be consumed as a vegetable. Young leaves and tips are suitable as a cooked green vegetable (Martin and Ruberte, 1975). Groundnut hulls are used for fuel, as filler for fertilizers and for livestock feed or sweeping compounds. Most U.S.A. production enters the peanut butter (50%), salted peanuts (21%), and confectionery (16.5%) markets. Elsewhere peanuts are processed mainly for oil (Duke, 1981a).

2.1.1. Cultivation of Groundnuts

All commercial groundnuts are propagated from seed. Virginia-type (alternately branched) peanuts have a dormancy period; Spanish-Valencia types (sequentially branched) have little or no seed dormancy (Putnam and Oplinger, 1991). Seedbed should be prepared, either on the flat or widely ridged. Seed often treated with antifungal dressing before planting. In countries of advanced agriculture, groundnuts are often grown in monoculture and by mechanized means. In many countries they are cultivated by hand and sometimes in mixed culture. The spacing and seed rate vary with growth rate, growth habit and production methods. Stands of 250,000 plants per hectare are sought in machine-drilled planting. However, much lower seed rates may be used for seeds planted by hand.

Weeds are controlled by cultivation and by pre- and post-planting applications of selective herbicides. Responses to Nitrogen applied early are common and large in short season cultivars in semi-arid regions of West Africa. Phosphorous (P) is added on tropical red earths but less on temperate sandy soils on which other crops in the rotation receive phosphorus fertilizer. Roots and fruits absorb nutrients. Calcium (Ca) supply in the pegging zone is essential for high yield of good quality peanuts in large-podded, alternate types. Seeds produced on Ca-deficient soil often have poor germination and poor seedling growth. In tropical red soils of Africa, addition of Sulphur may be beneficial (Baldwin and Beasley, 1990).

Although flowering may commence in 30 days, 80–150 days or more are required for fruit maturation. In hand-harvest, plants are pulled up and turned over on the ground or stacked or placed on racks to cure. Pods are picked and allowed to complete drying in depths of 5 cm or less on trays, or spread in the sun in the dry season tropics. In case of fully mechanized harvesting a single operation pulls up, inverts and windrows the plants where they remain a few days for preliminary drying. The pods are removed by combine machines and elevated into baskets attached to the combine or blown directly into trailing "drying wagons" which when full may be towed to a drying station where warm or ambient air is forced through the load of peanuts (Young *et al.*, 1982). In Argentina the combines pick and shell the pods in one operation so that the crop is marketed as dried seeds instead of dried pods.



Plate 2.1: Mechanical Groundnut Harvesting

Source: Bruce Coleman, Microsoft Encarta Encyclopedia, 2005.

2.1.2. Moisture Reduction for the Pods

After harvesting, moisture content of the groundnut should be reduced. Moisture content (mc) reduction in harvested groundnut is necessary for safe storage (Young *et al.*, 1982). Reduction of moisture content is achieved through drying. Drying is generally performed in two stages: field drying in inverted windrows to 20–25% dry-basis (db) mc and artificial drying in wagons or bins to 10% mc (Baldwin and Beasley 1990). Field drying is a natural process and Wagon or bin drying is a process in which water is removed through moisture and temperature gradients created by heated air flowing through the mass of groundnuts (ASAE, 2000). Moisture movement during air drying of thin-layer groundnut pods was studied and described by Whitaker and Young (1972a). Moisture flux was determined by the thermal and physical properties of the groundnuts and psychometric properties of the air (Suter *et al.*, 1975).

In Kenya drying is done in the field in open air. After stripping, the pods are left in the sun and by this method; moisture content of about 20% can be achieved. This means that if shelling efficiency of decorticators is influenced by moisture content such that as moisture content reduces, shelling efficiency increases then the moisture content must be reduced to an optimum value. Elsewhere, drying is performed in deep beds, where air is forced upwards through the groundnuts (Whitaker *et al.*, 1972b). A drying zone is created in the lower portions of the bed and moves upward through the bed of groundnuts as the process evolves. Requirements for air flow in terms of volume, temperature and relative humidity, in wagon drying, combined with the drying time (about 18 – 24 hrs) make drying in wagons an energy-intensive process. Studies have been conducted to determine ways to increase the energy efficiency in air drying of groundnuts (Chai and Young, 1995). Past studies have frequently focused on the use of high temperatures and on methods of reducing the amount of running time for fans (Blankenship and Chew, 1979). These conditions maintain groundnut quality but do not always result in active drying depending on ambient conditions. Table 2.1 provides the maximum moisture content for safe storage of pulses and oil seeds.

Table 2.1: Maximum moisture content for safe storage of pulses and oilseeds:

Species	Moisture content (%)
Bean	14.0
Pea	13.0
Soybean	11.0
Groundnut, unshelled	9.0
Groundnut, shelled	7.0

Source: CEEMAT (1988).

It can be seen that oilseeds (soybeans and groundnuts) require lower moisture content than pulses. Shelled groundnuts are especially demanding here, which means that they are especially vulnerable. Unfortunately, even such drying is not enough to provide immunity to parasite attack, particularly from weevils. An ad hoc method of combating this has seen further development and considerably improved by modern technology (CEEMAT, 1988). In this approach, the container is filled to capacity and then sealed hermetically so that the interstitial air becomes so rarified and inert that it anaesthetizes or even asphyxiates larvae and insects. When larger quantities are involved and the containers or storage space cannot be sealed hermetically, treatment with insecticide powder is recommended.

2.1.3. Groundnut Production in Kenya

Groundnut production in Kenya has been done in the past and will continue to improve. According to ICRISAT (2008), groundnut in Kenya is grown mostly by smallholder farmers under rain-fed conditions with limited inputs. Its production is mainly done in the western region of the country near towns like Kendu-Bay, Homa-Bay, Kisumu, Busia, Kakamega, Bungoma and Cheplamus in the rift valley. The mean yield per hectare in Kenya is about 520 kg and its price ranges between Kshs. 3,600 to 5,200 per 110 Kg bag in Mombasa and Kisumu

respectively (DN, 2007). Groundnuts are grown in most areas of Kenya for domestic consumption, however around Homa Bay in South Nyanza; the crop is raised as a small-scale cash crop, which is exported to Uganda in pods (Egerton University, VOPS, 1997). In Kenya groundnut farming has been neglected due to its labour intensive nature. According to Nyaanga *et al.*, (2003), the amount of groundnuts shelled from one hectare per man day is 14 Kg.

The production of edible fats and oils in Kenya is relatively insignificant when considering the consumption levels (Koguta and Kosambo, 2003). This is because only 2% of the arable land is under cultivation for oil seeds i.e. groundnuts, sunflower, simsim, rape seed and castor seed. The consumption of edible fats and oils has been growing generally at a rate of 13% per annum. The disparity makes Kenya have a deficit in edible fats and oils resulting in most of its consumption being met on the basis of imported oil seeds. As a result of poor production of groundnuts, many children in Kenya suffer from protein deficiencies due to gross reduction of animal proteins and the high cost of meat. Groundnuts can be used as alternative protein in the diet.

Consumption of edible oils in Kenya is higher relative to production. The reason for low production of groundnuts is the large amount of man hours spent in shelling the nut as even the available decorticators have very low shelling efficiencies (below 65%). Development of an affordable and more efficient groundnut decorticator can increase the productivity of groundnuts.

2.2 Groundnut Decorticators

A decorticator is a machine for stripping the husk off kernels in preparation for further processing, storage or use as food (Anandachar, 1990). The machine can dramatically reduce the labour costs associated with decortications, cleaning and preparing groundnuts for further processing. Decorticators are basically classified as manual or motorized. Manual decorticators are powered by human hand while motorized decorticators are powered by a motor or an engine.

2.2.1 Manually operated Decorticators

Groundnut shelling has been done by hand (manually) and also simple machines have been devised for use in shelling for example in the North-Eastern part of India, groundnut shelling was done using a bamboo crusher. Figure 2.1 shows the sketch of a bamboo groundnut crusher. Chinsuwat (1983) studied groundnut decorticators and reported that by using a bamboo crusher, 0.75 Kg of groundnut pod can be shelled in one hour. From his studies it was also concluded that the average percentage of the broken kernel is 1.1%. This low percentage of broken kernel was due to the fact that variation in pressure supplied to the groundnut pod is regulated by the human hand.

While this Bamboo groundnut crusher ensures no "sore thumb syndrome", the efficiency is still low and cannot be used to make significant returns to farmers and also meet the timeliness requirements for the kernels. Using this kind of decorticator still makes groundnut production labour intensive (Okumu, 2000). Furthermore, using it is the same as hand shelling except for direct hand contact with the pods.

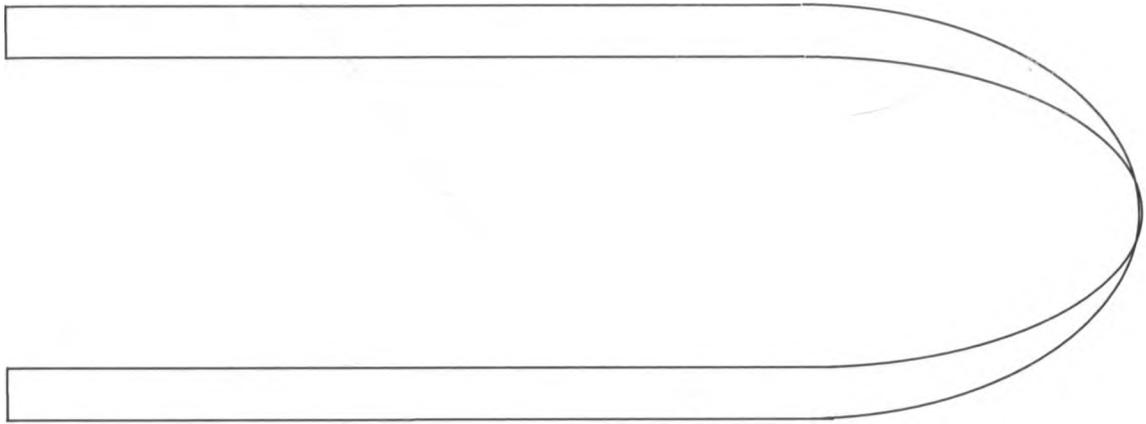


Figure 2.1: Schematic of a Bamboo groundnut crusher.

Source: Chinsuwan (1983).

Some hand operated decorticators can be found in some parts of groundnut producing areas in Kenya (ICRISAT, 2008). The decorticators mainly consist of a hopper, a wire mesh, shelling bars and a reciprocating arm. In operation, groundnuts are loaded into the hopper and the shelling bars are set so that, when moved backwards and forwards, they crush the shells of the groundnuts against the wire mesh, releasing the kernels which fall through the wire mesh into a container placed underneath. Separation of the shells from the kernels has to be done separately.

These machines have inherent shortfalls of which Nyaanga *et al.*, (2003) cites some as including the fact that the decorticators:

- (i) Do not have continuous feeding component which prompts the operator to stop operating and feeding.
- (ii) Do not have the provision to remove the shells after shelling, a situation that calls for winnowing.
- (iii) Require sorting the pods before feeding them into the machine.
- (iv) Require frequent adjustments between runs to accommodate pods of different sizes.

- (v) Are relatively expensive.
- (vi) Have no proper monitoring of the operation of the machine to reduce kernel bruising and are expensive to operate since they require several persons to operate and have limited capacity and lifespan.

Hand operated machines available in Senegal can produce up to 90 Kg of shelled nuts in a day which are unavailable in Kenya. The shelling percentage of such machines is 65-75%. But are relatively expensive and unavailable. The other groundnut shelling machines in the market include hand operated alternative decorticators, cottage decorticators, Super Cayon Decorticator, Sharpur Decorticator and Malian groundnut decorticator (Patil *et al.*, 1988). The others are revolving stone and rubber tire decorticator.

Rubber Tire Decorticator

Rubber tire decorticator shells by rubbing action between a rubber tire and a wire mesh. The decorticator consists mainly of a main frame, rubber tire, concave and hopper. The rubber tire used is a worn out rubber tire. Tire treads are cut to prevent excessive slip during operation. Wheel rim and inner tube are also used. The purpose of using the inner tube is to provide the correct inflation during shelling. The concave is an 11 x 11 mm wire mesh concave. The midpoint of the concave is directly underneath the center of the rubber tire. The clearance between the rubber tire and concave is narrowest at the midpoint of the concave and wider toward the inlet and outlet. This clearance is adjustable in a vertical direction. An opening of the hopper is also adjustable so that feed rate can be controlled. Schematic for rubber tire decorticator is shown in Figure 2.2.

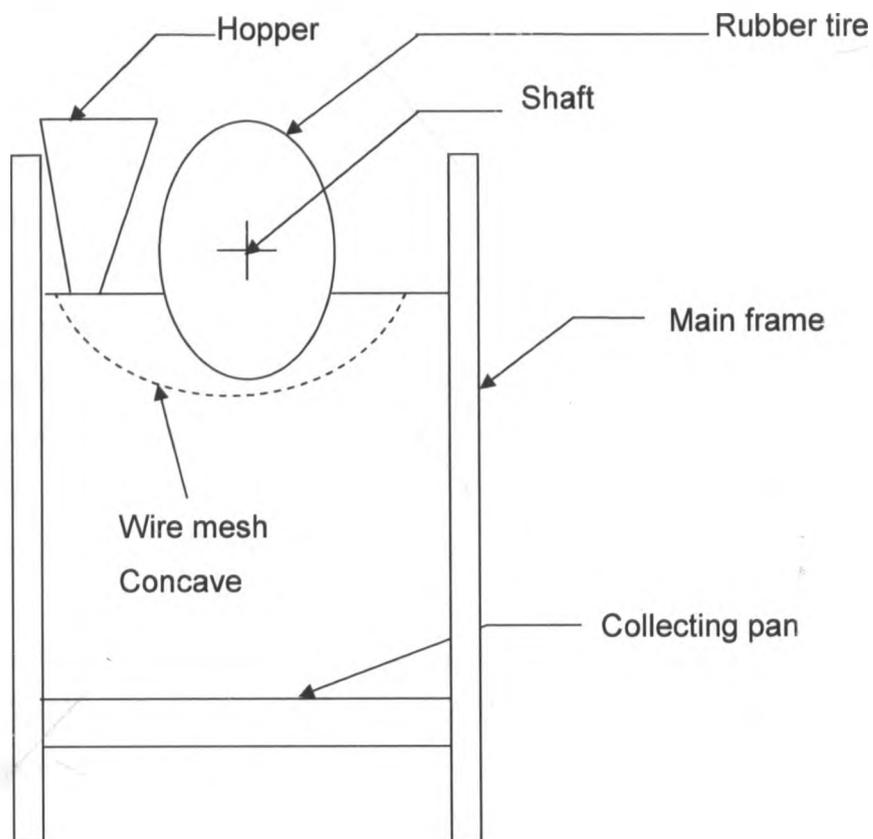


Figure 2.2: Schematic sketch of rubber tire decorticator

Operation of Rubber Tire Decorticator

In operation, groundnut in the hopper is fed into the clearance between the rubber tire and concave while the rubber tire is turning. The groundnut is then shelled by rubbing action between the rubber tire and wire mesh. After shelling, the kernel and husk fall through the wire mesh into a collecting pan. Separation of the groundnuts from the kernel is done manually. Chinsuwan (1983) analysed the factors that affect shelling efficiency of a rubber tire decorticator.

