Design, Construction and Performance Evaluation of Motor Driven Maize Sheller

by

Gudina Abdisa Duguma

Thesis Submitted to

Mechanical System and Vehicle Engineering Department

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Agricultural Machinery Engineering

Adama Science and Technology University

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DECLEARTION

I hereby declare that this MSc Thesis entitled “Design, Construction and Performance Evaluation of Motor Driven Maize Sheller” for the partial fulfillment of the requirements for the award of the degree of Master of Science in Agricultural Machinery Engineering is my own work carried out from January, 2017 to September, 2018 under the supervision of Dr.Ing.- Simie Tolla, Department of Mechanical Systems and Vehicle Engineering, Adama Science and Technology University.

This is my original work and has not been submitted by me for the award of any other masters or degree. All relevant resources of information used in this thesis have been dully acknowledged.

Gudina Abdisa Duguma ____________________ ____________________

Name of student Signature Date

This MSc thesis has been submitted for examination with my approval as thesis advisor.

Dr. Ing.- Simie Tolla ________________________ ____________________

Advisor Signature Date

APROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Gudina Abdisa have read and evaluated his thesis entitled Design, Construction and Performance Evaluation of Motor Driven Maize Sheller and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Masters of Science in Agricultural Machinery Engineering.

______________________	__________	________________
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Internal Examiner	Signature	Date
______________________	__________	________________
External Examiner	Signature	Date

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The moment has come to look into the deeper layer of heart, which is filled with the feeling of togetherness, loveliness, consolation and satisfaction, a sign of relief and sense of fulfill ment.Some are momentary and some are permanent, but both involve a number of near and dear persons to whom I acknowledge my warm regards and take this opportunity toexpress my feelings during the course of my study.

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DEDICATION

This work dedication goes to my mother for her consistent and unreserved help, support and prayers for my success until she has been died 21^{st} – June 2018.

LIST OF ACRONOMYS

ACMA	Adama City Metrology Agency
ANOVA	Analysis of Variance
ASME	American Society of Mechanical Engineering
ASTU	Adama Science and Technology University
CSA	Central Statistical Agency
DRC	Democratic Republic of Congo
EIAR	Ethiopian Institute of Agricultural Research
ES	Ethiopian Standard
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agricultural Organization Statistical Database
IRR	Internal Rate of Return
LHS	Left Hand Side
LSD	Least Significant Difference
M.S	Mild Steel
RARI	Regional Agricultural Research Institute
RHS	Right Hand Side
SAA	Sasakawa Africa Association
SAE	Society of Automotive Engineering
SNNP	South Nation, Nationality and Peoples
SPSS	Statistical Packages for Social Sciences

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ABSTRACT

Shelling is one of most critical post- harvest operations of grain crops. Varieties of grains are produced and shelled traditionally. The traditional shelling of maize is one of the most time consuming operations which involves drudgery, grain loss and breakage due to manual shelling by biting using a stick and using animal trampling in some places. The existing maize shellers are normally large and heavy; require high power input with high shelling capacity. Besides, the cost of purchasing such shellers is high for the rural small holder farmers. Therefore, this study aims to design, construct and evaluate the performance of small motor driven maize sheller. It was constructed from locally available materials and its cost is very low and affordable. The machine basic components are hopper, shelling unit (spike, drum and concave), outer cover, shaft, frame and outlet. The arrangement of these parts was connected by belt and pulley. A 2 hp electric motor provides drive through belt connections to drive pulley on shelling drum. The actual test was conducted using three different shelling drum peripheral speed and feed rates at 12% moisture content (wet basis).Analysis of variance (ANOVA) and Least Significant Difference (LSD) was used to determine the significant differences among treatments and to form regression equation. Levels of significance was used in F-test at ($P<0.05$) for the statistical analysis. Results showed that the maximum shelling efficiency of 98.78% was observed with 2000kgh^{-1} feed rate at10.1ms^{-1}shelling drum peripheral speed where as it was minimum 94.20% for 1000 kg hr^{-1} feed rate at 9.2 ms^{-1}shelling drum peripheral speed. The analysis of variance (ANOVA) of the results obtained at ($p<0.05$) probability confirmed that the shelling efficiency increases with an increase in shelling drum peripheral speed and decrease in feed rate. The output capacity ranged from 1500 kg hr^{-1}to 2000 kghr^{-1} with an average value of 1800 kghr^{-1}. Based on the performance evaluation results, it is concluded that the maize sheller prototype could be efficiently, effectively and economically used by the majority of Ethiopian farmers.

Key words: design, motor driven, shelling machine, shelling efficiency

CHAPTER ONE

1. INTRODUCTION

1.1. Background and Justification

Maize is the most important cereal grain in the world, after wheat and rice, providing nutrients for humans and animals and serving as a basic raw material for the production of starch, oil protein, alcoholic beverages, food and more recently, fuel (FAO, 1992).

Since last one decade, area under maize cultivation is continuously increasing to meet the raising demand in the world. Maize ranks first in the world cereal production which accounts 38% of the total grain production with 868 million tonnes from 168 million hectare whereas 30% and 20% of wheat and rice respectively (Anonymous, 2011).

Maize is the most widely-grown staple food crop in sub-Saharan Africa (SSA) occupying more than 33 million ha each year. The crop covers nearly 17% of the estimated 200 million ha cultivated land and produced in diverse production environments and consumed by people with varying food preferences and socio-economic backgrounds. More than 300 million people depend on maize as source of food and livelihood. The top 20 countries, namely South Africa, Nigeria, Ethiopia, Tanzania, Malawi, Kenya, Zambia, Uganda, Ghana, Mozambique, Cameroon, Mali, Burkina Faso, Benin, DRC, Angola, Zimbabwe, Togo, and Cote d'Ivoire, account for 96% of the total maize production in SSA (FAOSTAT, 2014).

Maize is Ethiopia's leading cereal in terms of production, with 6.4 million tons produced in 2013/14 by 8.8 million farmers across 1.99 million hectares of land. Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region. Maize is Ethiopia's most important cereal crop both in terms of level of production and area coverage. About 9 million farmers, i.e., 70% of the total farmers produced about 6 million tons of maize over two million hectares of land with an average yield of 1.74 tons per hectare (CSA, 2014). Within the country, maize is the largest cereal commodity in terms of total production and yield.

During the 2011/12 main cropping season, cereal crops accounted for 79% of the total area under crops, of which maize ranked second to teff and cereals accounted for 86% of total production, of which maize ranked first. It is also the most important crop in terms of number of farmers engaged in cultivation. The total number of small holder maize producers is 9.2 million farmers followed by 6.3 million teff producers and 5.2 million sorghum producers (CSA, 2012).

In Ethiopia, smallholder farmers almost in all regions of the country dominantly produce maize. In terms of regional distribution, 41.9% of the producers are found in Oromia, 28.6% in Amhara, 18.7% in SNNP, 6.9% in Tigray, and 2.4% in Benishangul Gumuz regional states. Farm size considerably varies from less than 0.5 ha to over 10.0 ha and almost 72% of maize producers own less than 2ha. The smallholder farmers owning 97% of the total maize land contribute 95% of the national maize and commercial farms owning only 3% of land contribute 5% of the total production (CSA, 2013).

Despite this potential however, Ethiopian agriculture has remained underdeveloped. The intensification and modernization of agricultural production is associated with use of better farm machines and increased power utilization. In Ethiopia, development and adoption of improved agricultural technologies including grain threshers/shellers and machinery has been a long term concern of agricultural experts, policy makers, and agricultural researchers and many others linked to the sector. However, evidence indicates that adoption rate of modern agricultural technologies in the country is very low (Kebedeet al., 1990).

The adoption of agricultural innovation in developing countries attracts considerable attention because it can provide the basis for increasing production and income. Small scale farmers' decisions to adopt or reject agricultural technologies depend on their objectives and constraints as well as cost and benefit accruing to it. Therefore, farmers will adopt only technologies that suit their needs (Million and Belay, 2004). In Ethiopia, about 69% of smallholder farmers own farmlands less than or equal to one hectare in size and average grain yield for various crop is less than one metric ton per hectare (CSA, 2013). It is very difficult for these farmers to own and operate costly agricultural machinery and equipment.

Hence, in most part of the country, manual shelling method of maize is still in use. This methods cause damage to the kernels and are time consuming involving drudgery. Maize shelling is among the major activities involved in the processing of maize like harvesting, drying, de-husking and storing. All these processes are costly and for the rural farmers to maximize profits on their produce, appropriate technology suiting their needs must be used.

Shelling is one of the most important crop processing operations which are used to separate the grains from ear heads and prepare its quality for the market. Maize grain harvesting comprises the dehusking operation for removal of outer cover and shelling involves the removal of maize grain from the cob without causing the damage to grains. Traditionally shelling of maize is carried out by manually which involves a lot of drudgery. The grains were detached from dried cobs by manual or mechanical devices.

Shelling of maize is done using three methods: manual, animal trampling, use of manual or motor driven shellers. The traditional method of shelling includes, beating with stick, rubbing the maize cobs against one another by hand or by direct removal of kernels pressing it between thumb and hand palm therefore consume much human energy and time. This option is being used and known for low shelling capacity of about 8kghr^{-1} to 10 kghr^{-1}. Shelling using simple tools like hand held maize shellers is another option compared to earlier conventional shelling method though the shelled grain average output capacity achieved by these devices range between 10 kg hr^{-1} to15 kg hr^{-1} (Dubale and Hussen, 2015).

Motorized and manually operated shellers with a satisfactory shelling performance have already been developed by research centers and being used in the country by few farmers. However, there are farmers who could not afford these improved shellers due to their prices and still using the conventional method at household level. Thus, this operation is highly labour intensive and more drudgery in addition to losses of grain in terms of quantity and quality. Therefore, this study aims to design and construct motor driven maize sheller for small and medium scale farmers with affordable cost and higher shelling efficiency.

1.2. Statement of the problem

Maize shelling is a necessary process subsequent to harvesting because the maize kernels when harvested are firmly attached to the hard cob. Shelling of the dried cobs by majority of farmers in Ethiopia is carried out by repeated beating of the cobs with a club while held inside Sacks, open barrels or spreading it over plastered ground floor in the house or outdoor and this methods cause damage to the kernels and are time consuming involving drudgery.

The existing maize shellers are normally large and heavy; require high power input to operate. To solve this problem a number of appreciable works have been done by different bodies among which Bako maize sheller and Melkassa maize shellers are the prominent one since long time. However, the high cost of the machines and their engines together with their weight have affected its adoption rate. In addition, the undulating topography of some parts of Ethiopia and small and fragmented land ownership of the farmer of this area plays a great role in limiting the adoption rate of the technologies.

Besides, the cost of purchasing such shellers are high for the rural farmer and therefore call for the need of a relatively low cost maize shelling mechanism that will be affordable to such farmers not only to meet their shelling requirement but also to improve the shelling efficiency and reduce damage to the seed. Rural areas require a conventional maize shelling technique that would significantly cater for the farmers harvest capacity and which many households can afford. This is with due consideration to the following reasons:

i. Most of the maize grown by such rural farmers is for food rather than for commercial.
ii. Industrial maize shellers are too expensive to be purchased by such rural farmers.
iii. For most of the farmers, the cost of hiring the service of industrial shellers is high with respect to the amount of grain output at the end of the farming season.

Thus, the search for a satisfactory, cheap and effective means of detaching the kernels from the cob is important alternative technology to the small and even medium size farmers in the country to be used at family level.

1.3. Objectives

1.3.1. General objective

The main objective of the study was to design, construct and evaluate the performance of motor driven maize sheller.

1.3.2. Specific objectives

i. To study the physical properties of BH660 and BH540 varieties of maize.
ii. To design and construct motor driven maize sheller.
iii. To evaluate the performance of motor driven maize sheller.

1.4. Significances of the study

There exists a number of maize shelling techniques and each of the technique has its own shortcomings which in general call for the design of this maize sheller. These drawbacks include the tediousness involved in manually operating hand held maize shelling devices, the cost of buying the existing engine driven maize sheller is unaffordable to the small scale maize farmers and hand operated rotary shellers especially those constructed by the local artisans require the farmer to use too much energy to shell very little maize.

This study provides alternative options that meet the sheller needs of such rural farmers. The design of this maize sheller aids its possible construction from locally available materials to shell maize and separate the cob from the grains and its cost is projected to be low and affordable with high shelling efficiency and acceptable grain damage. Thus, the sheller can solve the problem that rural farmers facing to shell maize for household consumption. Based on the performance evaluation results, the sheller could be efficiently, effectively and economically used by the majority of Ethiopian small holder farmers.

1.5. Scope and Limitations of the Study

The scope of this study was to design, construct and conduct performance evaluation of motor driven maize sheller. The crop physical properties obtained were limited to only two varieties of maize (BH660, BH540) that are dominant in the study area. The maize sheller prototype was tested using BH540 maize variety within constant moisture content of 12%, wet basis which is recommended for maize grain has been observed from different literatures.

The study considered shelling drum speed and feed rate as the machine operational factors and engineering properties (physical and frictional) were considered as machine design parameters. However, this work was limited to motor driven maize sheller without cleaning unit (blower) because, it is traditionally carried out by lifting and tossing the shelled material so that the lighter chaff and straw get blown to one side while the heavier seeds fall down vertically.

Aerodynamic factors such as fan speed drag coefficients and terminal velocity were not considered in this work because these properties are related to cleaning. The detailed comparison of the maize sheller prototype with the existing maize shellers not have been done due to budget constraints.

CHAPTER TWO

2. REVIEW OF LITERATURES

In the view of the objectives of this study, it is necessary to review the literature on the methods that are used in the past as well as that are presently in use for shelling of maize. The literature reviewed on methods of shelling, performance of shellers and their cost.

2.1. Different shelling methods

The different methods of maize shelling can be categorized based on various mechanization technology used. These include; hand tool technology, animal technology and engine power technology. Hand technology involves the use of hand tools in shelling, while in animal technology, and animals were used in threshing on the field by trampling on the maize. Engine powered technology involves the use of mechanical assistance in shelling of maize.

Dubale and Hussen (2015) found mini hand maize sheller adjustable to a varying cob diameter and having an overall dimension of 30cm×11.5cm×27cm was developed. The test crop maize had grain moisture content of 14.7% wet basis (w.b) and the result revealed that the sheller has mean shelling capacity of 26.26 $kghr^{-1}$.

Danfulani (2009) carried out an investigation on design of a maize shelling machine. He used a rotating shaft with threshing tooth on the surface to provide the shelling forces required. The machine designed to shell 5000 kg of maize per day. The prime mover selected as a diesel engine with a capacity of 5hp which could be easily be operated by rural dwellers. The design was done with readily available materials coupled with minimum cost without affecting the quality of its shelling output at the end of the operation.

Dubale et al. (2016) found multi-crop thresher accomplishing maize shelling by modifying the existing crop threshers to accommodate replaceable bar type drum besides units for threshing wheat, teff, sorghum and barley using peg type drum. The thresher operates on the principle of axial flow movement of the material. It was tested on maize, wheat, teff, sorghum and barley crops.

The values for highest visible grain damage, optimum thresher's output capacity, threshing and cleaning efficiency were observed at the maximum threshing drum speeds of 910, 1600, 1550, 1600 and 1690 rpm for maize, wheat, teff, sorghum and barley crops respectively. These threshing drum speeds under grain moisture content of 13%, 9.6%, 7.6%, 9.8% and 12.1% wet basis (w.b) indicated optimum threshing performance for the mentioned crops respectively. The mean output capacities of 2526.31 $kghr^{-1}$, 386.98 $kghr^{-1}$, 237.2 $kghr^{-1}$ 780.68 $kghr^{-1}$and 121.62 $kghr^{-1}$ for average grain-straw (cob) ratios of 1:0.36, 1:2.22, 1:2.56, 1:0.21 and 1:1.29 were recorded for maize, wheat, teff, sorghum and barley crops respectively.

a. Manually operated maize Sheller b. Engine or P.T.O. operated maize Sheller

Figure 1.1. Different maize shelling methods

Mahmoud and Buchele (1975) found that, ear axis parallel to cylinder axis orientation suffered the least damage at all moisture content levels tested, followed by ears fed randomly to the cylinder. The highest damage was suffered by ears fed with their axis perpendicular to the cylinder. The minimum damage for all orientations was at 20 to 22% moisture content. They found that the corn kernel damage increased with an increase in moisture content and cylinder velocity.

Tastra (2009) reported about the development of a new power sheller that could reduce grain damage and broken corncobs. The basic principle of this new machine was the reduction of the normal stress during the shelling process by developing a concave system that could vibrate without causing great impact on the maize grain.

Hassan et al. (2009) fabricated maize sheller from locally available materials and its cost was very low and affordable. This machine was constructed to shell maize and separate the cobs from the grains. Its threshing efficiency was 99.2% within acceptable ranges of visible seed damage $\leq$ 2%.

2.2. Performance of shellers

Comparative study between traditional threshing; trampling by animals and using improved multi-crop thresher in threshing maize indicates that to thresh a ton of maize, there is a need to invest 3 working days of 20 individuals and 4 or more donkey or oxen. Whereas using a multi crop thresher needs only four hours to thresh a tone of maize (Leonides and Toshiro, 2005).

Vas and Harrison (1969) stated that the cylinder speed is primarily influencing the damage caused to the seed than that of concave clearance although the concave clearance is an important parameter.

Singh and kumar (1976) reported that increasing the cylinder speed increases grain damage whereas increase in concave clearance decreases the grain damage and recommended that 1260 rpm of cylinder speed is optimum for threshing cereal crops. In their study on the effect of swinging hammer spiked tooth and rasp bar cylinder on threshing efficiency and damage of grains, it was found that an increase in cylinder speed and a decrease in concave clearance reduced the amount of threshed grain and increased grain damage and power requirement. The swinging hammer type consumed more power than the rasp bar and the spiked tooth drums.

Chowdhury and Bachelor (1976) found that kernel moisture content and cylinder speed were highly significant in analysis of variance for damaged corn kernel percentages, total damage increased from 26% to 41% as rotational speed increased from 450 to 650 rpm(12.8 and 18.7m/s). Minimum total damage was sustained at 23% moisture content (w.b). They found that the mechanical damage by the laboratory sheller ranged between 26.3 and 42 percent.

Tastra (1990) reported that, three types of local maize shellers were tested at three levels of grain moisture content and cylinder speed. The effective shelling capacity increased with an increase of the cylinder speed but decreased with an increase of the moisture content of maize. Mechanically damaged maize increased with increasing cylinder speed and with moisture content of maize.

Nalbant (1990) studied the percentage of corn grain damage caused by the cylinder and concave before and after the grains were shelled from the cob. The effect of grain moisture content and cylinder velocity on grain damage was also investigated. Corn varieties were shelled with grain moisture content of 15%, 20% and 25 %. Damaged grain percentage increased with an increase in moisture content and cylinder velocity. Damage was also affected by the concave clearance.

Ajav and Igbeka (1995) tested the performance of corn sheller using an international standard code to study the general qualities and design of sheller. The results show that the shelling efficiency varies with moisture content, speed of the shelling unit and feed rate. The machine has a shelling efficiency of 98%, 95% and 94% at a moisture content of 11%, 20% and 25 %, respectively. The sheller has a capacity of 260kg/h and the performance tests proved that the sheller performs best at shelling speed of 450rpm with minimum losses and high efficiency.

Tajuddin and Karunanithi (1996) carried out research on different types of hand operated maize shellers such as wooden maize sheller, hand held tubular maize sheller, rotary disc type, and bench mounted tubular maize sheller were evaluated and their performance compared with manual method of maize shelling. Rotary disc type and bench mounted tubular performed well in terms of kernel output, operational cost and performance index.

Olaoye (2002) reported that some crop parameters and machine variables are known to influence the performance of threshers. Each or combination of these parameters has influencing effects on the thresh ability and grain damage. He noted that the influences of both thresh ability and grain damage translates to measurable grain losses if not properly managed. These losses are directly measurable in economic, quantitative, qualitative, (nutritional) terms. Economic loss is the reduction in monetary value of maize grain as a result of physical loss. Quantitative maize loss involves reduction in weight and therefore can be defined and valued. Qualitative loss although difficult to assess because it is frequently based on subjective judgments (like damage), can often be described by comparison with locally accepted quality standards.

Sandhar and Panwar (1975) studied on machine crop variables influencing shelling of the maize. The study concluded that the shelling efficiency increased with increase in cylinder speed and reduction in concave clearance. The square section members shelling more than the round and rasp bars and shelling decreased with grain moisture. The grain damage was higher at higher cylinder speed and at lower value of the concave clearance.

Singh et al. (2010) conducted an experiment to minimize the drudgery of farm women in maize shelling. A tubular maize sheller was introduced and tested on farm women. The results revealed that the shelling efficiency of tubular maize sheller was 26 $kghr^{-1}$as compared to hand shelling by which they only could shell 13$kghr^{-1}$and about 43% saving in cardiac cost of workers per unit of output in comparison to the hand shelling.

Victor et al. (2006) conducted an evaluation of the performance of a tractor powered maize sheller and traditional shelling. In terms of shelling efficiency, grain output and grain damage. The test result revealed that shelling of maize with tractor powered incurred the highest percentage of grain damage. A maximum grain output of about 80 $kghr^{-1}$was obtained with the tractor powered maize sheller compared to13.19 $kghr^{-1}$ with the traditional shelling techniques.

2.3. Economics of shellers

Kumar and Parvathi (1998) studied the energy expenditure of woman laborers for corn shelling using tubular, modified tubular and hand operated corn shellers. The energy expenditure was compared with the traditional method of shelling. It was estimated that the average energy expenditure for operating the different manual shellers was 5-6 kcal/min. The output of the hand operated corn sheller was 23 $kghr^{-1}$, 92% higher than the hand operated, modified tubular and tubular corn sheller saved energy expenditure by 80, 60 and 52 percentages, respectively, compared to the traditional method.

Olaoye (2004) found that inappropriate threshing conditions in a manual threshing process reduces the grain output with respect to excessive and high energy input. In a mechanical threshing process the effect of the inappropriate operating conditions does not only affect the effective recovery of the grains from the other plant materials but it also leads to high grain loss. Grains loss is measured in term of the damage to the grain kernel, loss to the mechanical elements and non-germ inability of the seeds.