The factors considered included:

- Tire inflation
- Clearance between the rubber tire and wire mesh
- Concave
- Feed rate

Chinsuwan (1983) tested three levels of tire inflation, 0.35, 0.84, and 1.26 kg/cm² (5, 12, and 18 psi), for two varieties of groundnuts. He found out that tire inflation and the clearance significantly affect the shelling efficiency and damage for both varieties at the 1% significance level. More over the effect of feed rate was not significant at the 1% level (Atiku *et al.*, 2004). The test results however did not take into account any variation in moisture content of the pods while it is important since farmers shell pods at different moisture contents.

The shelling forces involved in shelling are functions of the pressure exerted during the shelling activity. Akcali (1996) provides the equation for the pressure exerted as:

$$P = a_0 + a_1 \frac{R_0}{R_2} (1-KY) \rho_{\text{groundnut}} \quad 2.1$$

Where:

P = Pressure exerted (units)

a₀ = Pressure strain coefficient at the surface of the beater (taken as 2.40)

a₁ = Pressure strain coefficient (taken as 10.1)

R₀ = Radius of the beater

R₂ = Radius of the concave from the center of the beater at the point of shelling and

$$R_2 = R_0 + \beta_s \quad 2.2$$

Where:

β_s = Average pod size

$\rho_{\text{groundnut}}$ = Bulk density of the groundnuts and

KY = Shelled ratio, given by

$$KY = \frac{\text{Shelled K}}{\text{Input K}}$$

2.3

Where K is the weight of groundnut.

Revolving Stone Decorticator

This type of decorticator is mainly available in Thailand. It consists mainly of a revolving stone, wire mesh, hopper and turn arm. The hopper is attached to the top of the concrete revolving stone. The bottom side of the revolving stone has grooves on its surface. There are two rectangular holes on the revolving stone for groundnuts in the hopper to flow through. The wire mesh, placed underneath the revolving stone, has a square sectional opening of 13 x 13 mm. The clearance between the revolving stone and wire mesh is adjustable. In operation, groundnuts are loaded into the hopper (Chinsuwan, 1983). The groundnuts flow into the clearance between the revolving stone and wire mesh, while the revolving stone is turning. The revolving stone then crushes the shells of the groundnuts against the wire mesh, releasing the kernels which fall through the wire mesh into a container. Separation of the shells from the kernels has to be done separately.

CIAE Model Manual groundnut decorticator

The CIAE Model Manual groundnut decorticator has the following parts as can be seen in Figure 2.3;

1. Handle
2. Hopper
3. Foot Rest

4. Sieve

The size of the decorticator is (250 mm X 500 mm X 630 mm) and weighs 5.7 Kg. Banshi *et al.*, (1992) tested the performance of the CIAE model groundnut decorticator and found out that the capacity is about 35-40 Kg pods/hr with 1-2% broken. It was found that there is no adverse effect on germination of seeds by use of this equipment.

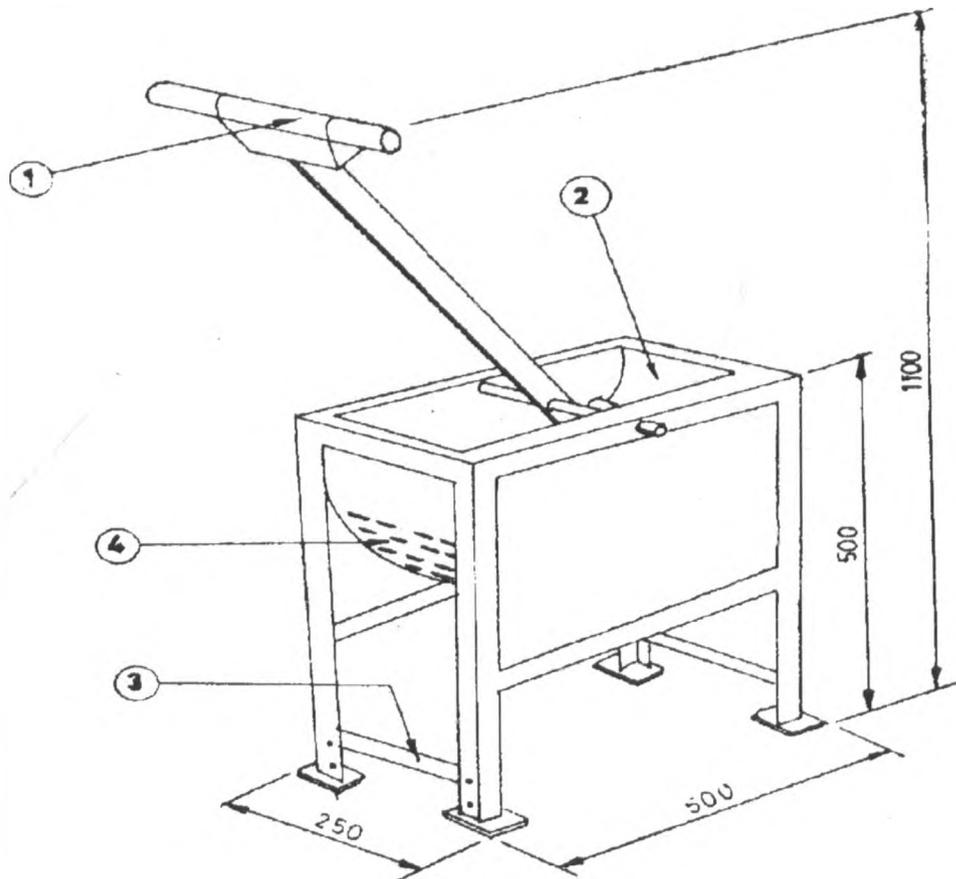


Figure 2.3: CIAE model manual groundnut decorticator

Source: Collins *et al.*, (1977)

This kind of a decorticator has its modification with a feeder and separator attachment and has a sieve of 250 mm X 500 mm size (diameter of holes 11 mm). The feeder facilitates easy operation of the equipment with an increased capacity of 50-55 Kg pods/hr, 25-37% more than the previous design. Damage to the kernels reduced from 2 to 1% giving 70-75% separation efficiency and 100% shelling efficiency.

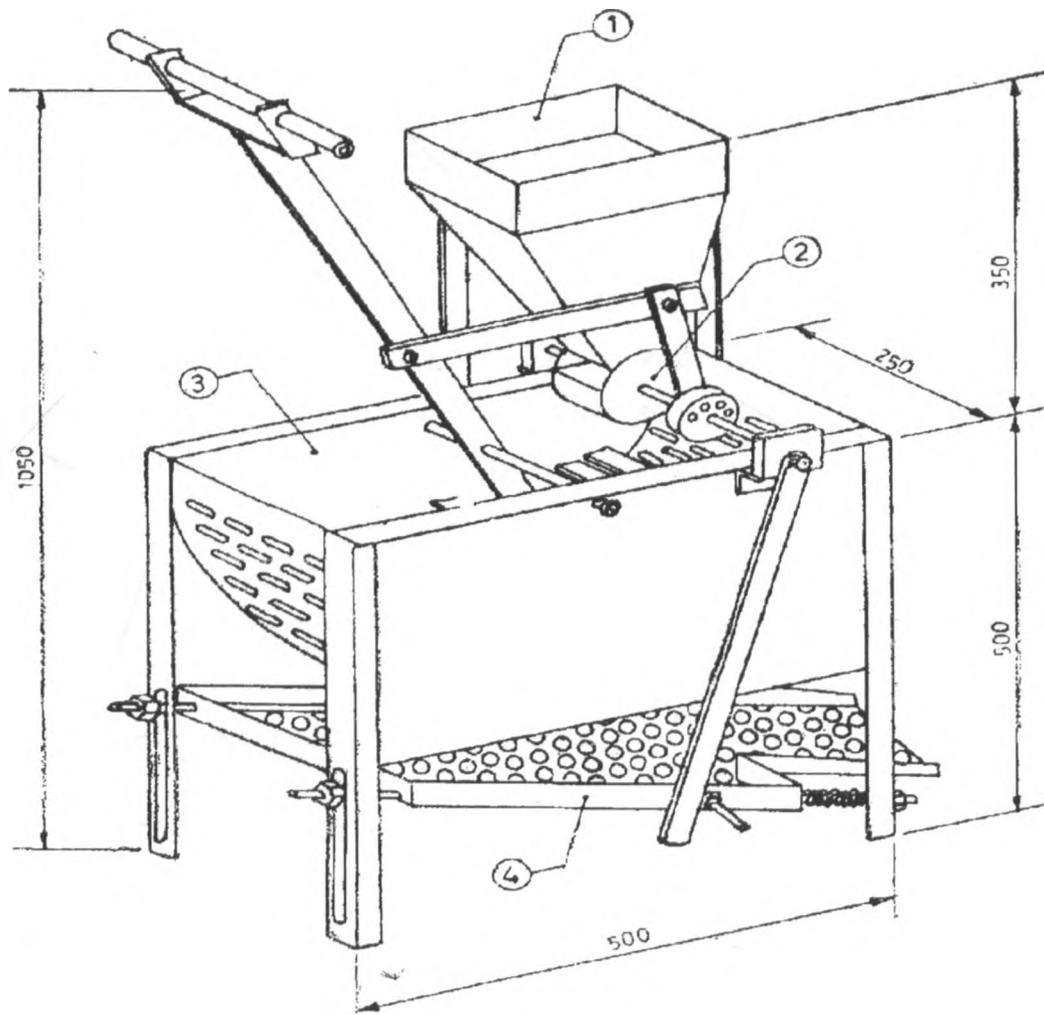


Figure 2.4: CIAE manual groundnut decorticator attached with feeder and separator.

Source: Collins *et al.*, (1977).

The parts of the manual decorticator are listed below:

1. Hopper
2. Feeder
3. Decorticating unit
4. Separator

Dash *et al.*, (1994) developed and evaluated a pedal operated groundnut decorticator and found out that there is no theoretical basis for selection of rotation speed of the decorticator. He suggested that the rotational speed of the shelling unit of the pedal operated groundnut decorticator should be about 100 rpm.

2.2.2 Motorized Decorticators

Motorized decorticators generally consists of a hopper, double crank lever mechanism, an oscillating unit with sieve bottom and a blower assembly, all fixed on a frame (Oluwole *et al.*, 2004). A number of cast iron assemblies are fitted in the oscillating unit. The groundnut pods are shelled between the oscillating unit and the fixed perforated concave screen. The decorticated shells and kernels fall down through the perforated concave sieve. The blower helps to separate the kernels from husk and the kernels are collected through the spout at the bottom. The shells are thrown away from the machine.

While motorized decorticators are efficient in shelling, they are also capital intensive, complex and expensive (Tromlow *et al.*, 2002). This makes motorized decorticators unavailable for ordinary Kenyan farmers who are mainly small scale farmers and are characterized by low incomes (Okumu, 2000). Moreover, motorized decorticators require an elaborate support structure of markets, training, raw materials, supplies and spares which are still not well established in Kenya. More appropriate to the needs and resources of poor ordinary Kenyan farmers is the development of such alternative technologies that can avoid many of the challenges that are inherent in the motorized and other decorticators.

Today it is impossible to ignore the fact that the conventional capital and energy intensive technologies, which still form the main currency of aid and development programmes, are by no means always in harmony with the needs and aspirations of poor countries. This is most obvious in relation to employment.

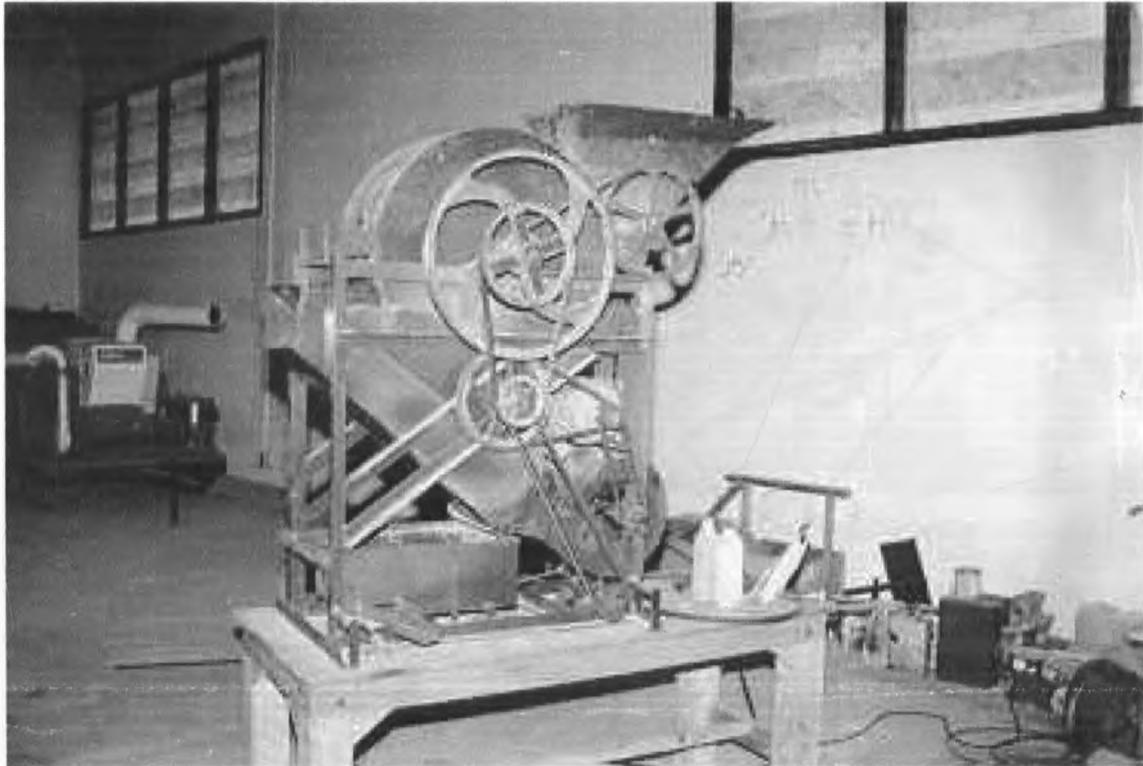


Plate 2.2: Modified Motorized Decorticator for Shelling Seed

Source: IDRC (1998)

Motorized rubber tyre decorticator

The motorized rubber tyre decorticator uses the same principle as the manual rubber tyre decorticator but with a motor to power it. The decorticator consists of the following parts as shown in Figure 2.5.