Hussain et al. (2009) reported that the horizontal maize cob sheller, very useful to the farmers of hilly region, was evaluated for three varieties and the results were compared with traditional methods of maize cob shelling (beating by sticks and hand rubbing). When the shelling capacity and labour requirement were concerned, the horizontal maize cob sheller was significantly superior over both traditional methods. Regarding shelling efficiency, the difference between mechanical maize cob shelling and shelling by hand rubbing was found to be non-significant.

Swapanet al. (2007) compared manual shelling with power operated maize sheller. The results indicated that power operated maize shellers was a wise investment (5-8 acres for 25% internal rate of return or IRR). However, it makes economic sense to operate shellers at higher capacities and along with the high capital cost to save large numbers of labours to farmers and maize traders. Therefore, power operated maize sheller can be able to overcome the shortage of expensive labour during peak harvesting season.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. The Experimental Site

The motor driven maize sheller prototype was designed and constructed at Adama Science and Technology University. Adama city is 99km from Addis Ababa to east. The geographical location of the area is $8^o33'$ to $8^o56'$N latitude and $39^o16'$ to $39^o28'$E longitude, having an elevation of 1712meters above sea level with annual rain fall of 700mm-1700mm (ACMA). All the mechanical works such as machining, welding, grinding, drilling and bending, etc. during construction of the maize sheller prototype was done at Mechanical Engineering Department Workshop. After the construction of the maize sheller prototype the performance were done at Mechanical System and Vehicle Engineering Department. The sample of maize grain with cob was bought from the local farmers of East Shoa Zone Adami Tullu district.

3.2. Materials

3.2.1. Experimental crops

Unshelled maize was used to evaluate the performance of the motor driven maize sheller prototype constructed at ASTU. The commonly grown varieties in East Shoa Zone (BH660 and BH540) were used to evaluate the performance of the motor driven maize sheller prototype.

3.2.2. Materials for the construction

Consideration for material selection was based on availability, ease of machining, durability, strength, mechanical and chemical properties and cost.Table3.1.shows the parts of the sheller, functions as well as the materials selected for each part.

Table 3.1. Parts of constructed motor driven maize shelling machine and its materials

S/N	Components	Functions	Materials
1	Frame	Supports all other component parts.	Angle bar Mild Steel
2	Shelling drum	To shell and give out grains.	Mild steel
3	Spikes	Makes impact for shelling.	Mild steel rod
4	Concave	To screen the seeds and the cobs of maize.	Mild steel rods
5	Outer cover	To avoid grains spilling out and It has a provision for attaching to hopper.	Mild steel sheet
6	Hopper	Inlet for the maize into the shelling unit.	Mild steel
7	Outlet	To collect grains from concave into a receiver.	Mild steel sheet
8	Shaft	It transmits torque and motion from the pulley to turn the shelling drum.	Mild steel
9	Bearing	To allow free movement of the shaft.	Mild steel
10	Stand	Set for a motor and absorb vibration.	Angle bar mild steel

3.2.3. Measuring devices

Table 3.2. List of different measuring devices

S/N	Instruments	Function	Accuracy
1	Vernier caliper	Used to measure dimension of materials and grains	0.1mm
2	Multi meter	To measure the line current strength (I) and the potential difference value (V).	± 0.01
3	Digital balance	used to determine weight grains and cobs	± 0.05
4	Grain moisture tester	Used to record moisture content of maize.	± 0.5
5	Digital Tachometer	Used to measure the shelling drum speed(rpm)	±0.05
6	Measuring tape	Used for measuring length	± 1mm
7	Measuring jar	Used for measuring true density of grains	__
8	Stop watch	Used to record time of operation of the sheller	__

3.3. Engineering properties of the selected maize varieties

Engineering properties are useful and necessary in the design and operation of various equipment employed for agricultural operations. The engineering properties of two maize varieties were considered for this study. Basic information on these properties such as physical (shape and size, roundness, spherecity, surface area, bulk density and true density) and frictional (angle of repose and coefficient of friction) were determined and used as design parameters of the sheller.

3.3.1. Physical properties of the selected maize varieties

The methods followed for determining the physical properties of maize were decided dimensions of the different machine components. Dimensions of the maize cob and grains, spherecity, surface area, true density were determined using (Mohsenin, 1970). The bulk density of grain, one thousand grains weight, moisture content of grain and grain to dry matter ratio of the selected maize variety (BH660 and BH540) were determined.

3.3.1.1. Dimensions of the maize cob and grains

For both varieties of the maize 10 unshelled maize were selected by simple random sampling method for the study. The length of un-shelled cob (mm), weight of un-shelled cob (g), linear dimensions of maize grains (mm), number of grain lines in cob and grain in one line, minimum diameter of cob without grains (mm), maximum diameter of cob without grains (mm), average length of shelled cob (mm), diameter of unshelled cob and shape are determined using digital verniercaliper and weighing balance with an accuracy of 0.01mm and 0.01g,respectively (Tarighi et al., 2011).

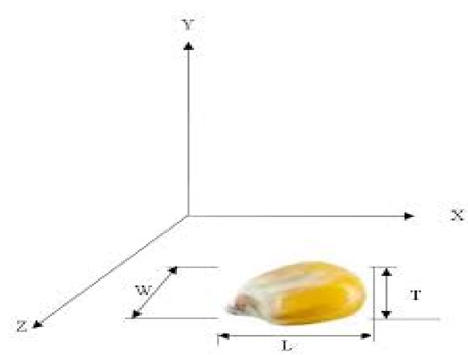

Figure 3.1. The three dimensions of maize grain

3.3.1.2. Roundness

Roundness is a measure of the sharpness of the corners of the solid. Several methods were proposed for estimating the roundness. The maize grains (10 numbers) are projected on a graph paper and traced and calculated by following formula (Jayan and Kumar, 2004).

$$\text{Roundnesss} = \frac{A_p}{A_c} \quad \text{..........} \quad (3.1)$$

Where: Ap - Largest projected area of maize grains in natural rest position (mm^2)

Ac - Area of smallest circumscribing circle (mm^2)

3.3.1.3. Arithmetic and geometric mean diameter of grains

For both varieties of maize, the length, width, thickness and mass of maize grains were measured on randomly selected 100maize grains. The length, width and thickness of grains are measured using a digital caliper with an accuracy of 0.01 mm. The arithmetic mean and geometric mean diameter was calculated by the three axial dimensions. The arithmetic mean diameter (Da) and geometric mean diameter (Dg) of the grains have been calculated by using the following equations (Mohsenin, 1970).

$$D_a = \frac{L+W+T}{3} \quad \text{..........} \quad (3.2)$$

$$D_g = (LWT)^{1/3} \quad \text{..........} \quad (3.3)$$

Where: L - mean length of maize grain (mm)

W - mean width of maize grain (mm)

T - mean thickness of maize grain (mm)

D_a _ arithmetic mean diameter of maize grain (mm)

D_g _ geometric mean diameter of maize grain (mm)

3.3.1.4. Spherecity

The spherecity ($\emptyset$) is defined as the ratio of the surface area of a sphere with the same volume as the grain to the surface area of the grain.

This measurement was determined using the following equation (Mohsenin, 1970).

$$\emptyset = \frac{(LWT)^{1/3}}{3} \quad (3.4)$$

Where: L - mean length of maize grain (mm)

W - mean width of maize grain (mm)

T - mean thickness (mm)

$\emptyset$ - mean seed sphericity

3.3.1.5. Surface area

The surface area (S) of an agricultural product is generally indicative of its pattern of behavior in a flowing fluid .The surface area of grains was found by analogy with a sphere of the same geometric mean diameter. The surface area of grains was calculated by using the following formula (Mohsenin, 1970).

$$S = \pi(D_g)^2 \quad (3.5)$$

Where: S - surface area (mm^2)

D_g- geometric mean diameter (mm)

3.3.1.6. Bulk density

The bulk density was found by taking maize in a container of cylindrical shape. The volume of the container was found by measuring diameter and height for cylindrical container. The weight of the grain in the container is found separately and three samples of maize were taken and average bulk density was calculated (Varnmakastiet al., 2007).

$$\rho_b = \frac{M}{V} \quad (3.6)$$

$$\rho_b = \frac{4M}{\pi D^2 h} \quad (3.7)$$

Where: M - Mass of the maize grain sample (g)

V - Volume of glass jar sampler (cm^3)

D - Diameter of glass jar sampler (cm)

h - Height of glass jar sampler (cm)

3.3.1.7. True density

The true density was defined as the ratio between the mass of maize grains and the true volume of the grains. The apparatus used for measuring true density of grains consists of a 100 ml measuring jar and a weighing balance 50 ml of toluene was taken in a measuring jar.

A known weight of grain sample was poured to the measuring jar and rise in the toluene level was recorded as the true volume of the grains without void space and the true density of the grain was calculated by using the following formula (Barnwal, 2012).

$$\text{True density} = \frac{\text{Wet of grains,g}}{\text{Volume of grains excluding void space,cm}^3} \ldots\ldots\ldots\ldots (3.8)$$

3.3.1.8. Moisture content of grains

The moisture content of maize grains was determined by oven drying method. The grain samples were kept for 24 hours at 105 °C temperature in oven and moisture content was calculated accordingly (ISTA, 1986).

$$\text{Moisture content of grains} = \frac{W1-W2)}{(W1-W3)} \times 100\% \ldots\ldots\ldots\ldots (3.9)$$

Where: W_1 - Weight of the wet maize grain sample (g)

W_2 - Weight of the dry maize grain sample (g)

W_3 - Weight of the tray (g)

3.3.1.9. Test weight of grains

For measuring the weight of the grains, digital electronic weigh balance having the accuracy of 0.01 g was used. In order to determine the one thousand grains weight (W1000), one thousand maize grains were counted by manually and weighed by an electronic balance. The three samples of both varieties were weighed and mean thousand grain mass of each variety was found out (Singh and Goswami, 1996).

3.3.1.10. Determination of the grain to dry matter ratio

The five samples of the cob with grains were selected for each weighing about one kg and separated the grains from cobs manually for each sample.

The mass of the grain and dry matter are measured separately as (Seifi and Alimardani, 2010).

Grain to dry matter = $\frac{W_g}{W_{t-}w_g}$... (3.10)

Where: Wg - Weight of maize grain from sample (g)

Wt - Weight of total maize cob sample (g)

3.3.2. Frictional properties

The frictional properties such as angle of repose and coefficient of friction are important in designing of hoppers, chutes, pneumatic conveying systems, screw conveyors, forage harvesters, storage bins etc.

3.3.2.1. Angle of repose

The angle of repose is the angle compared to the horizontal at which the material will stand when piled. For measuring the angle of repose, a rectangular box filled with grains was kept horizontal. The grains were then allowed to fall on a horizontal circular disc kept below the box. The flow of grains was stopped after the grains were fully heaped on the disc. The radius of the base of the heap and height of heap were measured and angle of repose was calculated using the following expression (Sahay and Singh, 1994).

$\emptyset = \tan^{-1}\left(\frac{h_0}{r}\right)$.. (3.11)

Where: ∅ - Angle of repose (degree)

ho - Height of heap (m)

r - Radius of heap (m)

3.3.2.2. Static coefficient of friction

The static coefficient of friction of maize samples against two different surfaces, namely; plywood and MS sheet were determined. The coefficient of friction was calculated from the following equation: (Tarighi et al., 2011).