1. Main frame
2. Blower
3. Trough

4. Grading
5. Rubber Tire frame
6. Concave
7. Blower chute
8. Rubber tire assembly
9. Cover
10. Feed hopper

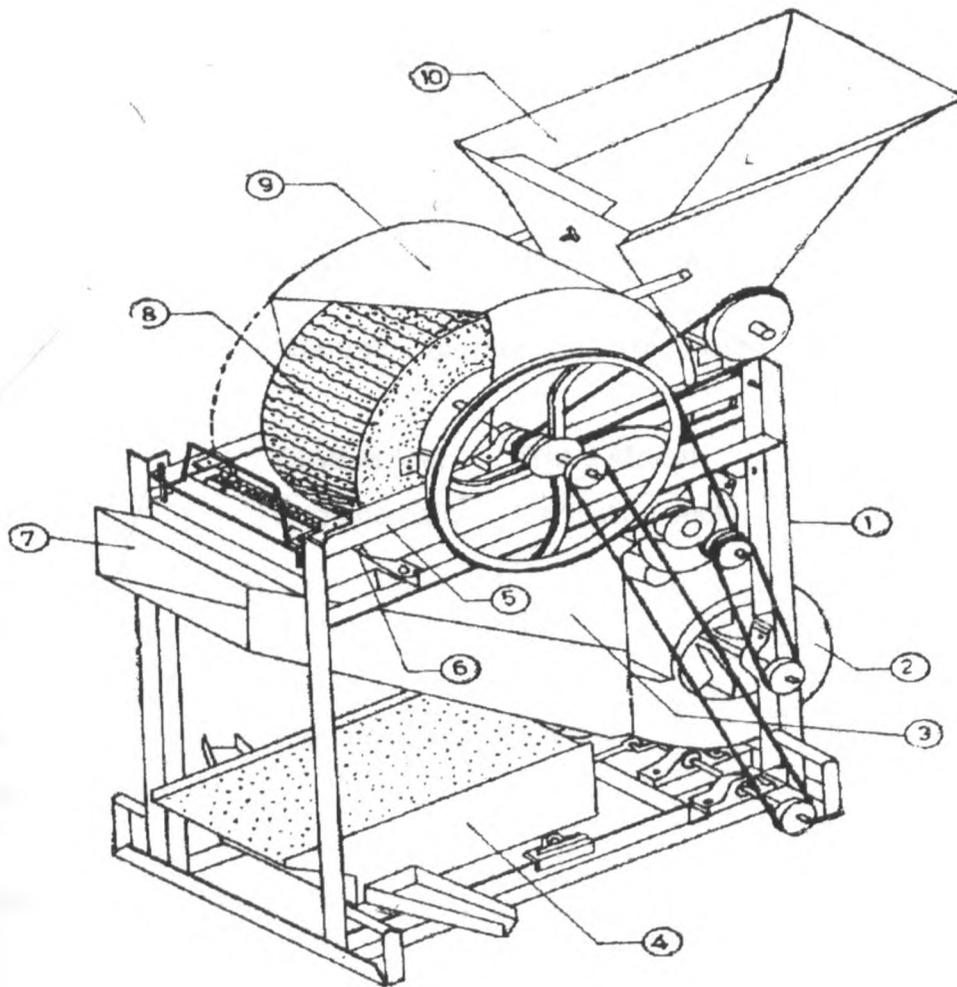


Figure 2.5: Motorized rubber tire – decorticator

Source: Chinsuwan (1983).

A manually-cum-power operated groundnut decorticator has been developed in Jawaharlal Nehru Technological University in India with one Hp electric motor. The unit can decorticate about 150 Kg pods/hr with 94-96% decortication efficiency. Banshi *et al.*, (1992) found out that no breakage takes place and 57-63% sound kernels are obtained which could be used as seed. Table 2.2 provides a comparative study of groundnut decorticators in India. With the manually operated decorticators, it is possible to achieve upto 99.0% shelling efficiency with the peg and batch CIAE model with two people operating it. These decorticators are of good performance capacity but not available in Kenya and would be unaffordable to the ordinary Kenyan farmers. Furthermore, repair and maintenance would not be readily available. The percent breakages were not also investigated for these decorticators.

Table 2.2: Comparative study of groundnut decorticators in India

Specification/Test results	Manually operated decorticators		Power operated decorticator
	CIAE Model	TNAU Model	TNAU Model
Type	Peg and batch	Oscillating sector	Oscillating drum concave
Capacity, Kg/h	45-60	12	260
Shelling efficiency, %	99.0	98.0	95.8
Power requirement	manual	Manual	5 hp
Labour requirement	2	1	2

Source: Banshi *et al.*, (1992).

Oluwole *et al.*, (2007) evaluated the performance of an impact Bambara groundnut sheller and found that moisture content, impeller slot angulations, number of impeller slots and interactions between these variables statistically affect performance indicators (shelling efficiency, percentage of breakage, percentage of partially shelled pods). Some of these performance indicators can be affected by decorticator settings which include clearance and sieve size which this study established.

2.3 Machine design

Machine design process involves the following processes provided by Allen *et al.*, (1967):

- The recognition of a need and a statement of this need in general terms. This defines the problem
- The consideration of different schemes for solving the problem and the selection of one to be investigated in more detail. Feasibility studies backed up by special research if necessary, are a feature of this stage in process
- A preliminary design of the machine, structure, system or process selected. This establishes broad overall features and makes it possible to write specifications for major components
- Design of all components and preparation of all necessary drawings and detailed specifications.

The design of the machine should follow a plan as shown in Figure 2.6

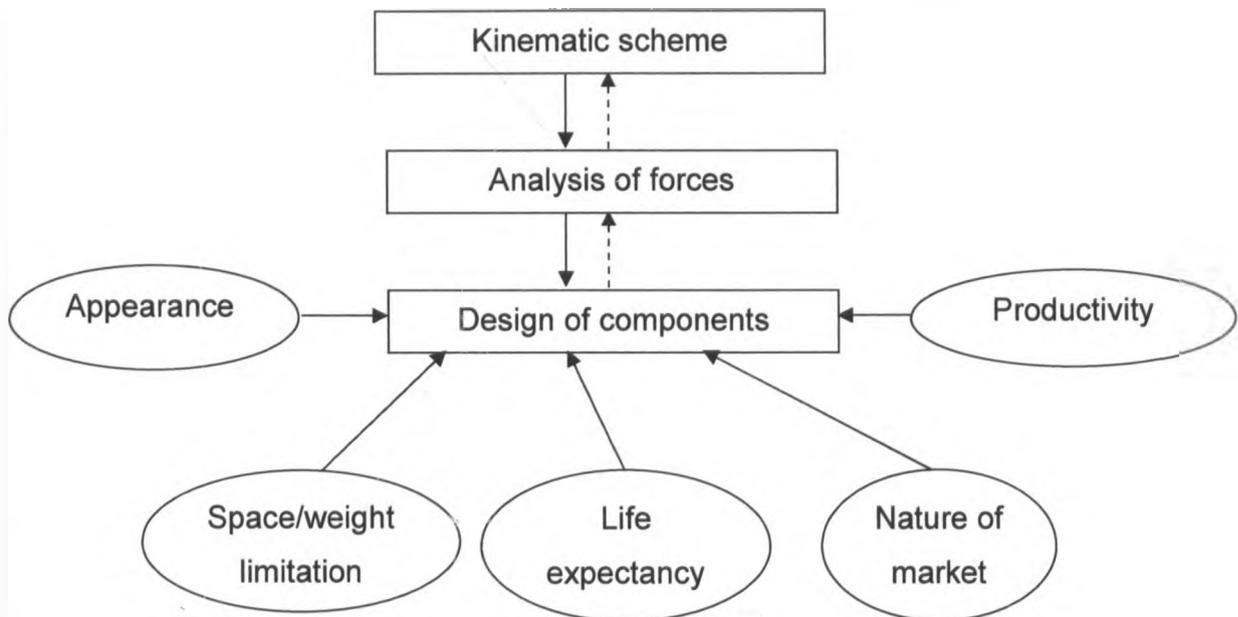


Figure 2.6: Schematic of machine design

Source: Allen *et. al.*, (1968)

The mode of transmission of power from the rotating arm to the shelling unit of the decorticator is the belt and pulley. Kinematic pairs involving a belt wrapped around the periphery of pulleys allows for transmission of power from one pulley to the other at different speeds (Dimarogonas, 2000). Input is the angular velocity ω_1 , output is the angular velocity ω_2 . The relationship between the input and output velocity is given by Equation 2.4. This is because the peripheral velocities of both pulleys given by $\omega_1 \frac{d_1}{2}$ and $\omega_2 \frac{d_2}{2}$ are equal (though approximately, due to some slipping).

$$\frac{\omega_2}{\omega_1} = \frac{0.985d_1}{d_2}$$

2.4

Where;

- ω is the angular velocity (rad/sec)
- d is the pulley diameter
- 1 and 2 refer to the driving (input) and driven (output) pulleys respectively
- 0.985 is an approximate slippage factor for preliminary design purposes.

In machine design, similitude engineering can be applied to establish relationships between parameters (Mendez and Ordonez, 2005). If we have a physically meaningful equation involving a certain number n of physical quantities and these variables are expressible in terms of k independent fundamental quantities, then the original expression is equivalent to an equation involving a set of $P = n - k$ dimensionless variables constructed from original variables (Sheppard, 2007). In mathematical terms:

$$f(q_1, q_2, \dots, q_n) = 0 \quad 2.5$$

Where q_i are the n physical variables which can be sieve size, sieve clearance, speed, feed rate and moisture content.

2.4 Multiple objective programming

Most optimization models are based on the optimization of a single objective function. There are situations where multiple and possibly conflicting objectives are to be determined for example, in optimization of the performance of a manually operated groundnut decorticator, it is necessary to maximize the shelling efficiency, minimize the cost and percentage damage. In such situations, it is impossible to find a single solution that optimizes the conflicting objectives (Taha, 2003) and so an efficient solution is the most appropriate.

Multi-objective optimization (or programming), also known as multi-criteria or multi-attribute optimization, is the process of simultaneously optimizing two or more conflicting objectives subject to certain constraints (Steuer, 1986). In each case a solution is determined for which each objective has been optimized to the extent that further optimization causes other objective(s) to suffer as a result. The goal when setting up and solving a multi-objective optimization is to find a solution and quantifying how much better the solution is compared to other such solutions as there are generally many solutions.

In mathematical terms, the multi objective problem can be written as:

$$\min_x [\mu_1(x), \mu_2(x), \dots, \mu_n(x)]^T \quad 2.6$$

Subject to;

$$g(x) \leq 0$$

$$h(x) = 0$$

$$x_l \leq x \leq x_u$$

Where μ_i is the i th objective function, g and h are the inequality and equality constraints, respectively, and x is the vector of optimization or decision variables. The solution to the above problem is a set of Pareto points. Pareto solutions are those for which improvement in one objective can only occur with the worsening of at least one other objective (Sawaragi *et al.*, 1985). Thus, instead of a unique solution to the problem (which is typically the case in traditional mathematical programming), the solution to a multi-objective problem is a (possibly infinite) set of Pareto points. A design point in objective space μ^* is termed Pareto optimal if there does not exist another feasible design objective vector μ such that $\mu_i \leq \mu_i^*$ for all $i \in \{1, 2, \dots, n\}$, and $\mu_j < \mu_j^*$ for at least one index of j , $j \in \{1, 2, \dots, n\}$.

2.5 Economic Analysis

Production of groundnut is a labour intensive operation (Okumu, 2000). A lot of labour is required in all the processes of field cultivation. This has led to low productivity of groundnuts in Kenya as most farmers depend on manual operations. The amount of labour can be reduced by more efficient systems especially during shelling but this increase in efficiency has costs associated with it. According to Tromlow *et al.*, (2002), low productivity of smallholder farming systems and enterprises is attributed mainly to the limited resources of farming households and to the application of inappropriate skills and practices that lead to high production costs. Groundnut production benefits may be raised by improved mechanization (considering the whole spectrum of power sources) that makes better use of human labour and other resources (Tangka and Penda, 2007). However, mechanization programmes, which facilitate groundnut production, have to consider cultural and social factors as well as the immediate technical and economic issues.

Cost analysis for the decorticators involves quantifying in monetary terms the costs and benefits for aggregation and comparison. It also involves calculating the payback period defined as the investment of time required for the profit of an investment to equal the cost of the investment (Newnan, 1980).

Okumu (1998) provides the procedure for quantifying the costs and benefits. The costs include ownership and operating cost. Ownership costs include depreciation of the machine, interest on investment, cost of taxes, insurance and housing of the machine. Operating costs include cost of labour, power, repair and maintenance. However, for manually operated groundnut decorticators, some of the costs do not apply for example cost of fuel. Increase in technical efficiency is often associated with increased costs (Thirupathi *et al.*, 2004). The optimum technical efficiency is reached at maximum profit or benefit subject to other non quantifiable benefits such as safety, environment and other social conveniences.