$\mu = \tan\emptyset$.. (3.12)

Where: μ - Static Coefficient of friction

∅- Angle of repose (degree)

3.4. Design of the motor driven maize sheller prototype components

During the design of motor driven maize sheller the equipment should be suitable for small and medium scale farmers for capacity in between 1000 to 2000 kg hr^{-1}. The methodology and procedure adopted in design of different components of motor driven maize sheller are presented in the following subsections. The prototype sheller consisted of frame, hoppers, shelling unit, power source (motor or diesel engine, 2ph), transmission system (belt and pulley), and outer cover and outlets. To achieve the best performance from the sheller, the important factors were optimized by proper design and selection of the components required to suit the requirements of both maize varieties.

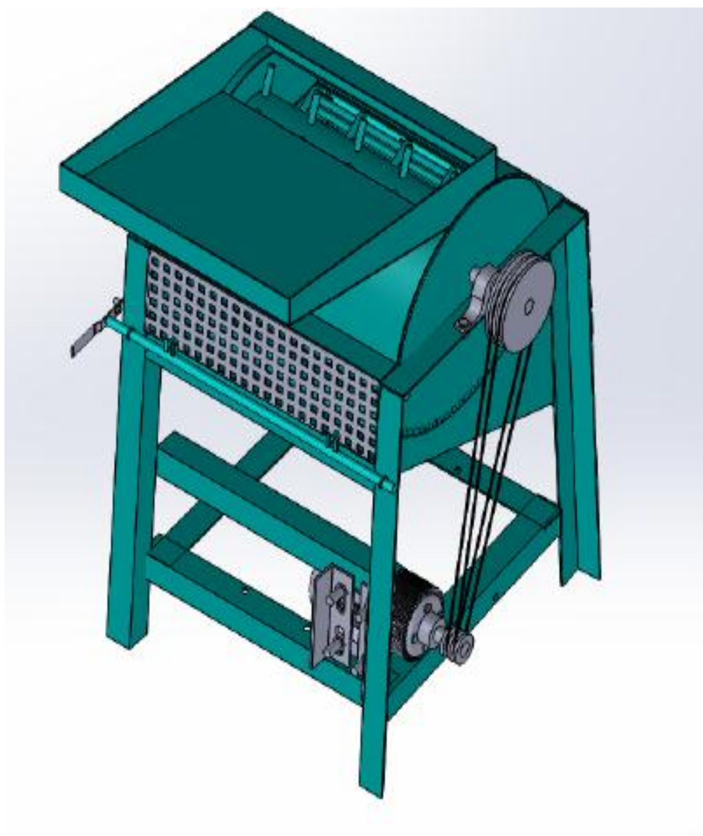

Figure 3.2. Isometric view of the maize sheller prototype

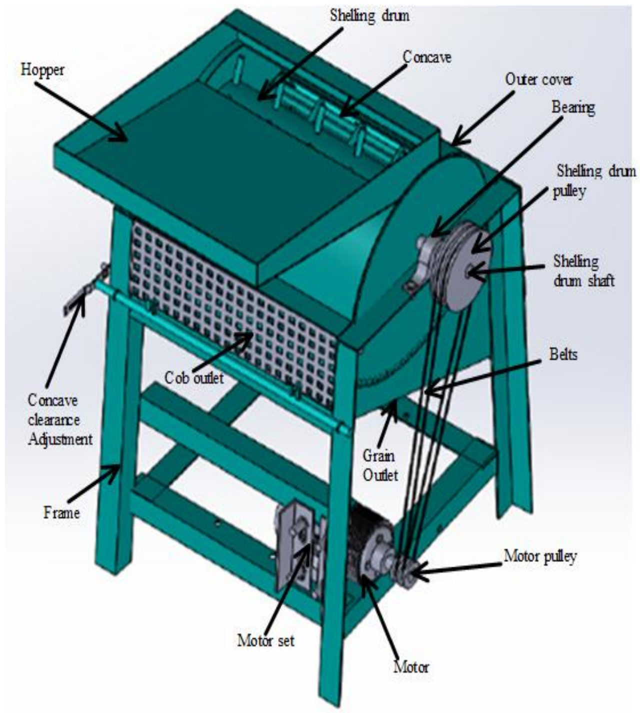

Figure 3.3. Component parts of the motor operated maize sheller prototype

Figure 3.4. The constructed maize sheller prototype

3.4.1. Design of frame

The frame is the skeleton of the sheller which supports all other component parts. It was made strong enough to resist the maximum magnitudes of compressive, tensile and impact forces and simultaneously support the other parts of the machine fixed on it. The two design factors considered in the determination of the material required for the frame were weight and strength.

In this work, mild steel angle bar of 40mm by 40mm and 3mm thickness was used to give the required strength and rigidity from properties of material so that it can withstand all types of load during operation. The overall dimensions of frame were 420mm length, 400mm width top and 400 by 500mm bottom with 600mm height. The frame has an adjustable bottom set for motor.

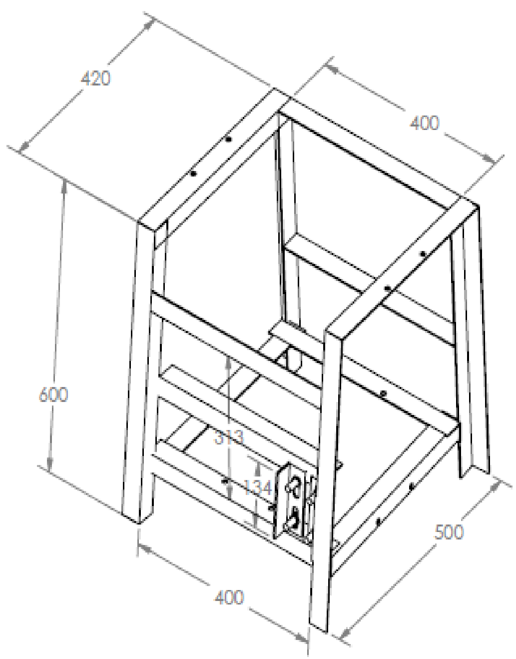

Figure 3.5. Frame of the maize sheller prototype (all dimensions in mm)

3.4.2. Design of shelling mechanism

3.4.2.1. Design of shelling drum

The off cross flow and radial flow shelling system was adopted in this prototype design. As material passes through the shelling zone between the radial flow shelling drum and concave several times due to backward movement in the helical path, rather than making single pass in a cross flow drum.

This feature with radial flow shelling system helps in getting more retention time for un-shelled cob during continuous feeding. The various engineering properties of the maize cobs and grains were considered while designing the shelling drum. The length of the drum shelling drum was decided by using following equation (Singh, 2010).

$$q = q_0 L M \quad (3.13)$$

Where: q - feed rate (kgm^{-1})

q_o- permissible feed rate(kgm^{-1})

L - shelling drum length (mm)

M - number of spike rows/beater

The feed rate (q) was taken as $0.4167 kg\,s^{-1}$ for feeding cobs continuously to the machine. Permissible feed rate (q_o) was taken as $0.165 kg\,s^{-1}m^{-1}$ length of the shelling drum. Number of beaters (M) for making drum was taken as seven, as the recommended values for the cereal shellers were 4 to 8 and thus, the shelling drum length were calculated by (Kleninet al., 1985).

$$L = \frac{q}{q_{o \times M}} \quad (3.14)$$

$$L = \frac{0.4167 \text{ kg s}^{-1}}{0.165 \text{ kg s}^{-1}\text{m}^{-1} \times 7} = 0.3608 \text{ m} \approx 361 \text{ mm}$$

The total length of shelling drum was kept as 380mm, this is slightly more than the designed length of 361 mm to get more retention time for maize cobs inside the drum and concave which in turn help for completely shelling of cobs before they reach to main outlet. The row of solid spikes on drum peripheral surface were used as beater and was taken as seven for providing sufficient impediment and space to avoid carrying of un-shelled maize cobs to periphery of shelling drum, which in turn helps in reducing total power requirement for shelling.

For this prototype, the shelling drum was made from a mild steel of 3mm thickness and 5408.2mm $\times$380mm cross-section.The metal sheet was rolled with the rolling machine to form a drum of length; 380mm and diameter, 130mm. Faceplates were marked out as 130mm circles and cut out. They were then welded to the drum and the right centers were drilled to accommodate the shaft. The actual cylinder drum diameter with spike height on circular surface of the drum is given by (Aremu et al., 2015).

Designed cylinder diameter, mm + (spike height, mm × 2) ……………………………... (3.15)

130mm + (40mm x 2) = 210mm

3.4.2.2. Design of Spikes

They were made from a mild steel rod of10mm diameter. They were cut to give 40mm length and were welded unto the shelling drum. The spikes cover 2/3 of the shelling drum and used for shelling by impacting the maize to the concave.

Based on minimum length of cob, number of spikes was kept alternatively on each row as 5 and 4 numbers on the drum to act as shelling element of prototype. The spikes center to center distance on each row was kept as 80 mm. The spikes were arranged in zigzag fashion on consecutive rows and during rotation, spike spacing of 90 mm is obtained. The size of each round solid spike was of 10 mm diameter x 40 mm height. The spikes were placed at an angle of 45° in clockwise.

For desired output capacity of the shelling of maize cobs, the number of spikes required was found by following formula (Kleninet al., 1985).

$$N_s = \frac{q}{q_p} \quad \ldots\ldots (3.16)$$

Where: N_s - number of spikes on the shelling drum

q - Handling capacity, kg s^{-1}(the desired capacity is 0.4167kg s^{-1})

q_p - Permissible feed rate per tooth (0.013kg s^{-1})

$$N_s = \frac{0.4167 \text{ kg s}^{-1}}{0.013 \text{ kg s}^{-1}} = 32$$

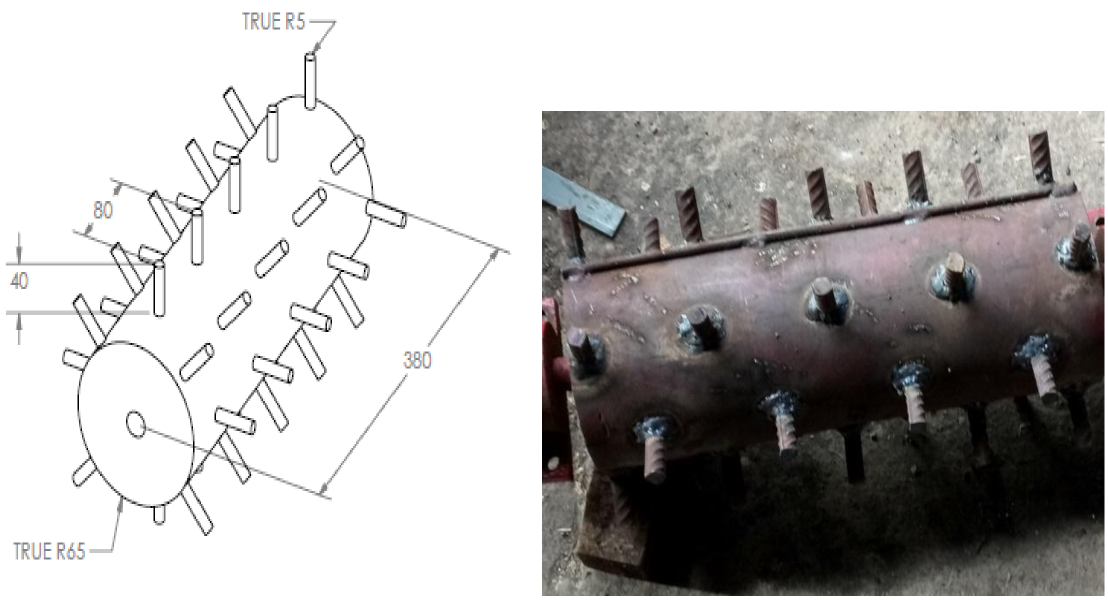

Figure 3.6. Shelling drum with spikes assembly drawing

3.4.2.3. Design of Concave

Concave is the component which provides space for shelling of maize and is located at bottom side of the cylinder and it was constructed using10 mm mild steel rods. In order to detach the grains, the sizes of the rods were selected based on the arithmetic and geometric mean diameter of the maize grains i.e., 7.8 and 7.4 mm. The length of the concave was 40 cm with slotted opening size 10 x 1.5 cm.

The clearance between concave and cylinder was adjustable based on the average geometric mean diameter of maize cob, cm but normally it is around 4 to 7cm. The concave covers 2/3 of the drum circumference with spike. The whole concave was supported on top four corner of the frame. The bottom of the concave was provided with grain collecting tray 430 mm lengths at 35° inclined manner along drum axis for collecting grains from either side of cylinder to center after shelling.

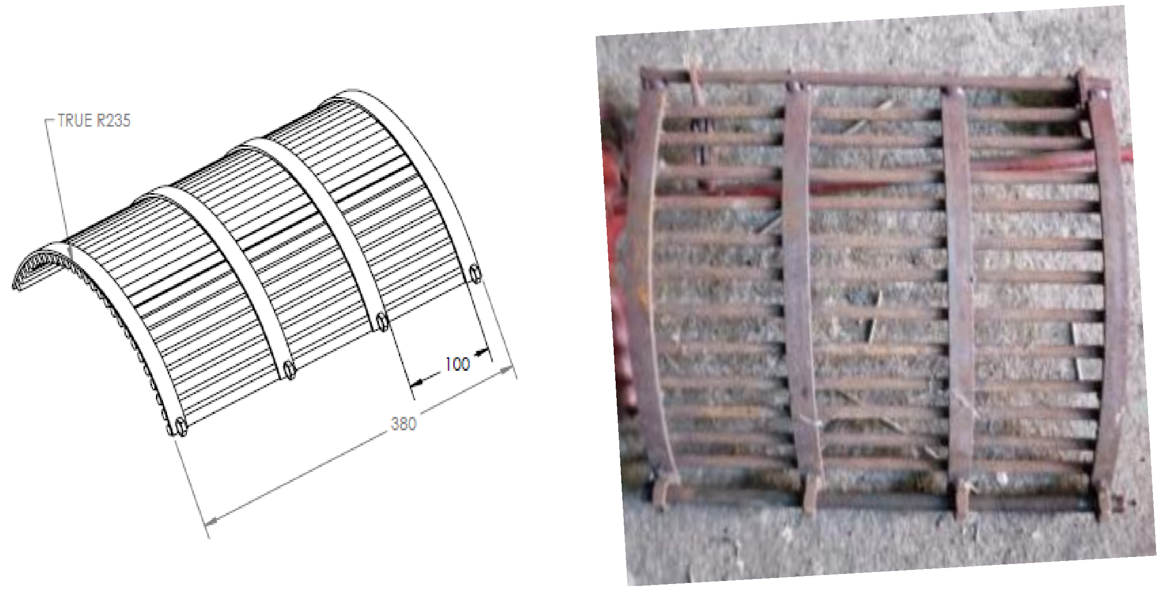

Figure 3.7. Concave of the maize sheller prototype

3.4.3. Design of hopper

Angle of repose: hopper design is based on a common criterion for it to function. The criterion is called the "Angle of repose". Angle of repose is the maximum slope at which a heap of any fragmented bulk material will stand without sliding. It can also be called the angle of friction of rest. This type of hopper is a gravity discharge one and the recommended angle of inclination of hopper for agricultural materials is8^{o}or more, higher than the angle of repose. The angle of repose of maize is 27^{o}(Aremu et al., 2015).The measured angle of repose of the two selected maize varieties were presented in appendix D.

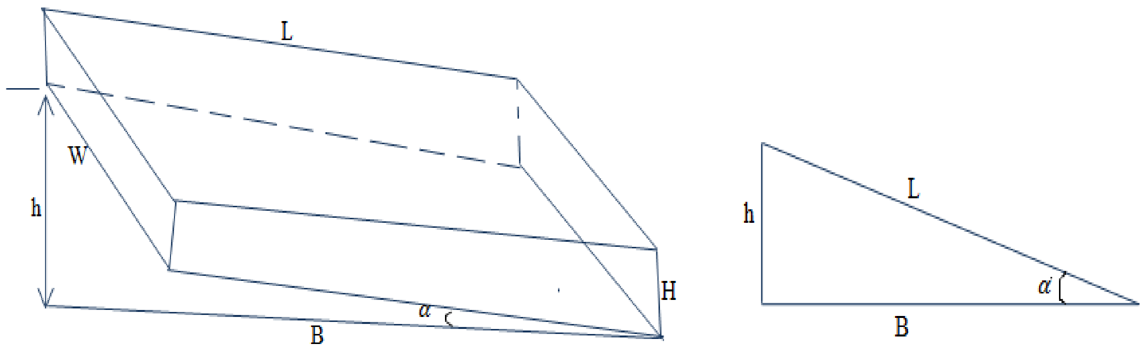

Figure 3.8. Right angle triangles of hopper (all dimensions in mm)

Where: W - Width of hopper (mm)

L - Length of hopper (mm)

B - Base of hopper bottom (mm)

H- Vertical height of hopper from front (mm)

h - Vertical height of hopper from horizontal (mm)

α- angle of repose (inclination) of hopper from horizontal (degree)

The base of the hopper bottom was found using the Pythagoras formula (Aremu et al., 2015).

$$B^2 = L^2 - H^2 \quad (3.17)$$

$$B^2 = 48^2 - 5^2$$

$$B = 47.74\text{cm}$$

Therefore, from the right angled triangle

$$\tan\alpha = \frac{\text{opposite}}{\text{adjecent}} \quad (3.18)$$

$$\tan\alpha = \frac{40}{47.7} = 0.8378$$

$$\alpha = \tan^{-1}(0.8378) = 39.96^o$$

Hence, since the angle of inclination of hopper, αis greater than the angle of repose of maize plus8^o; the hopper will do the required job.

The volume of hopper: The hopper was designed to be a rectangular prism in shape and has the following dimensions that were chosen based on proportionality. The length, width and height of the rectangular hopper are 480mm mm, 400 mm and 50mm respectively. The height of the hopper from the horizontal is 400 mm and the angle of the base to the vertical α is the measured angle of repose or angle of friction of maize. The volumetric and gravimetric capacities of the hopper were determined. The volumetric capacity of the hopper, V_h was determined from the equation by (Eric et al., 1982).

$$V_h = W \times L \times H \qquad (3.19)$$

$$V_h = 0.4 \times 0.48 \times 0.05 = 0.0096\ m^3$$

The gravimetric capacity of the hopper G_h is related to the volumetric capacity of the hopper, V_h using the Equation by (Eric et al., 1982).

$$G_h = \rho V_h \qquad (3.20)$$

Where: ρ - density of maize cobs (kgm^{-3})

V_h - volume of hopper (m^3)

$G_h = 415\ kg/m^3 \times 0.0096 m^3 = 3.984\ kg = 39.08\ N$

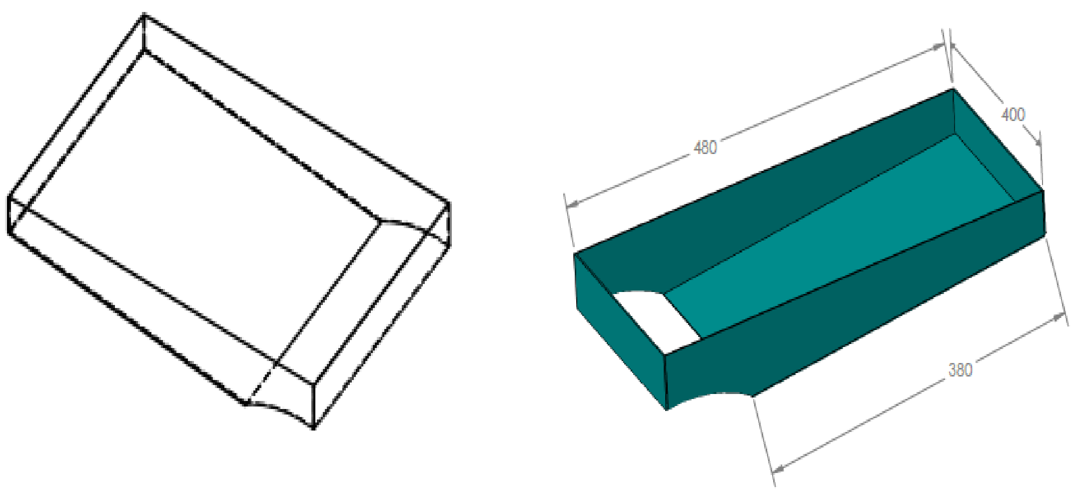

Figure 3.9. Isometric view of the hopper of the maize sheller prototype

3.4.4. Outer cover

This was made of a 1.5mm thick mild steel sheet of 633mm by 400mm. It was rolled to form a half cylinder of 352mm diameter; both sides were bent by40mm and holes were drilled to permit bolting to the frame. A face plate was marked out and cut to give 352mm diameter which was divided into two halves and were welded to both sides of the cylinder giving space for the shaft to pass through. The outer cover was designed to cover the upper part of the shelling drum and to support the feed hopper. It was horizontally on the main frame with nut and bolt arrangement so that it could be easily opened whenever required.

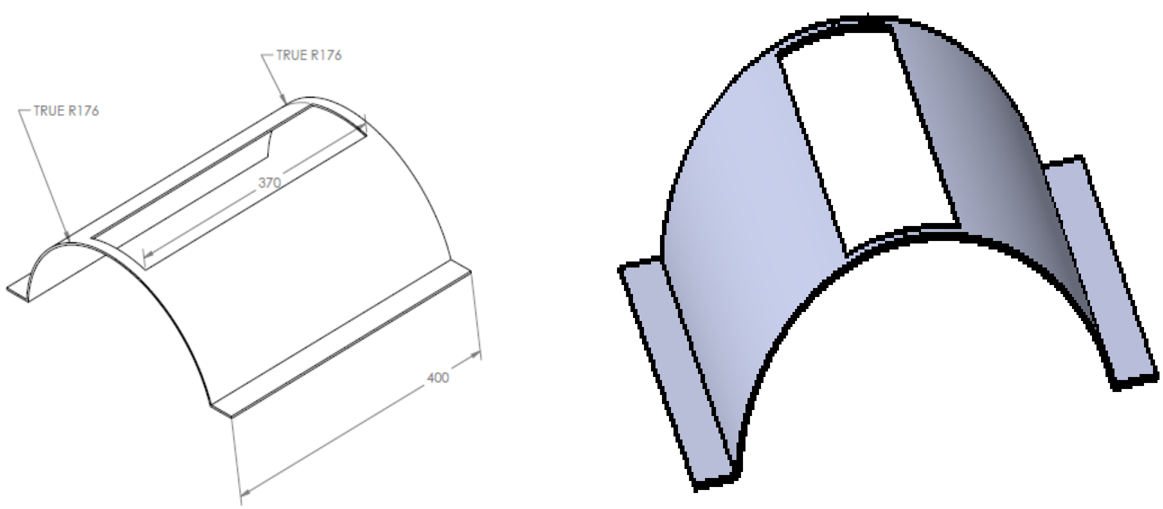

Figure 3.10. Outer cover of the maize sheller prototype

3.4.5. Outlet

The outlet was made up of metal sheet which is placed at the bottom of the shelling drum to collect the grains without shattering outside. The outlet was designed based on the frictional properties of the grains with grains and MS sheet. The rectangular shaped 1mm thickness MS sheet of 400×570 mm were provided at bottom of concave at 35° inclined manner along drum axis for collecting grains from either side of cylinder to center after shelling.