Nyaanga *et al.*, (2003) also provides the procedure for determining the quantifiable costs and benefits.

Economic performance of the decorticator using cost analysis provided by Nyaanga *et al.*, (2003) can be performed. In this procedure, the shelling capacity of the decorticator can be computed using Equation 2.7.

$$Q = \frac{\Theta}{t} \quad 2.7$$

Where;

- Q is the shelling capacity of the machine (Kg/h),
- Θ is the total through put in to the machine and
- t is the time taken to shell in hours.

The period taken shelling from an average Kenyan farm can be computed using Equation 2.8.

$$P = \frac{Q_{ha}}{Q_t} \quad 2.8$$

Where;

- P is the duration of shelling (days),
- Q_{ha} is the average harvest (kg/ha),
- Q_t is the shelling capacity of the machine.

Total wages paid to casual workers can be calculated using Equation 2.9

$$T = \omega * n * p \quad 2.9$$

Where:

- T is the total wages (Kshs)
- ω is the wage per person per day (Kshs)
- n is the number of casuals per day
- p is the duration of shelling (days)

2.6 Summary of Literature Review

Manual groundnut decorticators are important equipment in post harvest processing of groundnut as the crop is a cash crop and income generator and also makes important contribution to the human diet. Most research in the area of groundnut production is concentrated only on the Agronomic aspects, while the processing ones have been neglected. This indicates that more research in groundnut should be directed toward post harvest processing which include stripping, decortications, storage of pods and kernels and value addition. Decortication requires emphasis as it is the process in which a lot of time is lost and production of kernels for seeds is compromised.

In rural households in Kenya, groundnut pods are decorticated by hand shelling and also separation done by hand. By this method, the output is low which result in very high unit cost of shelling. Several decorticators have been developed in other parts of the world and studies done but optimization of the performance of manually operated groundnut decorticators have not been done in Kenya and elsewhere. From the studies which have already been done, there is opportunity to improve on the factors affecting the shelling efficiency.

3. MATERIALS AND METHODS

3.1 Identification of the pertinent parameters

Pertinent parameters affecting the performance of groundnut decorticator were identified from literature as indicated in Table 3.1

Table 3.1: Pertinent parameters affecting efficiency of groundnut decorticators

Parameters	Source
Feeding rate	Nautiyal (2007)
Moisture content	Liang <i>et al.</i> , (2004) and Atiku <i>et al.</i> , (2004)
Variety	Tanimu (1997)
Percentage of matured nuts	Rajkumar <i>et al.</i> , (2004)
Drying method	Rogers (1977)
Rotations per minute	Dash <i>et al.</i> , (1994)
Clearance	Atiku <i>et al.</i> , (2004)

3.2 Determination of Physical Properties of the Nuts

A bulk quantity of the pods of each of the three groundnut varieties used in this study were obtained from ICRISAT farms in Alupe, western Kenya. The pods were cleaned using the cyclone separator to remove dust and other unwanted materials. The varieties were referred to as ICGV 12991, ICGV 90704, and ICGV 99568. 100 pods from each variety were randomly selected and put in the bowls. For each pod, the axial dimensions of length, major diameter and minor diameter were measured using the vernier callipers reading to 0.05 mm accuracy and readings recorded. 1000 pod weight was determined by physically counting 1000 pods and then weighing in the electronic balance. Weight measurement was replicated three times and average weight computed. For determination of angle

of repose, a pod was placed on the 70 mm by 70 mm metal sheet and one side of the sheet metal lifted until the pod just rolled down. The angle of repose was then measured using angle protractor and recorded. This was repeated for 10 pods and the average determined for each of the varieties. The bulk density of the pods was determined using the AOAC (1980) recommended method. This involved filling 1000 cm³ plastic container with the pods and then weighing the pods. The bulk density was calculated by dividing the weight by the volume.

The pods were conditioned using the method of Ezeaku (1994). This involved soaking the pods in clean water for a period of 48 hrs. At the end of soaking, the pods were spread out in thin layer to dry in natural air for about 8 hrs. The pods were then sealed in marked polythene bags and stored in that condition for a further 24 hrs. This enabled equilibrium moisture content of the pods to be achieved. The moisture content of the kernels was determined using electrical moisture meter. In this method, 100 g of nuts were placed in the moisture meter and moisture content read.

Variation of moisture content was achieved through drying of the pods in the tray drier. Measurements of the moisture content using the moisture meter were taken at intervals of 5 minutes during the first two readings and intervals of 10 minutes for the other three readings. All the readings were recorded and mean and standard deviations determined.

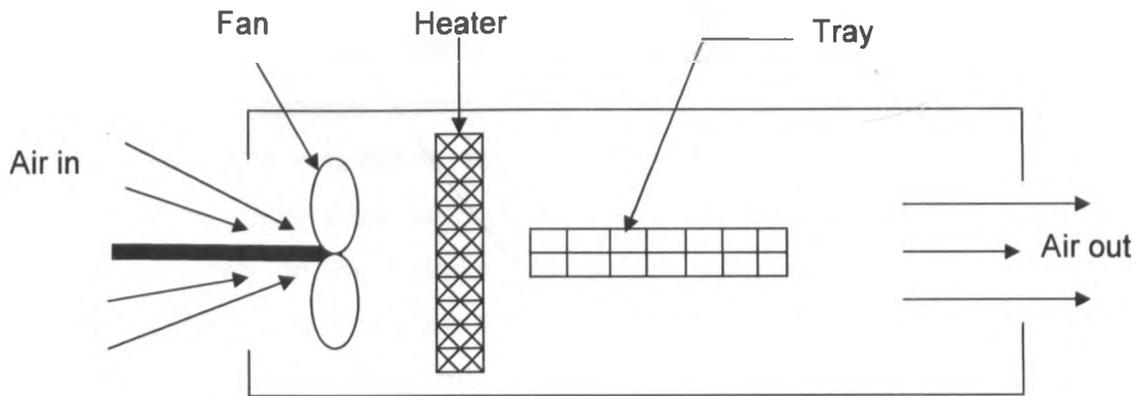


Figure 3.1: Schematic layout of a tray drier

3.3 Description of the decorticators

The decorticators tested were the rod beater decorticator and the wooden beater decorticator. Plates 3.1, 3.2 and 3.3 show the decorticators tested.

3.3.1. Rod beater decorticator

The rod beater decorticator is powered manually. During operation, groundnut pods are fed into the machine through the hopper. Shelling is accomplished between the rotating cylinder and stationary concave sieve. While in the shelling chamber, the pod is subjected to a combination of impact, shear and compressive forces and tangential force provided by the rod bars, which have a rubbing effect on the pod thereby shelling the kernel. The shelled kernels together with unshelled pods and husks pass through the stationary sieve to the winnowing unit where the husks are separated from kernels and unshelled pods. The husks are blown away by the fan through the chaff outlet. The overall dimensions of the decorticator are: length of 800 mm, width of 250 mm and height of 940 mm. A description of two essential units of the decorticator: the shelling and cleaning units are given in the following sections.

Shelling unit

The shelling unit consists principally of a rotating cylinder and a stationary concave sieve. The cylinder is 190 mm in diameter and 200 mm in length. Twelve shelling metal bars each of 10 mm diameter and 200 mm long are mounted uniformly on the cylinder surface and parallel to its axis. Plate 3.2 shows the shelling unit. The sieve is made of bars spaced at 13 mm which allow for the passage of groundnut kernels and husks to the winnowing unit.

Winnowing unit

The cleaning unit consists of a fan powered through the pulley belt from the shelling unit which provides the draught. The fan has four blades and also a circular air inlet at both sides through which air is allowed in and discharged in the direction perpendicular to the fan axis. The preliminary tests were run to determine how the winnowing unit functioned and the speed of rotation which ensures draught that enables separation of kernels from the husks. Both the preliminary and actual tests were conducted in the laboratory.

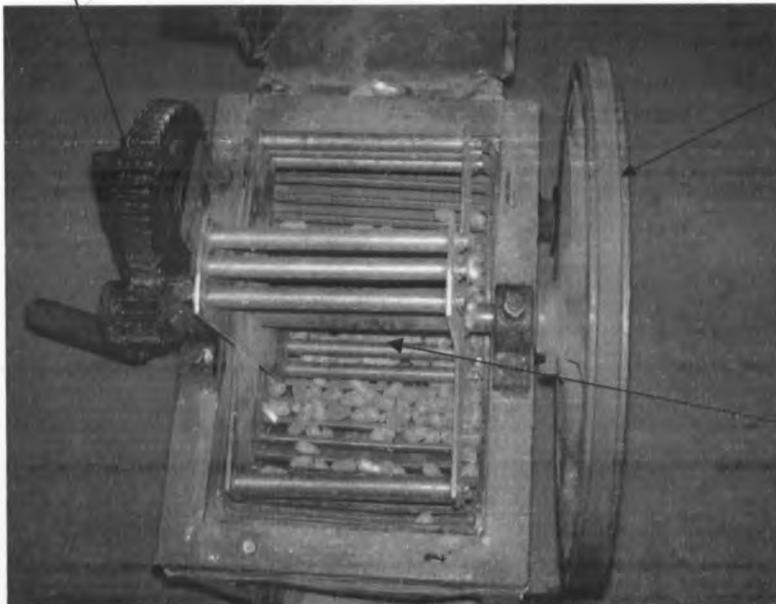


Hopper

Fan case

Plate 3.1: Rod beater decorticator

Gears



V-Belt and pulley

Rod beater

Plate 3.2: Rod beater decorticator shelling unit

3.3.2. *Wooden beater decorticator*

The wooden bar decorticator is powered manually and operates in the same manner as rod beater decorticator except that the impact, shear and compressive forces and tangential force are provided by wooded bars. The overall dimensions of the decorticator are: length of 745 mm, width of 270 mm and height of 1250 mm. A description of two essential units of the decorticator: the shelling and cleaning units are given in Plate 3.3.

The shelling unit

The shelling unit consists principally of a rotating cylinder and a stationary concave sieve. The cylinder is 160 mm in diameter and 380 mm in length. Four wooden bars are mounted uniformly on the cylinder surface and parallel to its axis.

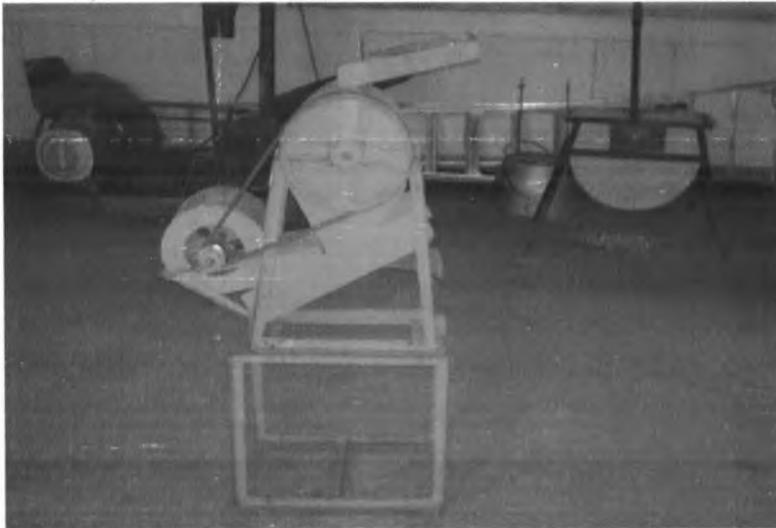


Plate 3.3: Wooden bar decorticator

The winnowing unit

The cleaning unit consists of a fan powered through the pulley belt from the shelling unit which provides the draught. The fan is 200 mm in diameter with four blades and also a circular air inlet at both sides through which air is allowed in and discharged in the direction perpendicular to the fan axis.

3.4 Testing of decorticators performance

The groundnut varieties used in the test was obtained from ICRISAT. The pods were cleaned using the cyclone separator. A known weight of groundnut pods were manually loaded in the hopper and the decorticator was set to run at clearance settings of 12 mm, 14 mm and 16 mm and sieve sizes of 12 mm, 13 mm and 15 mm respectively. Before the groundnut pods were released into the shelling chamber, the decorticator was run empty to stabilize the rotation. At each clearance and sieve size setting, groundnut pods were continuously fed to the decorticator for about 3 min.

The weight of the pods that were completely shelled and unbroken, completely shelled but broken, partially shelled and unbroken, partially shelled and broken and the weight of unshelled pods were determined at the end of each run. The quantity of shells winnowed out and those collected with the seeds were noted. The performance of the groundnut decorticators was determined in terms of shelling efficiency and kernel damage. The shelling efficiency and kernel damage were calculated using the following formula:

$$\text{Shelling efficiency (\%), } S_e = \frac{W_k}{W_t} * 100 \quad 3.1$$

$$\text{Percent kernel damage (\%), } D = \frac{W_b}{W_k} * 100 \quad 3.2$$

Where;

W_k = Weight of kernels shelled including broken kernels

W_t = Total weight of kernels fed into the decorticator

W_b = Weight of broken kernels

For each run of shelling, the variety, clearance, sieve size, moisture content, shelling efficiency and percent kernel damage were recorded. Moisture content was measured electronically using the electronic moisture meter.

Table 3.2: Results recording table

Variety	Clearance (mm)	Sieve size (mm)	Moisture content (% wb)	Shelling efficiency (%)	Kernel damage (%)

Two operators were involved in the testing of the decorticator. One fed the pods into the hopper making sure that none spilled. All weight measurements were done with the electronic weighing balance.

Before modifications were done on the decorticator, a baseline survey was conducted in Rachuonyo district to find out if the farmers in the area know about decorticators. 50 farmers growing groundnuts from Kosele, Kakwajuok and Kanyaluo areas were interviewed using the questionnaire in Appendix C. Selection of the interviewees was done using random sampling method in which the interviewer walked in a predetermined direction and stop at every farm in the path until 15 eligible respondents from each area were found.