It was designed to collect all the grains from the slotting concave and direct into a receiver.

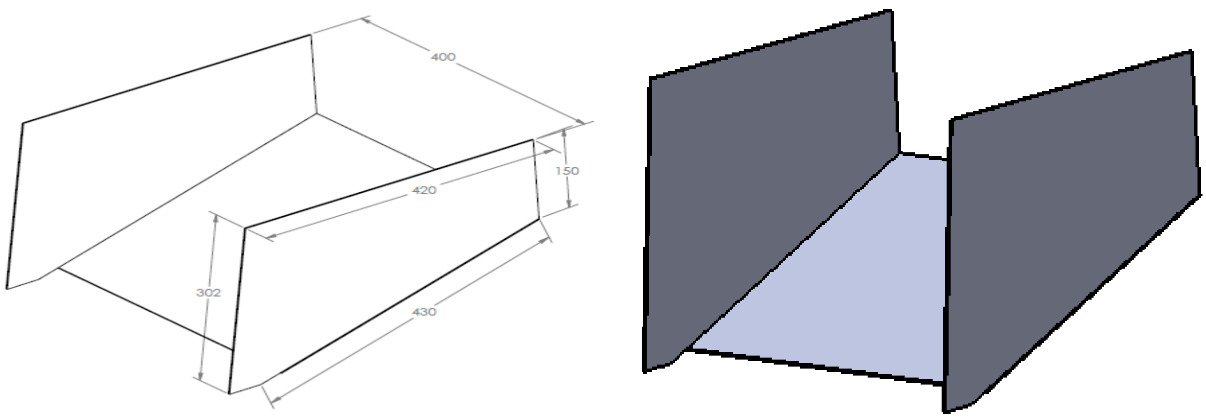

Figure 3.11. Out let of the maize sheller prototype

3.4.6. Power transmission system

The selection of the pulley and belts were made based on the rated power developed by electric motor, rated speed of motor drives pulley and maximum peripheral speed of shelling drum. For this maize sheller prototype, rated speed of motor drives pulley of 0.08cm diameter running at 950 rpm and average shelling drum peripheral speed of, 9.6 $\mathrm{ms}^{-1}$is chosen based on the load conditions.The speed of the drum was calculated by follow equation.

$$N = \frac{\text{Shelling drum peripheral speed}}{\pi D} \quad \ldots\ldots (3.21)$$

Where: D - Diameter of shelling drum (mm)

N - Shelling drum shaft speed (rpm)

$$N = \frac{9.6 \times 60}{3.14 \times 0.21} = 874 \text{ rpm}$$

$$\text{Velocity ratio} = \frac{\text{Motor shaft speed,rpm}}{\text{Shelling drum shaft speed,rpm}} \quad \ldots\ldots (3.22)$$

$$\text{Velocity ratio} = \frac{950 \text{ rpm}}{874 \text{ rpm}} = 1.2$$

3.4.6.1. Selection of motor

The motor is prime drive in the machine and it converts electrical power into mechanical power which gives rotary motion to mechanism. The purpose of an electric motor is to develop the necessary power required for a task. The motor selection is a very important design aspect in machine design practice. For this maize sheller prototype, a three phase motor of 2hp running at 950 rpm is chosen based on the load conditions.

It is evident from the literature that, there exist a definite relationship between feed rate, cylinder peripheral speed and power requirement for shelling of maize crop. The power requirement increases with the increase in the feed rate and cylinder peripheral speed. It has been observed from literature that, for a feed rate of above 1000 $\mathrm{kg\,hr^{-1}}$, the cylinder peripheral speed varied in between 9 to 12$\mathrm{m\ s^{-1}}$, while it was 5.5 to 9$\mathrm{m\ s^{-1}}$for a feed rate in between the 300 to 1000 $\mathrm{kg\,hr^{-1}}$(Singh et al., 2011).Since, the design of maize sheller was carried out for the feed rate in between the 1000 to 2000$\mathrm{kg\,hr^{-1}}$ soshelling drum peripheral speeds of 9 to 11$\mathrm{m\ s^{-1}}$, were selected.

3.4.6.2. Pulley

Williams (1953) gives the horse power rating at a maximum pitch diameter of pulleys and the corresponding speeds. The diameter of the driver pulley was determined from horsepower rating of the electric motor and the diameter of pulley shaft was obtained from the velocity relationship.

$$\mathrm{D_2N_2 = D_1N_1} \quad \text{(3.23)}$$

Where: $\mathrm{N_1}$ - electric motor speed (rpm)

$\mathrm{D_1}$- diameter of electric motor pulley (cm)

$\mathrm{D_2}$- diameter of shelling drum pulley (cm)

$\mathrm{N_2}$-shelling drum speed (rpm)

$$\mathrm{D_2} = \frac{\mathrm{D_1N_1}}{\mathrm{N_2}} = \frac{0.08 \times 950}{874} = 12\mathrm{cm}$$

3.4.6.3. Selection of belts

The selection of a V belt drive involves specifying the sheave diameters needed to implement a desired speed ratio existing between an input and output shafts of a system, belt size, length and number of belts required to transfer the amount of power from one shaft to another required by the application consistent with the shaft to shaft spacing that can exist in a particular application. A belt provides a convenient means of transferring power from one shaft to another. Belts are frequently necessary to reduce the higher rotational speeds of electric motors to lower values required by mechanical equipment (Spotts, 1985).

When the belt connecting two pulleys is stationary, the tensions in the two portions of the belt are equal but when torque is applied to the driving pulley, one portion of the belt is stretched and the other portion becomes slack. The procedure for selecting a V-belt drive is dependent on the motor horse power and the speed (rpm) rating. The properties of a V-belt of A cross section such as density, cross sectional area and allowable tensile stress (σ) were taken as $1000 kgm^{-3}$, $104 mm^2$ and 2.5 MPa. A groove angle (2β) of 35° pulley of 0.3 was considered as coefficient of friction (μ) between pulley and belt (Khurmi and Gupta, 2005).

Table 3.3. V-belt horse power

Cross section	Load of drive (Kw)	min. pulley pitch diam., d (mm)	Nominal top width, w (mm)	Nominal thickness(mm)	Weight per meter (kg f)
A	0.75 – 5	75	13	8	0.106
B	2-15	125	17	11	0.189
C	7.5-75	200	22	14	0.343
D	22-50	355	32	19	0.596
E	30-190	500	38	22	____

Source: Design data (PSG Tech 1989)

Centre Distance of Belt: The following factors determined the center distance of pulleys,the class of V-belt used, the configuration of the machine and the space available.

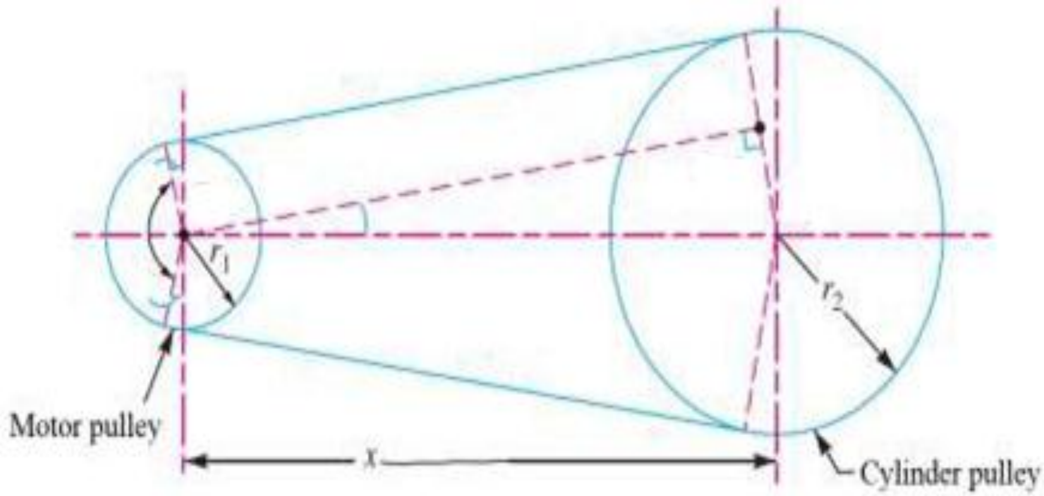

Figure 3.12. Sketch of power transmission system using a v-belt

However, the two pulleys must be near to each other. The maximum center distance of belt in use depends on the size of the two pulleys and is given as (Bharati, K., 1998).

X_{max}= 2(d_2+d_1) ………………………………………………………………………......... (3.24)

Where: X_{max} - maximum center distance of belt (cm)

d_2 - diameter of shelling drum pulley (cm)

d_1 - diameter of motor pulley (cm)

X_{max}= 2(12+8) = 40cm

The length of belt: The length of the belt was calculated based on the diameters of the driver and driven pulleys and center to center distance between the pulleys.

The formula used for calculating the length of the belt is given by (Bharati, K., 1998).

$$L = \pi(r_2 - r_1) + 2x + \frac{(r_2 - r_1)^2}{x} \quad \text{.......... (3.25)}$$

Where: L - length of belt (cm)

r_2- radius of shelling drum pulley (cm)

r_1- radius of motor drum pulley (cm)

X - center distance of belt (cm)

$$L = 3.14(6-4) + 2 \times 40 + \frac{(6-4)^2}{40} = 86.3\text{cm}$$

The mass of the belt per unit length

$$m = A \times L \times \rho \quad \text{.......... (3.26)}$$

Where: m - mass of the belt (kgm^{-1})

A - cross sectional area of belt (m^2)

L - length of belt (m)

ρ - lensity of belt material (kgm^{-3})

$m = 104 \times 10^{-6} \times 1 \times 0.863 \times 1000 = 0.08975kgm^{-1}$

The centrifugal tension of the belt

$$T_c = mv^2 \quad \text{.......... (3.27)}$$

Where: T_c - centrifugal tension of the belt (N)

m - mass of the belt per meter length (N)

V -velocity of the belt (ms^{-1})

$$V = \frac{\pi \times d1 \times N}{60} \quad \text{.......... (3.28)}$$

Where: d_1 - diameter of motor pulley (mm)

N- speed of motor (rpm)

$$V = \frac{3.14 \times 0.08 \times 950}{60} = 4\ ms^{-1}$$

$$T_c = 0.08975 \times 9.81 \times 4^{\,2} = 14.08N$$

Maximum tension in the belt: To calculate the maximum belt tension, which does not in all cases takes place at the head pulley; the following formulae must be used:

$$T = \sigma \times A \quad \text{(3.29)}$$

Where: σ - allowable tensile stress (Nmm^{-2})