3.5 Modifications done on the decorticator

Various modifications were done on the tested decorticator which included:

- **Change of orientation of sieve holes.** Orientation of the sieve holes influences the pressure exerted on the pods. When the pods fall such that the length of the pods run parallel to the sieve holes, the shelling efficiency reduces due to a higher percentage of pods passing through. At the same time when the orientation is against the length of the pods, there is a higher chance for the pods to be shelled. However, the assumption is that most of the pods fall when the length is vertical.
- **Change of sieve hole size.** The pressure exerted on the pod shell depends on the force with which the pod is forced through the sieve hole. The smaller the hole size, the greater the pressure thus most pods are broken. However, the size should not be so small that the kernels are broken in the process of shelling.
- **Modification of the shelling unit beaters.** While the shelling unit had wooden beaters, more breakages occurred due to the hardness of wood. If the material in contact with the pod is made of a softer material, it would cushion the contact and reduce percentage breakages. Rubber being a softer material was used. Furthermore, the wooden beater had no studs and this enabled the pods to slide away without being shelled. For the rubber beater, studs were made which increased the grip and also reduced breakages.
- **Tension of the V-belt.** The tension in the V-belt influences the amount of torque applied in rotating the shelling unit. If the length of the V - belt is increased, the tension reduces and thus the amount of torque required reduces. The length also should not be such that there is slip when the rotating handle is turned. For the wooden beater decorticator, the tension was high making the decorticator's work tiring.

3.6 Optimizing the Performance of the Decorticator

Optimization of the performance of the decorticator was done using the weighting method of goal programming technique described in detail in (Appendix A). In this method, the model is optimized using one goal at a time such that the optimum value of a higher priority goal is never degraded by a lower priority goal. Shelling efficiency was the higher goal while percentage damage was the lower goal. Supposing the goal programming model has n goals and that the i th goal is given as

$$\text{Minimize } G_i, \quad i = 1, 2, \dots, n \quad 3.3$$

The combined objective function used is defined by Equation 3.4

$$\text{Minimize } Z = W_1 G_1 + W_2 G_2 + \dots + W_n G_n \quad 3.4$$

3.7 Economic Analysis

Economic performance of the decorticator using cost analysis provided by Nyaanga *et al* (2003) was performed. In this procedure, the shelling capacity of the decorticator was computed using Equation 2.7. The period taken shelling from an average Kenyan farm was computed using Equation 2.8. Total wages paid to casual workers was calculated using Equation 2.9.

3.8 Statistical Analysis

Regression analysis was run to determine the relationships between various factors including shelling efficiency, moisture content, percent breakage, sieve size and shelling unit clearance. Analyses of Variance of shelled pods with unbroken seeds were done as provided by Hill and Lewicki (2006).

The variation between the treatment means is measured by the sum of squares for treatments (SST) given by Equation 3.5

$$SST = \sum_{i=1}^p n_i (\bar{\Pi}_i - \bar{\Pi})^2 \quad 3.5$$

The sampling variability within the treatments is given by the sum of squares for error (SSE) is given by Equation 3.6

$$SSE = \sum_{j=1}^{n_1} (x_{ij} - \bar{\Pi}_1)^2 + \sum_{j=1}^{n_2} (x_{2j} - \bar{\Pi}_2)^2 + \sum_{j=1}^{n_p} (x_{pj} - \bar{\Pi}_p)^2 \quad 3.6$$

To make the two measurements of variability comparable, each is divided by degrees of freedom to convert the sum of squares to mean of squares. The mean square for treatments which measure the variability among the treatment means is given in Equation 3.7

$$MST = \frac{SST}{p-1} \quad 3.7$$

Where the number of degrees of freedom for the p treatments is (p - 1).

The mean square for error MSE which measure the sampling variability within the treatment is given in Equation 3.8

$$MSE = \frac{SSE}{n-p} \quad 3.8$$

The ratio of MST to MSE an F statistic is given by Equation 3.9

$$MSE = \frac{MST}{MSE} \quad 3.9$$

4. RESULTS AND DISCUSSION

4.1 Physical Properties of the Nuts

Physical properties of groundnuts play an important role in the determination of decorticator features and performance characteristics. The pod size governs the clearance between shelling unit and sieve rollers that would result in effective shelling operation. The true and bulk densities, porosity and coefficient of friction influence the pressures exerted on hopper walls and flow through the orifice. The one thousand pod weight was used for the theoretical determination of the pod's effective diameter and the angle of repose was used to determine the hopper inclination. Values of the physical properties of various varieties of groundnut determined are presented in Table 4.1. The maximum, minimum and average values are reported with their standard deviation.

The major diameter is the part of the pod which houses the kernel and is the one used in grading the pods. The mean major diameters were 11.02 mm for ICGV 12991, 13.31 mm for ICGV 90704 and 13.24 mm for ICGV 99568. Koyuncu *et al.*, (2004) studied cracking characteristics of walnut and found that the energy for shelling nuts decreases with increase in the geometric mean diameter for the nuts. With the mean major diameter for ICGV 99568 being the largest, the contact with the sieve and the shelling unit is higher which translate to higher shelling efficiency and highest damage for the same settings.

Effective shelling operation requires that the clearance between the rollers for the various varieties should be just smaller by about 2 mm than the mean major diameter of the pods. This argument would result into effective shelling clearances to be 10 mm for ICGV 12991, 12 mm for ICGV 90704 and 13 mm for ICGV 99568. Apart from clearance and diameter, the other parameters that can affect the breakage of the pods include size, shape, shell thickness and texture which were also reported by Xavier (1992) and Liang *et al.*, (1984).

Table 4.1: Physical properties of the groundnut pods

Physical Properties	Values			
	Maximum	Minimum	Mean	SD
Axial dimension- Length (mm)	25.10	14.95	21.10	1.966
	34.90	15.35	26.25	5.000
	34.55	16.05	26.72	3.820
Major diameter (mm)	12.85	8.65	11.02	0.720
	16.95	10.25	13.31	1.620
	15.90	10.65	13.24	0.960
Minor diameter (mm)	11.65	8.55	9.97	1.160
	10.95	5.65	9.21	1.330
	13.50	8.85	11.36	1.295
Bulk density (Kg/m ³)	760.40	508.50	690.42	100.200
	720.90	490.90	672.78	98.400
	680.70	410.60	589.22	130.800
1000 pod weight (g)	572.10	560.90	569.70	1.220
	582.50	560.70	570.40	2.350
	591.40	569.30	575.80	3.220
Angle of repose (degrees)	36	26	30.10	3.300
	35	27	28.20	1.400
	32	25	29.40	3.200

Note: For each physical property, the first row is for ICGV 12991, second row ICGV 90704 and third row ICGV 99568 respectively.

ICGV 12991 had a mean bulk density of 690 Kg/m³, ICGV 90704 had 673 Kg/m³ while ICGV 99568 had 589 Kg/m³. The shelling efficiencies for ICGV 12991 is expected to be high as it had high bulk density but the results showed that it was lower. This indicated that other parameters supersede bulk density in influencing

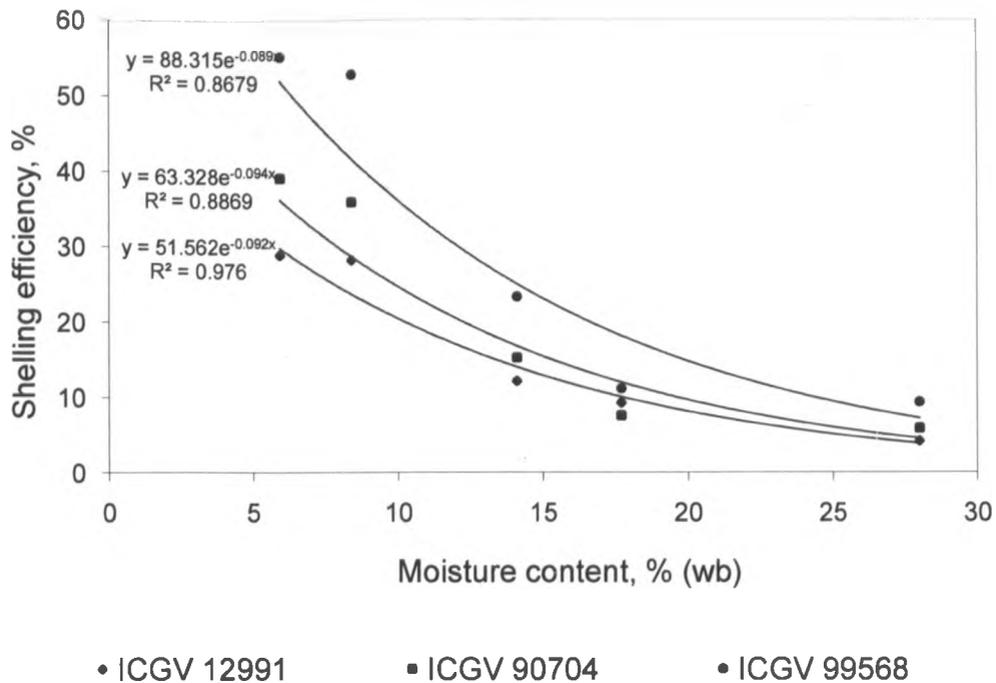


Figure 4.1: Effect of moisture content on shelling efficiency of WBS at 22.6 mm clearance and 30 Kg/hr feed rate.

4.2.2. Rod Beater Decorticator

Decorticator clearance significantly influenced the shelling efficiency of the groundnut decorticator for all the varieties and also had significant effect on percent kernel damage. Shelling efficiency is affected by the decorticator clearance such that as the clearance increases, shelling efficiency decreases but the efficiencies are higher for ICGV 90704 and ICGV 99568 as shown in Figure 4.2. Clearance of the decorticator influences the compressing forces that the nuts experience. Similar results were reported by Oluwole *et al.*, (2007) when evaluating centrifugal impactor devices for shelling Bambara groundnut. As the clearance reduces, the pods are compressed against the sieve with great force thus ensuring shelling. When the size of the pod is big, the relative clearance is reduced and the shelling efficiency increases as also reported by Bhagawan *et al.*, (1985).

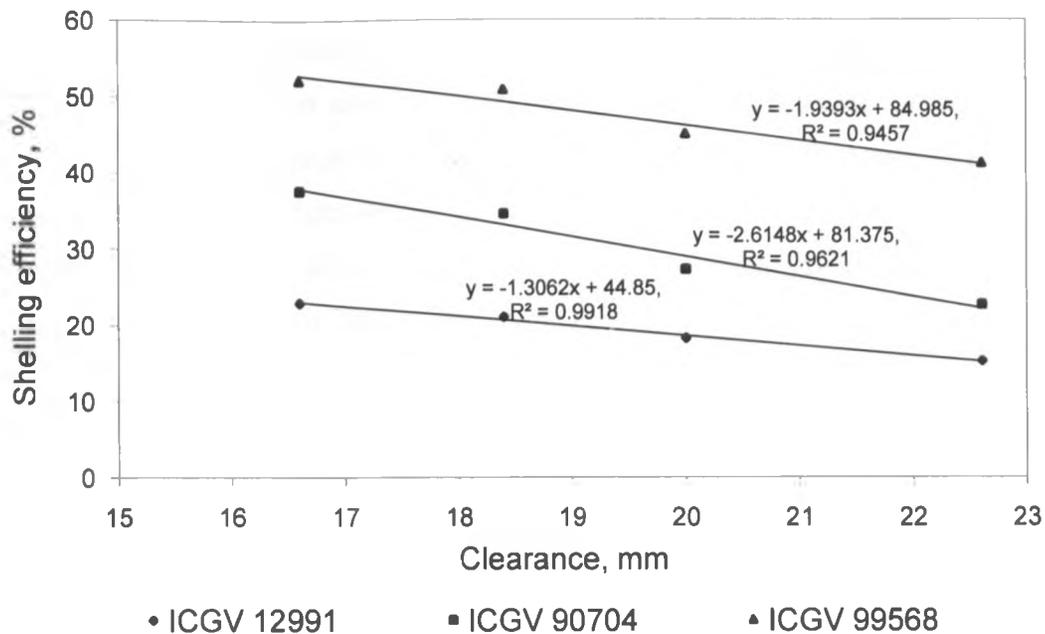


Figure 4.2: Effect of decorticator clearance on shelling efficiency of RBS decorticator

Selection of the decorticator to modify was based on affordability, availability and ease of operation. WBS is fabricated by local artisans and using local materials while RBS is imported. WBS was chosen for modification based on the fact that it is easy to operate and therefore would be appropriate for women since according to the baseline survey conducted; they make 86% of the people involved in shelling (Appendix D). WBS being fabricated locally means there is capacity for maintenance and this also creates employment for the youth.

Optimization was done before modification. Equations for optimization were obtained from the results of regression analysis for the tests. Modifications done included change of sieve hole size, clearance and orientation. Shelling unit beaters were modified and tension of the belt adjusted. The drawings in Appendix E were done based on the existing dimensions of the decorticator.

4.3 Results for Modified Decorticator

Modifications done on the shelling unit and the sieves can be seen in Appendix E. Fabrication was done using procedures provided by Makoko *et al.*, (1991). The orientation of the sieve holes was modified and shelling unit also modified to have rubber lining to reduce kernel breakages and increase shelling efficiency.

The results after modifications show that the shelling efficiency increased and the percent breakage reduced due to the modifications regarding sieve hole size and orientation, clearance of the shelling unit, shelling unit beaters and tension of the V-belt. The results obtained from the performance evaluation of the modified decorticator are presented in Figure 4.3. The shelling efficiency for the decorticator varies between the different varieties because of the different physical properties of the pods. Generally, the size of the sieve for the decorticator is inversely proportional to shelling efficiency. However, this is expected as when the sieve size is small, the pod is subjected to high shear and impact forces thus separating the kernel from the pods. With the pods experiencing high shear and impact forces, the kernels also experience the same and so high kernel breakages. To reduce the impact and shear forces, softer but firm material like rubber with cushioning effects is used, percent breakage can be reduced. This is shown by the fact that the kernel breakages are lower for the modified decorticator than either WBS or RBS decorticators. This agreed with the results reported by Akani *et al.*, (2000)

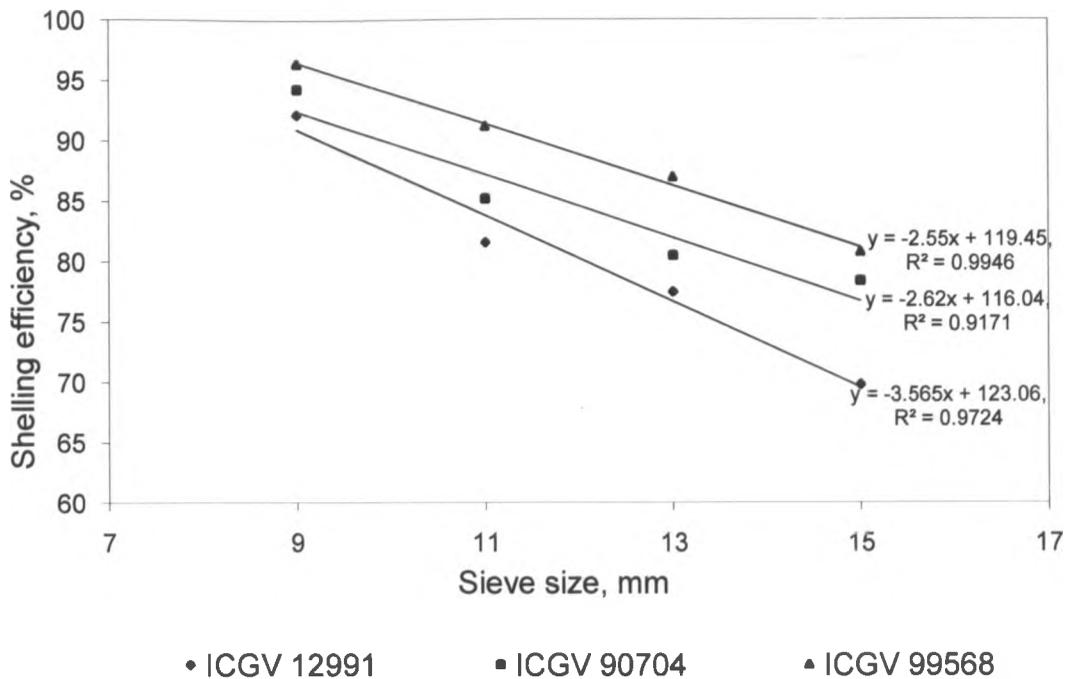


Figure 4.3: Effect of sieve size on shelling efficiency for modified decorticator

Figure 4.4 show that shelling efficiency increases with decrease in clearance. The highest shelling efficiency of 87% was obtained at a clearance of 10 mm for ICGV 99568 which is the largest in size from the three varieties. The general efficiency of the modified decorticator is far above those of the RBS and WBS which could only go to a maximum of 55% because of sieve sizes and clearances which are not optimum. With the clearance increasing, damage is expected to reduce as shear and compression forces are reduced.

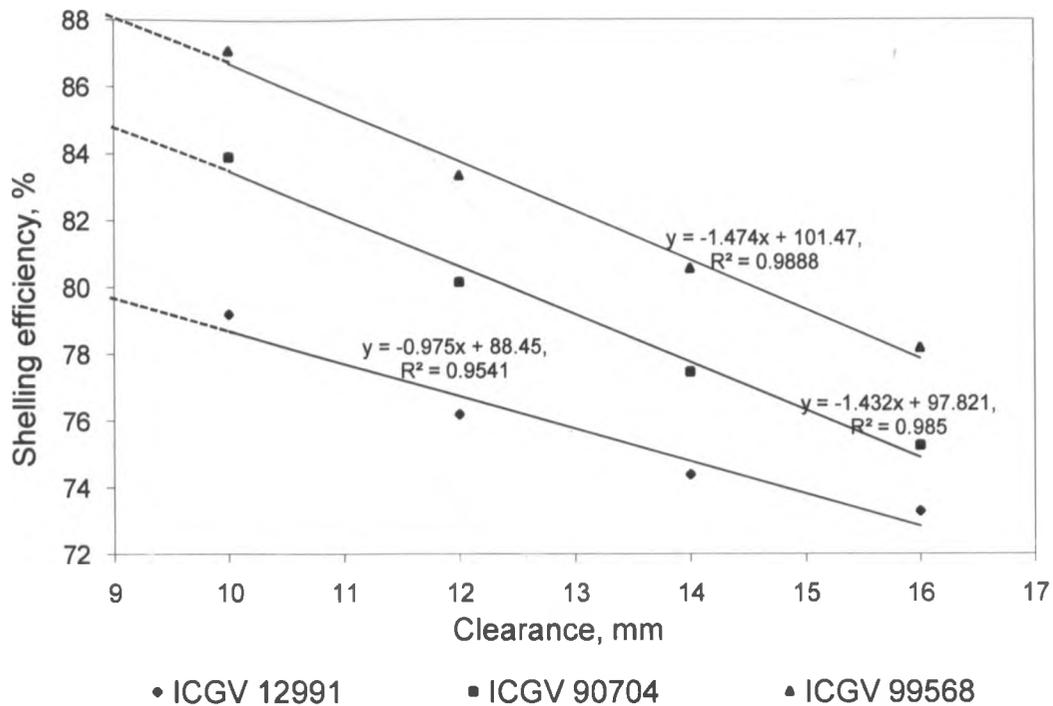


Figure 4.4: Effect of clearance on shelling efficiency for modified decorticator

Figure 4.5 shows the graph of damage versus clearance for the modified decorticator. ICGV 99568 had the highest percent damage of upto 18% which can be due to fact that it is the biggest in terms of size. As the size increases, the pods tend to be weaker thus making it easy to break. On the other hand ICGV 12991 had the lowest percent damage which can be due to small size. With a clearance of 16mm it is possible to get percent damage of less than 6% for ICGV 12991. This is not as was predicted by the optimization, which can be attributed to the fact that optimization did not take into account breakage characteristics of the pods of the different varieties.

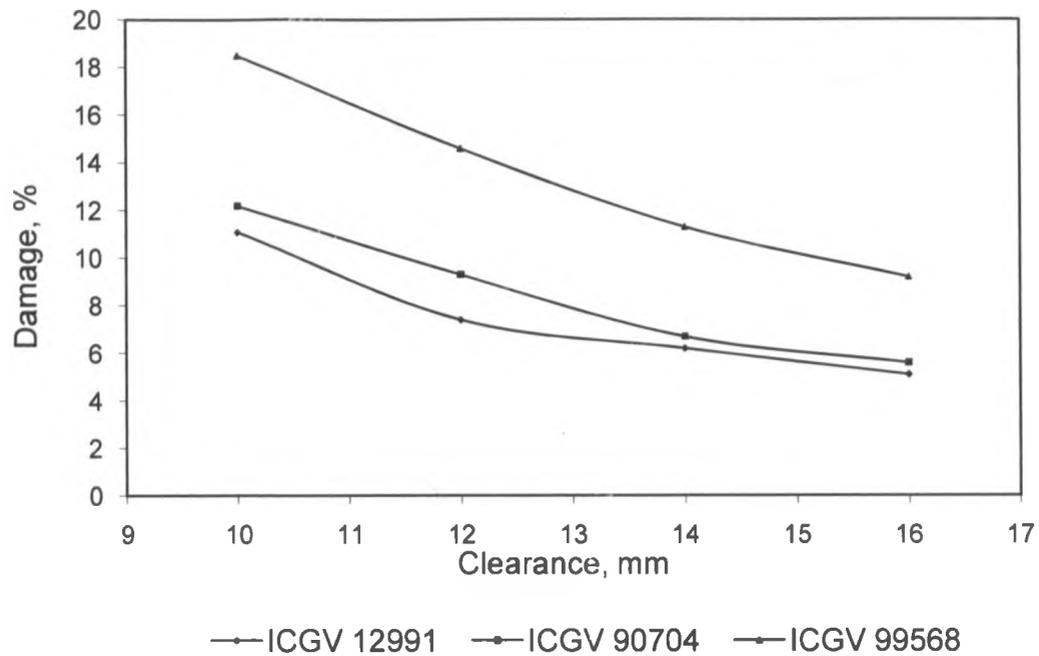


Figure 4.5: Graph of damage versus clearance for modified decorticator

4.4 Optimization of performance of decorticator

To optimize the performance of the manually operated groundnut decorticator, the relationship between shelling efficiency and sieve size and clearance was tested under laboratory condition. For optimization, the parameters affecting the performance majorly the clearance and sieve size were identified as the goals of optimization.

4.4.1. Relationship of shelling efficiency to sieve size and clearance

Regression analysis was run for two factors namely sieve size and decorticator clearance which can best predict shelling efficiency and percent damage. The model which can best predict the shelling efficiency by sieve size and clearance is given by:

$$SE = -1.048 SS - 0.031 C + 99.82$$

4.1

Where:

SE is shelling efficiency, (%)

SS is sieve size, mm

C is clearance, mm

The ANOVA results show that the model is acceptable from a statistical perspective with a significant F statistic ($p = 0.000$) < 0.05 indicating that the model can be used to predict the shelling efficiency (Appendix B). In determining the relative importance of the significant predictors i.e. sieve size and clearance, the standardized coefficients were checked. Even though sieve size and clearance between shelling unit and sieve contribute to the model, sieve size contributes more to the model than clearance because it has a larger absolute standardized coefficient of 0.855. Clearance is a non significant coefficient for clearance ($p = 0.955$) > 0.05 implying that decorticator clearance does not contribute much to the model.

The strength of the relationship between the model predicted values and the observed values of the dependent variable is such that the R^2 value is 0.731 showing that more than 70 % of the variation in shelling efficiency is explained by the model. This implies that the model can be used to predict the shelling efficiency.

4.4.2. Relationship of percent damage to sieve size and clearance

The estimates of the coefficients of linear equation involving the two independent variables that best predict the percent damage is given by Equation 4.2

$$D = 0.09 SS - 0.881 C + 17.094 \quad 4.2$$

Where D is damage, %

The model can be used to predict the percent damage from the sieve size selected and the clearance selected because it has a p value of $0.000 < 0.05$ which means the variation explained by the model is not due to chance. The regression sum of squares is slightly more than residual sum of squares which indicates that more than half of the variation in percent damage is explained by the model.

The model summary in Table 4 in Appendix B reports the strength of the relationship between the model and percent damage. R, the multiple correlation coefficient, is the linear correlation between the observed and model-predicted values of percent damage. Its large value indicates a strong relationship. The R^2 value for the model was 0.561 showing that about half the variation in percent damage is explained by the model.

4.5 Optimization of shelling efficiency and percent damage

The goals of optimization which included maximizing efficiency and minimizing damage were ranked in order of priority. Coefficients of the equations developed were entered into TORA which defined the optimum value of the deviational variable. Constraints included minimum and maximum sieve size and clearance. The LP was solved with the same constraints plus an additional constraint from the previous procedure. The optimum solution was then determined by TORA.

Optimization of technical performance of the decorticator requires maximization of shelling efficiency and minimization of percent damage. Equations 4.1 and 4.2

show the separate equations for shelling efficiency and percent damage which need to be maximized and minimized respectively. Optimization of the two equations using TORA show that the maximum shelling efficiency of 88.73% can be achieved with percent damage of 4% when the sieve size is 11 mm and clearance is 16 mm.

4.6 Economic analysis results

In this section, a cost analysis of the decorticator was evaluated. A payback period was employed to determine the duration required for a profit that could be attributed to using the decorticator. The modified decorticator has a shelling capacity of 30 Kg/hr. Working for 6 hours in a day; the machine can shell a total of 180 Kg/day. The period taken shelling 520 Kg/ha from an average Kenyan farm (Nyaanga *et al.*, 2003) is 3 days/ha. The number of casual workers required to work with this machine at a wage rate per person per day of Kshs 200 means the total wages paid to the casuals is Kshs 1,200/ha. The cost of fabricating the decorticator is Kshs 12,000 and the life time of the decorticator has an estimated life span of 5 years when used carefully. For commercial purposes where shelling is charged at 50 cents per Kg, the owner generates about Kshs 50 per day to save. Therefore to realize profit, the payback period becomes 8 months.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Shelling efficiency

Two manually operated groundnut decorticators were tested and one of them modified. The performance tests showed that the requirements of the farmers including low kernel breakages and high shelling efficiencies could be achieved by the modified decorticator. Two equations relating shelling efficiency and kernel damage to clearance and sieve size were developed and optimization of the two equations using TORA show that the maximum shelling efficiency of 88.73 % can be achieved with percent damage of 4 % when the sieve size is 11 mm and clearance is 16 mm. These values indicated that the machine performance is comparable to that of power operated decorticators.

Kernel damage

Kernel damage is affected by clearance and sieve size. The kernel damage for the different varieties was significantly different indicating that the different varieties have difference in pod resistance to shear and compressive stresses.

The important implication of the results of this study is that the modified groundnut decorticator can effectively be used to shell the local groundnut varieties. It has also been modified using materials available locally and it is sufficiently simple for local production and operation.

5.2 Recommendations

- Studies should be done on kernel resistance to compressive and shear stresses. This is because different varieties of groundnuts do have different physical characteristics. Moreover, the cracking characteristics of the pods differ and it is expected that the physical characteristics of the kernels also differ.
- The advantage of the modified sheller is that it can be used to shell for seed purposes. By using the sheller for seed purposes, the labour cost for shelling, time and labour can be substantially reduced. It is therefore recommended that the performance be evaluated over time for improvement.
- Even though farmers could earn more income by shelling groundnut, the shelling of groundnut for direct selling may cause marketing problems to the farmers. It is recommended that studies be done to check if shelling the groundnut through farmers' cooperative societies can produce more monetary benefits to the farmers through economy of scale. This is because buyers may tend to give lower prices to individual farmers for selling small amounts of groundnuts than through cooperatives.