A - cross sectional area of belt (mm^2)

$$T = 2.5 \times 10^6 \times 104 \times 10^{-6} = 206N$$

Therefore, Tension in tight side of the belt

$$T_1 = T - T_c \quad \text{(3.30)}$$

Where: T_c- centrifugal tension of the belt (N)

T_1- tension in tight side of the belt (N)

T - maximum tension in the belt (N)

$$T_1 = 260 - 14.08 = 245.92N$$

The tension in the slack side of the belt (T_2) for open belt drive is calculated as follows

$$\sin\alpha = \frac{r_2 - r_1}{x} = \frac{d_2 - d_1}{2x} \quad \text{(3.31)}$$

Where: r_1-radius of motor pulley (cm)

r_2- radius of shelling drum pulley (cm)

d_1 - diameter of motor pulley (cm)

d_2 - diameter of shelling drum pulley (cm)

α - angle of lap on shelling drum pulley (degree)

$$\alpha = \sin^{-1}\frac{12-8}{2\times 40} = \sin^{-1}(0.05) = 2.866°$$

Angle of lap on smaller pulley (i. e. pulley on motor shaft)

$$\theta = 180 - 2\alpha \quad \text{(3.32)}$$

$$\theta = 180 - 2 \times 2.866° = 174.2685°$$

$$\theta = 174.2685° \times \frac{\pi}{180} = 3.04 \text{ rad.}$$

To find tension at slack side,T_2 the following formula was used

$$2.303\log\left(\frac{T_1}{T_2}\right) = \mu \times \theta \times \operatorname{cosec}\left(\frac{\beta}{2}\right)$$

$$2.303\log\left(\frac{T_1}{T_2}\right) = 0.3 \times 3.04 \times \operatorname{cosec}\left(\frac{35}{2}\right) = 3$$

$$\log\left(\frac{T_1}{T_2}\right) = \frac{3}{2.303} = 1.3$$

$$\frac{T_1}{T_2} = 19.95$$

$$T_2 = \frac{245.92}{19.95} = 12.33\text{N}$$

The power transmitted per belt: According to Hannah and Stephens (1970), the power transmitted by belt is given by the following formulae.

$P = (T_1 - T_2)\, v$ ………………………………………………………………...... (3.33)

Where: P - power transmitted per belt (kW)

T_1 - tension in tight side of the belt (N)

T_2 - tension in slack side of the belt (N)

v- speed of belt (ms^{-1})

$$P = (245.92 - 12.33)4 = 0.934\text{Kw}$$

Therefore, Number of V-belts required transferring power to drum pulley from motor pulley

$$\text{Number of v belt} = \frac{\text{Total power transmitted}}{\text{Power transmitted per belt}} \quad \text{(3.34)}$$

$$\text{Number of v belt} = \frac{1.492\text{kw}}{0.93436\text{Kw}} = 1.6 \approx 2$$

3.4.6.4. Selection of bearing

Bearing must be selected based on its load carrying capacity, life expectancy and reliability (PSG Tech 1989). The relationship between the basic rating life, the basic dynamic rating and the bearing load carrying capacity;

$$C = p \times \left(\frac{L}{L5}\right)^{1/k} \qquad (3.35)$$

Where: P = equivalent dynamic bearing load (N)

L = required life of bearing in million revolutions

C = basic dynamic load rating (N)

K = exponent for life equation with (K = 3 for ball bearing)

Since the average life of the bearing is 5 years at 8 hours per day, therefore life of the bearing in hours and since the rotational factor for most of the bearings is 1, therefore dynamic equivalent load is equal to the radial load (283.2N).

$L_5 = 5 \times 60 \times 8 = 24\ 00$ hours (Assuming 60 working days per year)

$$L = 60 \times n \times L_5 = 60 \times 874 \times 125856000 \text{rev/mill}$$

Where: n = rotational speed (rev/min)

$$C = 283.2 \times \left(\frac{125856000}{2400}\right)^{1/3} = 10.4\text{KN}$$

A single row angular contact ball bearing number 204 was selected based on its load carrying capacity, life expectancy from basic static and dynamic capacities of various types of radial ball bearing in appendix table I.

3.5. Determination of the weight of component parts of the sheller

In order to estimate the total weight of the Sheller and loads on the drum shaft of the prototype Sheller, it was necessary to estimate weight of the shelling drum, spikes, shelling drum pulley, Shelling drum shaft, outer cover, concave, out let and frame. Accordingly, and all the weights of component parts were estimated using appropriate equations (Hall et al., 1988)

3.5.1. Determination of the weight of shelling drum

The weight of the shelling drum was determined in order to know the amount of load being exerted on the shaft by the shelling drum. This weight is expressed as the following equations.

$$W_d = \rho V_d \times g \quad \ldots\ldots (3.36)$$

$$V_d = \pi D L t \ldots\ldots (3.37)$$

Where: W_d- weight of shelling drum (N)

ρ - density of the shelling drum material (kgm^{-3})

V_d - volume of the shelling drum (m^3)

g - gravitational acceleration (ms^{-1})

D - shelling drum diameter (cm)

L- length of the shelling drum (cm)

t- thickness of the shelling drum material (cm)

$V_d = 3.142 \times 13\ cm \times 38\ cm \times 0.30cm = 465.348cm^3 = 0.000465\ m^3$

$W_d = \rho V_d \times g = 8750\ kgm^{-3} \times 0.000465\ m^3 \times 9.81ms^{-2} = 40N\ (4\ kg).$

3.5.2. Determination of the weight of spikes

$W_S = N_s \times \rho A_S \times Lg$………………………………………………………………….. (3.38)

$A_S = \frac{\pi D^2}{4}$…………………………………………………………………………..… (3.39)

Where: W_S - weight of spikes (N)

N_S - number of spike

A_S – area of spike (m^3)

ρ - density of the spike material (kgm^{-3})

D - diameter of spike (cm)

g - gravitational acceleration (ms^{-1})

L- length of spike (cm)

$$A_S = \frac{3.14 \times 0.012m^2}{4} = 0.000113m^2$$

$W_S = 32 \times 7850\ kgm^{-3} \times 0.00000942m^2 \times 0.04m \times 9.81ms^{-2} = 11N$(1.1 kg)

3.5.3. Determination of weight of shelling drum shaft

The weight of shelling drum shaft can be determined as follows

$W_{sh} = \rho \frac{\pi d^2}{4} \times L_{sh} \times g$……………………………………………………….... (3.40)

Where: W_{sh} - weight of shaft (N)

g - gravitational acceleration (ms^{-1})

ρ - density of the shaft material (kgm^{-3})

d - diameter of shaft (mm)

L_{sh} - length of shaft (mm)

$W_{sh} = 7850 \times 3.14 \frac{20}{4} \times 540 \times 9.81$ = 13.05N (1.305kg)

3.5.4. Determination of weight of shelling drum pulley

The weight of pulley on a shaft can be determined as follows

$$W_P = \rho \frac{\pi d^2}{4} \times L_P \times g \quad \ldots (3.41)$$

Where: W_P - weight of pulley (N)

g - gravitational acceleration (ms^{-1})

ρ - density of the pulley material (kgm^{-3})

d -diameter of pulley (m)

L_P -length of pulley (m)

$$W_p = 7200 \times 3.14 \frac{0.12^2}{4} \times 0.03 \times 9.81 = 24\text{N } (2.4\text{kg})$$

3.5.5. Determination of the weight of the sheller outer cover

The weight of the outer cover of the maize Sheller prototype was estimated as follows:

$$W_{OC} = V_{OC} \times \rho \times g \quad \ldots (3.42)$$

$$V_{CM} = T_{OC}[(ABxBC) - (EF \times FG)] \quad \ldots (3.43)$$

$$V_{OC} = 1.5[(400x633) - (380 \times 100)] = 3.23 \times 10^{-4} m^3$$

$$W_{OC} = 3.23 \times 10^{-4} m^3 \times 7850 kgm^{-3} \times 9.81\ ms^{-1} = 25N\ (2.5Kg).$$

Where: W_{OC} - Weight of outer cover material (N)

V_{OC} - Volume of outer cover material (m^3)

T_{OC}- Thickness of outer cover material (mm)

ρ - Density of outer cover material (kgm^{-3})

g - Gravitational acceleration (ms^{-1})

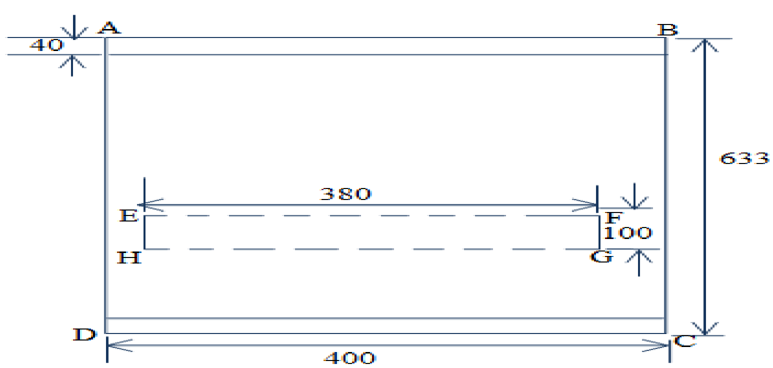

Figure 3.13. Diagram of the metal sheet used in the construction of the outer cover

3.5.6. Determination of the weight of the hopper

The weight of the hopper of the prototype maize sheller was estimated as follows:

$$W_H = V_H \times \rho \times g \ldots\ldots (3.44)$$

$$V_H = T_H[(ABxBC) \times 2 + (BC \times CD) \times 2 + (HI \times HJ] \ldots\ldots (3.45)$$

Where: W_H - Weight of the hopper material (N)

V_H - Volume of the hopper material (m^3)

T_H - Thickness of the hopper material (mm)

ρ - Density of the hopper material (kgm^{-3})

g - Gravitational acceleration (ms^{-1})

$$V_{CM} = 1[(480x50) \times 2 + (50 \times 400) \times 2 + (400 \times 380] = 1.608 \times 10^{-3} m^3$$

$$W_H = 1.608 \times 10^{-3} \times 7850 kg\, m^{-3} \times 9.81\ ms^{-1} = 124N(12.4Kg)$$