6. REFERENCES

- Adigun, Y. J. and Oje, K. (1993).** Thevetial fruit processing: Energy requirements for cracking the nut. Proceedings of the Nigerian Society of Agricultural Engineers (NSAE). 15: 128 – 139.
- Akani A. O., Ohanwe C. N., Omonyi I.O., (2000).** Determination of optimum impact for decortications of Bambara groundnut. Proc. Nigerian Soc. Agric. Eng., 22, 87-89.
- Akali I. D. (1996).** An approach to developing a peanut sheller: Agricultural Mechanisation in Asia, Africa and Latin America, Vol. 27, No. 3, pp. 44-50.
- Allen, S. H., Alfred, R. H. and Herman, G. L. (1967).** New machine design. Schaums outlines. Mc Graw – Hill.
- Anandachar M., Mathew M. and Adwani M.R. (1990).** Effect of decortications method on groundnut seed quality. *Seed Res.* 18: 144-147.
- AOAC (Association of Official Analytical Chemists) (1980).** Official methods of analysis, 13th edition. Association of Official. Analytical Chemists, Washington D.C.
- ASAE Standards (2000).** Moisture Measurement – Groundnuts. ASAE S410.1 December 1997. American Society of Agricultural Engineers, 2950 Niles Road, St. Joseph, MI 49085–9659, U.S.A.
- Atiku, A.A. (2000).** Bambara groundnut processing and storage practices in North Eastern Nigeria. Postgraduate seminar paper, Department of Agricultural Engineering, University of Maiduguri, Maiduguri, Nigeria.
- Atiku N., Aviara N., and Hague M., (2004).** "Performance evaluation of a Bambara ground-nut Decorticator". Agricultural engineering international: the CIGR Journal of scientific research and development manuscript PM 04 002. Vol. VI July, 2004.
- Baldwin, J.A. and Beasley, J.P. (1990).** Groundnuts – A Grower's Guide to Quality. Planters LifeSavers, Winston-Salem, NC.

Banshi D. Shukla, Prabhat K. Srivastava, Ram K. Gupta (1992). Oil seeds processing technology. Central institute of agricultural engineering, Nabi Bagh.

Bhagawan S., Varshney B.P., Nasim A. and Tiwari J.P. (1985). Development and testing of groundnut decorticator. *J. Agri. Engg. ISAE*, **25**:15-20.

Blankenship, P.D. and Chew, V. (1979). Groundnut drying energy consumption. *Groundnut Sci.* **6**, 10–13.

CEEMAT (1988). Conservation des grains en régions chaudes. Paris.

CGIAR (2008) <http://www.cgiar.org/impact/research/groundnut.html>.

Chai, L. and Young, J.H. (1995). Simulated air flow rate effects on drying times and costs for conventional and recirculating groundnut drying facilities. *Groundnut. Sci.* **22**, 8–14.

Chinsuwan, W. (1983). Final Report: Groundnut Decorticators Project. A Report Submitted to the International Development Research Centre (IDRC). March 1983.

Collins, G.A., Coward, L.D.G., and Pinson, G.S. (1977). Performance of a hand operated ground-nut decorticator. Rural technology guide, Issue 4. Tropical products institute.

Dash, A.K., Das, .K. and Das S.K. (1994). Development and performance evaluation of a pedal operated groundnut decorticator. *AMA*, **25**: 61-65.

Dimarogonas D. A. (2000). Machine design: A CAD approach. Edition II illustrated. Published by Wiley-IEEE.

Duke, J.A. (1981a). Handbook of legumes of world economic importance. Plenum Press. New York.

Ezeaku, C. A. (1994). Fracture characteristics of Bambara groundnut in compressive loading. Unpublished M. Eng. Thesis. University of Nigeria, Nsukka.

FAO (2008) <http://www.fao.org/inpho/content/compand/text/Ch21sec2.htm>.

- Goli, A.E. (1997).** Bambara groundnut. Bibliographic review. In Bambara groundnut.
- Hill, T. and Lewicki, P. (2006).** Statistics: Methods and applications. www.statssoft.com.
- ICRISAT (2008).** <http://www.icrisat.org/GroundNut/GroundNut.htm>.
- IDRC (1998).** <http://archive.idrc.ca/library>.
- Jha, S.K., Singh Amar, Kumar Adarsh (2008).** Physical characteristics of compressed cotton stalks. Biosystems Engineering, 99: 205-210. Journal of Technology (In press).
- KAPP (2007).** Newsletter. Issue 1. Volume 1. July/Sept 2007.
- Koguta, T. J. and K'Osambo, L. (1999).** The industrial survey of metal based agroprocessing technologies for development of micro and small enterprises in Kenya. A report on sectoral study in facts and oils processing technologies. KIRDI.
- Koyuncu, M.A., Ekinci, K., Savran, E. (2004).** Cracking characteristics of Walnut. Biosystems Engineering, 87 (3): 305-311.
- Lagat, C.K., Okemwa, P., Dimo, H., Kipkurui, L., Korir J.K., (2007)** "The State of Agricultural Mechanisation in Uasin Gishu District, Kenya, and its Impact on Agricultural Output." Agricultural Engineering International: the CIGR Ejournal. Invited Overview No. 8. Vol IX. June, 2007.
- Liang, T.A., Chin, L., Mitchell, J.B. (1984).** Modelling moisture influence on Macadamia nut kernel recovery, Transaction of ASAE, 27: 1538-1541.
- Makoko, M. S. and Balaka, H. R. (1991).** Instruction manual for the construction and use of a hand operated wooden groundnut sheller. Farm machinery unit, Ministry of Agriculture. Lilongwe, Malawi.
- Martin, F.W. and Ruberte, R.M. (1975).** Edible leaves of the tropics. Antillian College Press, Mayaguez.

Mendez P.F., Ordonez F. (2005). "Scaling laws from statistical data and dimensionless analysis. *Journal of applied statistics*.

Nautiyal P. C (2007) National Research Centre for Groundnut (ICAR) (<http://www.icar.org.in/>).

Newnan, D. G. (1980). *Engineering Economic Analysis*. Engineering Press Inc., California.

Nyaanga, D.M, Chemelil, M.C., Kimani, P.K., Kirui, W.K., and Musimba, S.K (2003) Development and evaluation of a portable hand operated groundnut sheller. Paper presented at the KSAE International conference on 27-28 November, 2003.

Okumu M. O. (2000). Economic evaluation of groundnut production as an alternative cash crop for small holder farmers in Matunda, Transmara district. Ministry of Agriculture and rural development, Kenya.

Oluwole F., Abdulrahim A. and Olalere R. (2007). "*Evaluation of some centrifugal impaction devices for shelling Bambara groundnut*". *Agricultural Engineering International: The CIGR Ejournal*. Manuscript PM 07 007. Vol. IX. October.

Oluwole, F.A; Aviara, N.A. and Haque, M.A. (2004). Development and performance tests of a sheanut cracker. *Journal of Food Engineering*, 65(1): 117 – 123.

Patil R.B., Bharid R.W. and Pokharkar S.M. (1988). Mechanical shelling and damage in groundnut. *Seed Res.* 16: 112-113.

Putnam, D.H and Oplinger, E.S (1991). "Peanut". Center for Alternative Plant and Animal Products, University of Minnesota, St. Paul, MN.

Rajkumar P., Varadharaju N., Sreenarayan V.V. (2004). "Studies on milling outturn of paddy varieties using rubber roll sheller". *The Madras Agricultural Journal*. Vol-91-1-3 Jan-March 2004.

Rogers, R.A. and Brusewitz, G.H. (1977). Drying Spanish groundnut pods with short duration, high-temperature air cycled daily. *Groundnut Sci.* 4(1), 12–15.

Sawaragi, Y.; Nakayama, H. and Tanino, T. (1985). Theory of Multiobjective Optimization (vol. 176 of Mathematics in Science and Engineering). Orlando, FL: Academic Press Inc. ISBN 0126203709.

Sheppard, M. (2007). Systematic search for expression of dimensionless constants using NIST data base of physical constants.

Steuer, R.E. (1986). Multiple Criteria Optimization: Theory, Computations, and Application. New York: John Wiley & Sons, Inc. ISBN 047188846X.

Suter, D.A., Agrawal, K.K. and Clary, B.L. (1975). Thermal properties of groundnut pods, hulls and kernels. *Trans. ASAE* 18, 370–375. ISI.

Taha, A. H. (2003). Operations research an introduction. Pearson education Seventh edition.

Tangka, J.K. and Penda, P.M. (2007). Development and performance evaluation of a medium scale system for processing bitter leaf. *Journal of Biosystems Engineering*, 96 (2): 223-229.

Tanimu, B. and Aliyu, L. (1997). Bambara groundnut, country report: Northern Nigeria. In Bambara groundnut. *Vigna Subterranea (L.) verdc.* Promoting the conservation and use of underutilized and neglected crops. Proceedings of the workshop on conservation and improvement of Bambara groundnut (*vigna subterranea (L.)verdc.*

Thirupathi, V., Viswanathan, R. and Thangavel, K. (2004). Intensive evaluation of power operated groundnut decorticator. *Research notes. Madras Agricultural J.* 91 (1-3): 140 – 141. Jan – March 2004.

Thomas Schoepe (2007). www.plant-pictures.de

Tromlow, S., O'Neill, D., Sims, B., Ellis,-J., Jim, J. T. (2002). An Engineering perspective on sustainable smallholder farming in developing countries. *Journal of Biosystems Engineering*, 8 (3): 355-362. *Tropical crop communication*, 15: 1 – 14.

Whitaker, T.B. and Young, J.H. (1972a). Simulation of moisture movement in groundnut kernels: Evaluation of the diffusion equation. *Trans. ASAE* 15, 163–166. ISI.

Whitaker, T.B. and Young, J.H. (1972b). Application of the vapor-diffusion equation for concentric spheres in describing moisture movement in groundnut pods. *Trans. ASAE* 15, 67–171, 174.

Xavier, J.A. (1992). Study of Macadamia nut breakage. MSc Thesis, Botukatu, SP UNESP, Brazil.

Yao, G., (2004) "Peanut Production and Utilization in the People's Republic of China", University of Georgia.

Young, J.H., Person, N.K., Donald, J.O. and Mayfield, W.D. (1982). Harvesting, curing and energy utilization. In *Groundnut Science and Technology* (H.E. Pattee and C.T. Young, eds.) pp. 458–485, American Groundnut Research Education Society, Yoakum, TX.

7. APPENDICES

Appendix A: Goal Programming

This section presents two algorithms for solving the goal-programming problem. Both methods are based on representing multiple goals by a single objective function. In the weighting method, a single objective function is formed as the weighted sum of the functions representing the goals of the problem. The preemptive method starts by prioritizing the goals in order of importance. The model is then optimized using one goal at a time and in such a manner that the optimum value of a higher-priority goal is not degraded by a lower priority goal. The proposed two methods are distinct, in the sense that they will not generally produce the same solution. Neither method, however, can be claimed superior because each technique is designed to satisfy certain decision-making preferences.

The Weighting method

Suppose that the goal programming models has n goals and that the i^{th} goal is given as:

Minimize $G_i, i = 1, 2, \dots, n$

The combined objective function used in the weighting method is then defined as

Minimize $Z = W_1G_1 + W_2G_2 + \dots + W_nG_n$

The parameter $W_i, i = 1, 2, \dots, n$, represents positive weights that reflect the decision maker's preferences regarding the relative importance of each goal. For example, $W_i = 1$ for all i , signifies that all goals carry equal weights. The determination of the specific values of these weights is subjective. Indeed, the apparently sophisticated analytical procedures developed in literature are still rooted in subjective assessments.

The optimization was done through the following procedure:

1. The goals of the model were identified and ranked in order of priority. Shelling efficiency (E) was taken as the higher goal and Percent damage (D) was taken as the lower goal.
2. Linear program (LP) that maximizes E was solved using TORA software which defined the optimum value of the deviational variable. Constraints included the minimum and maximum sieve size and minimum and maximum clearance.
3. The LP which minimizes the damage (D) was solved with the same set of constraints in step 2 plus the additional constraint from the result of step 2.
4. The optimum solution was then obtained by TORA.

Example

The following are the equations relating the shelling efficiency and kernel damage to clearance and sieve size. Let X_1 and X_2 be the size of clearance and sieve size respectively. The goal programming formulation of the problem is given as:

Minimize $G_1 = S_1^+$ (Satisfy shelling efficiency goal)

Minimize $G_2 = S_1^-$ (Satisfy Damage goal)

Subject to:

$$4X_1 + 8X_2 + S_1^+ - S_1^- = 45 \quad (\text{Shelling efficiency goal})$$

$$8X_1 + 24X_2 + S_2^+ - S_2^- = 100 \quad (\text{Damage goal})$$

$$X_1 + 2X_2 \leq 10 \quad (\text{Clearance limit})$$

$$X_i \leq 6 \quad (\text{Sieve size limit})$$

$$X_1, X_2, S_1^+, S_1^-, S_2^+, S_2^- \geq 0$$

The efficiency goal is more important than damage goal.

$$\text{Minimize } Z = 2G_1 + G_2 = 2S_1^+ + S_2^-$$

The optimum solution is obtained by TORA is

All the remaining variables equal to zero.

Appendix B: Table of results for analysis

Table 7.1: ANOVA results for shelling efficiency

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2194.999	2	1097.500	61.055	.000
Residual	808.906	45	17.976		
Total	3003.905	47			

Table 7.2: Coefficients of the model

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	99.820	2.030		49.181	.000
Sieve size	-6.048	.547	-.855	-11.050	.000
Clearance	-.031	.547	-.004	-.057	.955

Table 7.3: ANOVA table for relationship of damage to sieve size and clearance

	Sum of Squares	df	Mean Square	F	Sig.
Regression	550.648	2	275.324	28.771	.000
Residual	430.625	45	9.569		
Total	981.273	47			

Table 7.4: Model summary for prediction of percent damage

R	R Square	Adjusted R Square	Std. Error of the Estimate
.749	.561	.542	3.09345

Appendix C: Questionnaire

Instruction

Please tick where appropriate and fill the spaces where appropriate

Date of interview

Time of interview

Place of interview.....

Part I: Interviewee background

Sex: Male Female

Marital status: Married Single Divorced Separated

Level of education: Illiterate Primary High school University

Age: 15-25 26-35 36-45 46-60 >60

Occupation.....

Part II: Decorticators

1) Do you grow groundnut?

Yes No

2) For what use do you grow groundnut?

Domestic Sale

3) What do you use to shell the groundnut?

Hand Decorticator Other.....

4) Do you at times hire people to shell for you your groundnut?

Yes No

5) If yes in Q 4, how much do you pay for the hire?

Kshs.....

6) Have you seen a groundnut decorticator?

Yes No

7) Would you like equipment that can shell the groundnut faster?

Yes No

If No, why

.....

8) When shelling by hand, approximately how many kilograms of kernels on average can you shell in a day?.....

9) In hand shelling, which people are mostly involved?

Women Men

Appendix D: Survey Results

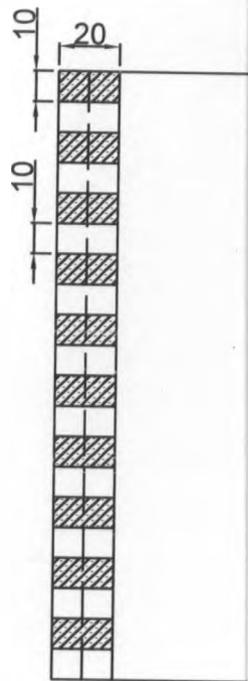
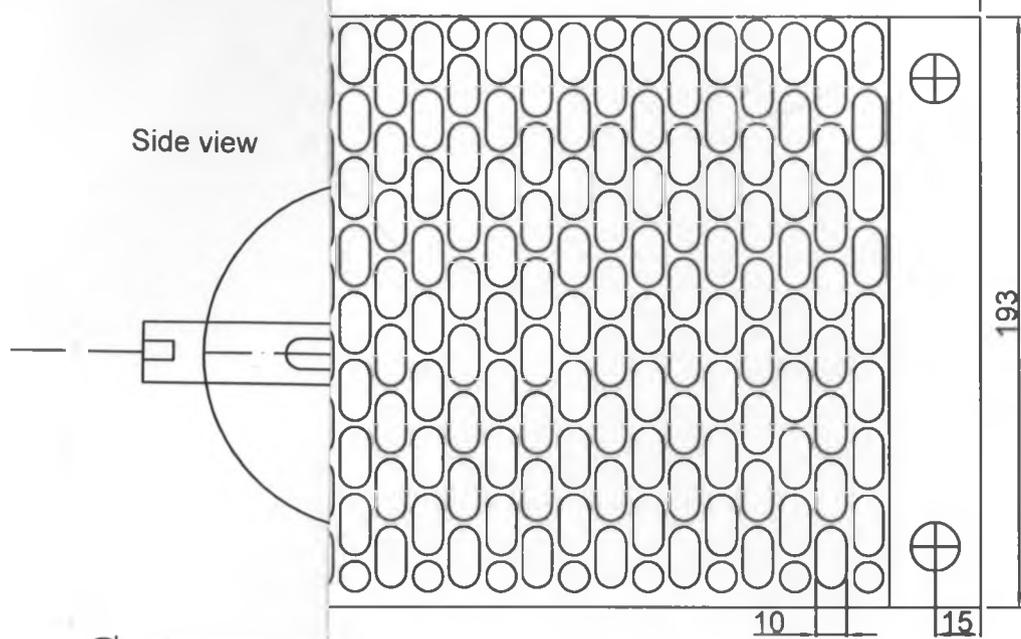
Response	Respondent would like a Decorticator	Respondent hires people to shell
Yes	81	76
No	19	24

Mode of Shelling	Percentage
Hand	95
Decorticator	5

People Involved in Shelling	Percentage
Women	86
Men	14

Appendix E: Modification Sieve 10 mm

SI 376



Tc

Schedule of materials for modification

No.	Item description	Size	Qty
1.0	Metal plate 3 mm thick	38X20cm	1
2.0	Bolts	14/15"	8
3.0	Shaft	Di 20mm	1
4.0	Bearing + Housing	204	2
5.0	V-Belt	A55	2
6.0	Used Rubber tire	Small	1
7.0	Welding rod	Packet	1
8.0	Plate Punch		1

Modifications drawing of decorticator

Dimensions in mm

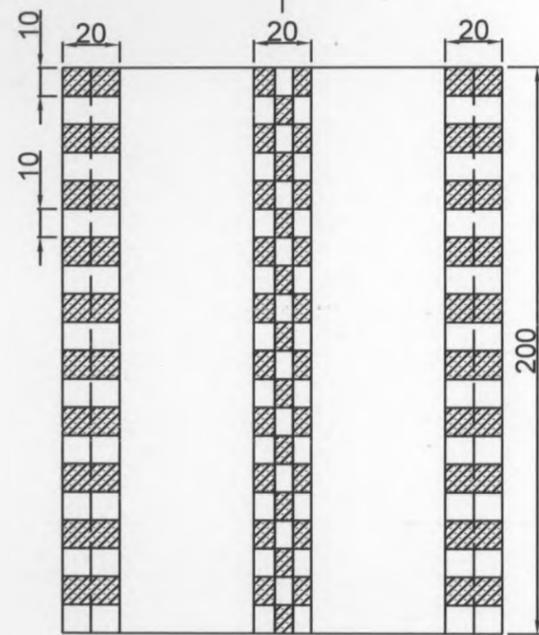
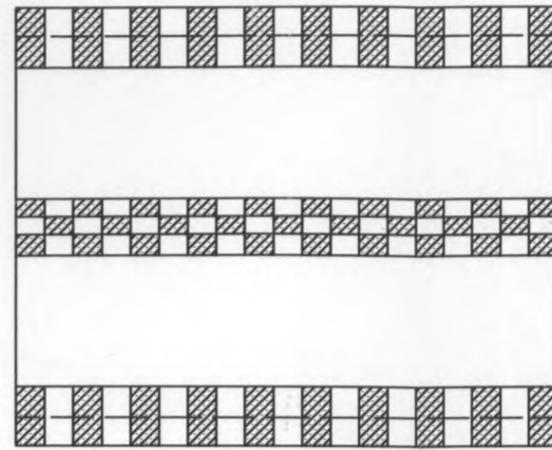
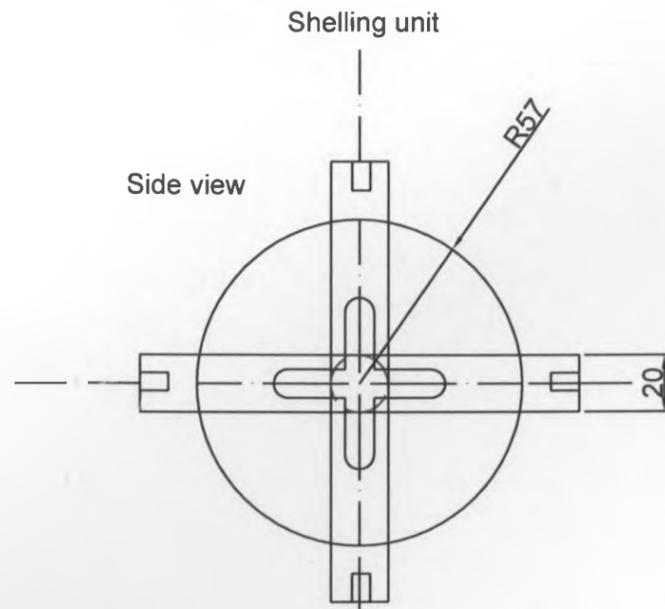
Scale: 1:1

Drawn by: Mboya Paul

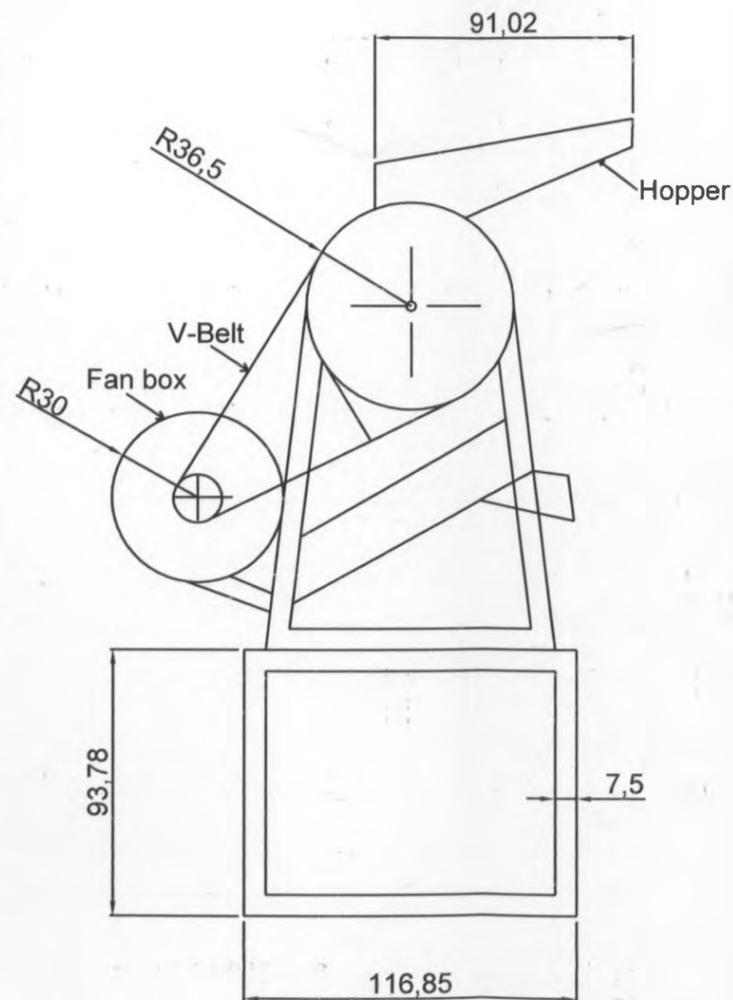
Reg. No.: F56/9192/06

Date drawn: 25 May 2008

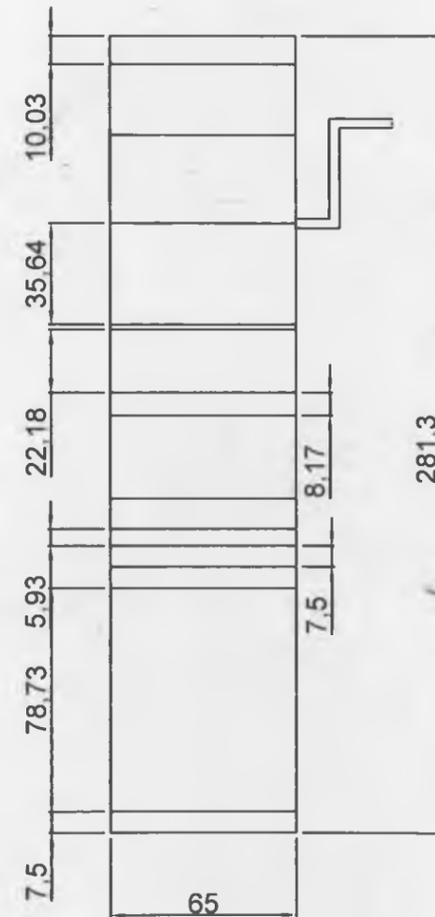
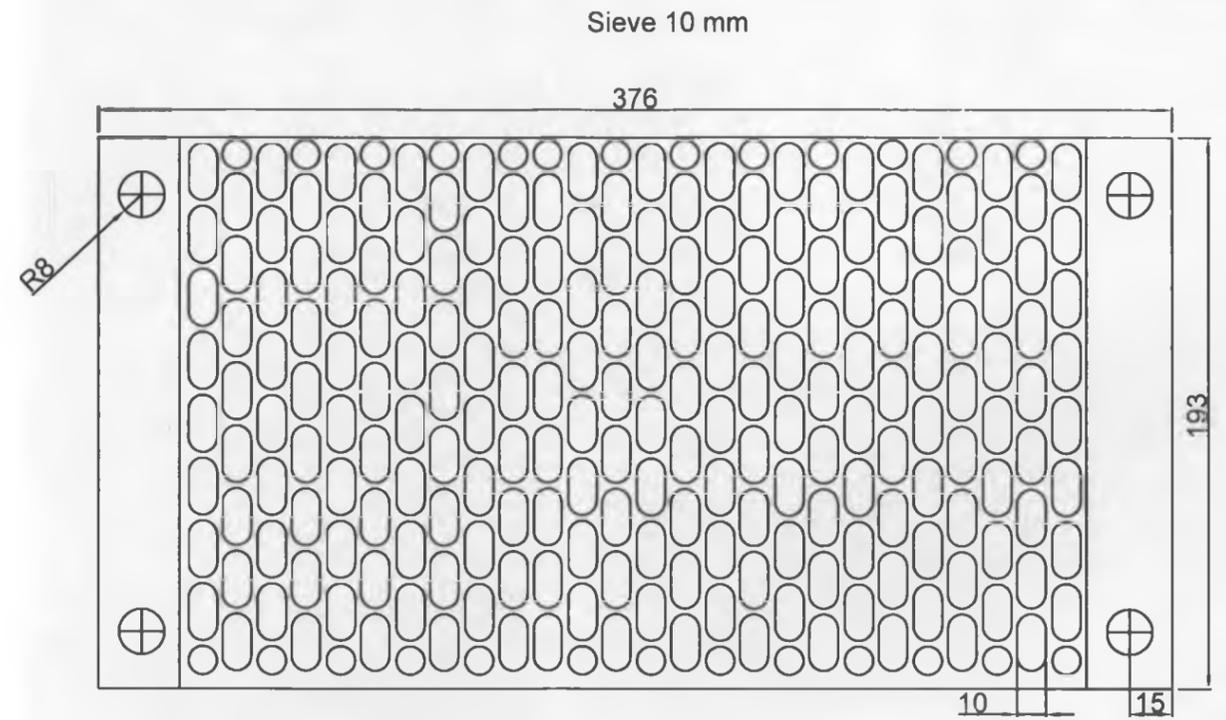
Appendix E: Modification drawings of decorticator



Top view



Side view
Sheller



Front view

Schedule of materials for modification

No.	Item description	Size	Qty
1.0	Metal plate 3 mm thick	38X20cm	1
2.0	Bolts	14/15"	8
3.0	Shaft	Di 20mm	1
4.0	Bearing + Housing	204	2
5.0	V-Belt	A55	2
6.0	Used Rubber tire	Small	1
7.0	Welding rod	Packet	1
8.0	Plate Punch		1

Modifications drawing of decorticator

Dimensions in mm

Scale: 1:1

Drawn by: Mboya Paul

Reg. No.: F56/9192/06

Date drawn: 25 May 2008