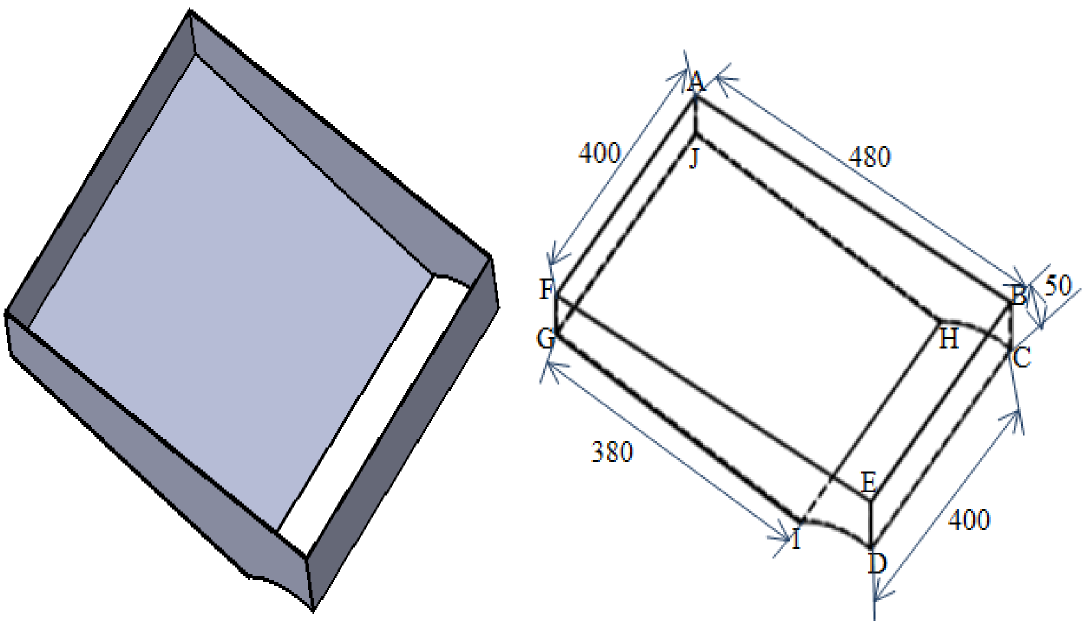

Figure 3.14. Diagram of the metal sheet used in the construction of the hopper

3.5.7. Determination of the weight of the concave of the sheller

$W_{RM} = V_{RM} \times \rho \times g$……………………………………………………………………...… (3.46)

$W_{FM} = V_{FM} \times \rho \times g$……………………………………………………………………….... (3.47)

$V_{RM} = \left[\left(L_{RM} x \frac{\pi D^2}{4}\right) \times nr\right]$……………………………………………………………………... (3.48)

$V_{FM} = T_{FM}[(L_{FM} x\, W_d) \times nf]$………………………………………………………………..... (3.49)

Where: W_{RM} - weight of round mild steel material (N)

W_{FM} -weight of flat mild steel material (N)

V_{RM} - volume of round mild steel material(m^3)

V_{FM} - volume of flat mild steel material(m^3)

T_{FM} - thickness of flat mild steel material (mm)

ρ - density of mild steel material($kg\, m^{-3}$)

g - gravitational acceleration (ms^{-1})

D -diameter of the round mild steel (mm)

L_{RM} - length of round mild steel material (mm)

L_{FM} - length of flat mild steel material (mm)

W_d - width of flat mild steel material (mm)

Nr - number of round mild steel material

n_f - number of flat mild steel material

$V_{RM} = [(400 \text{ x } 3.14 \times 10^2) \times 21] = 6.5394 \times 10^{-4} m^3$

$V_{FM} = 2[(710 \text{x } 20) \times 4] = 1.136 \times 10^{-4} m^3$

$W_{RM} = 6.594 \times 10^{-4} m^3 \times 7850 kg\, m^{-3} \times 9.81\ ms^{-1} = 50.78N$ (5.3Kg)

$W_{RM} = 1.136 \times 10^{-4} m^3 \times 7850 kg\, m^{-3} \times 9.81\ ms^{-1} = 8.8N$ (0.88Kg)

Therefore the total weight of the concave was calculated as

$W_{RM} + W_{FM} = 5.3 + 0.88 = 6.1Kg$

3.5.8. Determination of the weight of the Sheller outlet

Figure 3.15 shows the metal sheet used in the construction of the outlet. The weight of outlet was calculated as follows.

$W_{FM} = V_{FM} \times \rho \times g$……………………………………………………………………….... (3.50)

$V_{FM} = T_{FM}\left[(AFxFE) + (BC \times CD) \times 2 + \frac{1}{2}(AB \times BG) \times 2\right]$…………………………...… (3.51)

Where: W_{FM} - Weight of outlet material (N)

V_{FM} - Volume of outlet material (m^3)

T_{FM} - Thickness of outlet material (mm)

ρ - Density of outlet material (kgm^{-3})

g - Gravitational acceleration (ms^{-1})

$$V_{FM} = 2\left[(150x420) + (50 \times 352) \times 2 + \frac{1}{2}(430 \times 152) \times 2\right] = 4.9068 \times 10^{-4} m^3$$

$$W_{FM} = 4.9068 \times 10^{-4} m^3 \times 7850 Kgm^{-3} \times 9.81\ ms^{-1} = 37.78N\ (3.8\ kg)$$

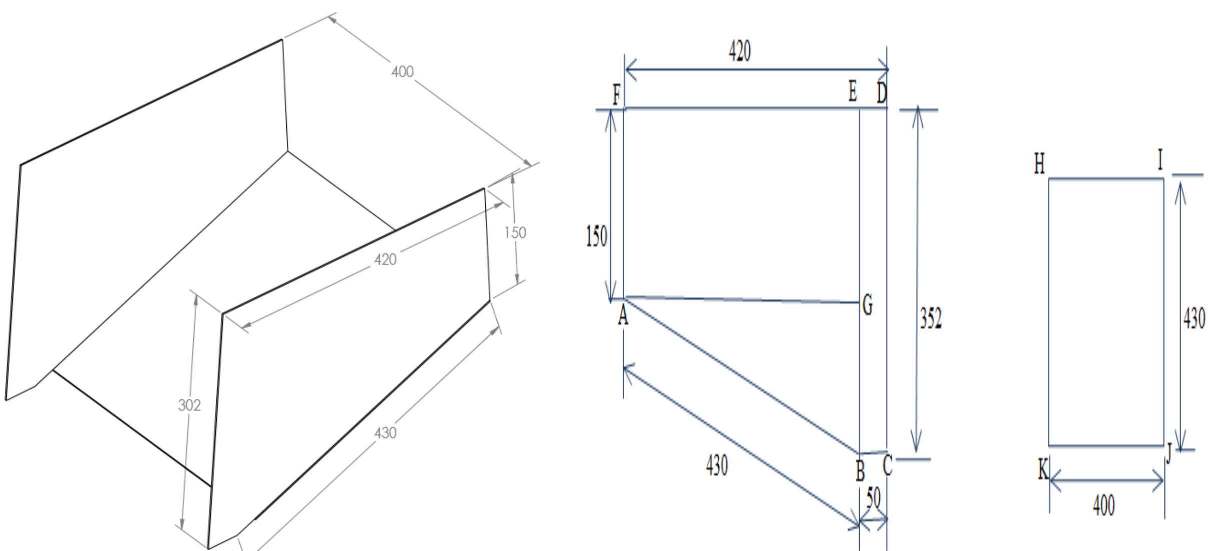

Figure 3.15. Diagram of the metal sheet used in the construction of the outlet

3.5.9. Determination of the weight of the sheller frame

Figure 3. 16 shows the metal sheet used in the construction of the frame. The weight of frame was calculated as follows.

$$W_{FM} = V_{FM} \times \rho \times g \quad (3.52)$$

$$V_{FM} = T_{FM}[\sum L_{FM} \times ns\,]W_d \quad (3.53)$$

Where: W_{FM} - Weight of frame material (kg)

V_{FM} - Volume of frame material (m^3)

W_d-Width of frame material (kg)

L_{FM}- Length of frame material (m)

T_{FM} - Thickness of frame material (m)

ρ - Density of frame material (kgm^{-3})

ns -Two times number of parts

$$V_{FM} = 3\left[\sum (600x\,8) + (420 \times 4) + (400 \times 4)\right] \times 40 = 9.696 \times 10^{-4} m^3$$

$$W_{FM} = 9.696 \times 10^{-4} m^3 \times 7850 kgm^{-3} \times 9.81 ms^{-2} = 75N\ (7.5Kg)$$

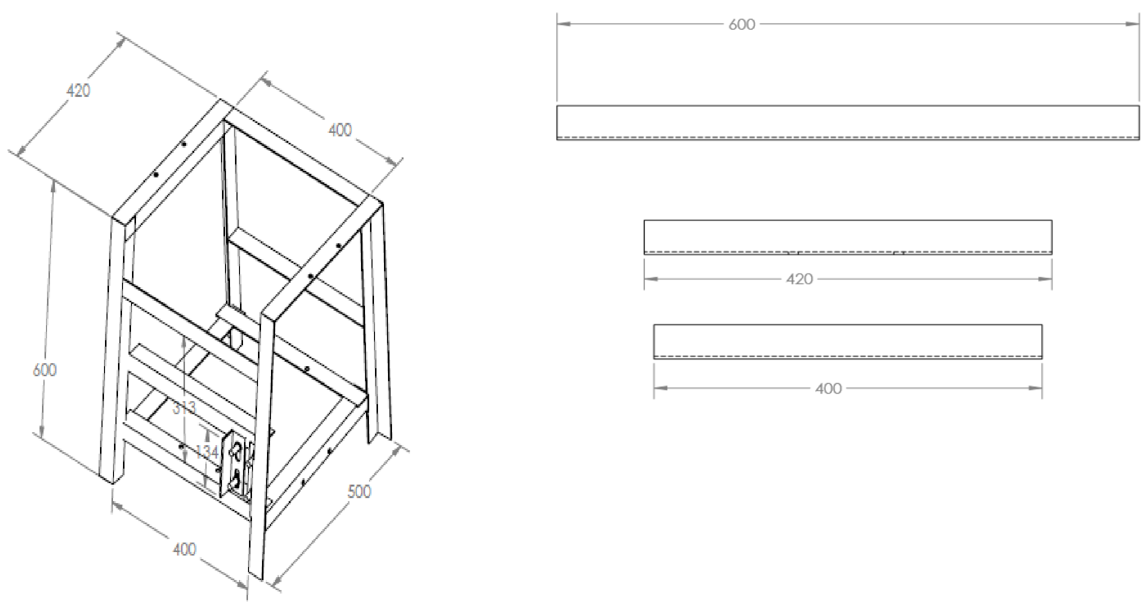

Figure 3.16. Diagram of the angle iron used in the construction of the sheller frame.

Table 3.4.Total mass of all components parts of the maize sheller prototype

S/N	Components	Materials	Quantity	Total weight (kg)
1	Frame	Angle bar Mild Steel	1	7.5
2	Shelling drum	mild steel	1	4
3	Spikes	mild steel rod	1	1.1
4	Concave	mild steel rods	1	5.3
		flat mild steel		0.88
5	Outer cover	mild steel sheet	1	2.5
6	Hopper	Mild steel	1	12.4
7	Outlet	mild steel sheet	1	3.8
8	Shaft	Mild steel	1	1.3
9	Bearing	Mild steel	1	1
10	Stand	Angle bar Mild Steel	1	1.5
11	Pulley	Angle bar Mild Steel	1	2.4
12	Bolt and nuts	mild steel rod	16	1.32
13	Others small parts	__	__	1
Total				46

3.6. Determination of force acting on drum shaft

The force acting on drum shaft is the weight of the driven pulley and weight of shelling device (drum and spike) the vertical forces applied by shelling drum and pulley are represented at the point C to D and E, respectively. The point C to D considered as uniformly distributed load on the shaft i.e. 53N over the 380mm length of the drum. The force applied at the point E calculated by following formula (Khurmi and Gupta, 2005).

$$W_E = T_1 + T_2 + W_P \quad (3.54)$$

Where: W_E-The force applied at the drum shaft pulley (N)

T_1 - Tension at tight side (N)

T_2 - Tension at slack side (N)

W_P-Weight of pulley (N)

The weight of the pulley was found as24N (or 2.4 kg). So, the force applied at the point E

$W_E = 246 + 12.3 + 24\text{N} = 282.3\text{N}$

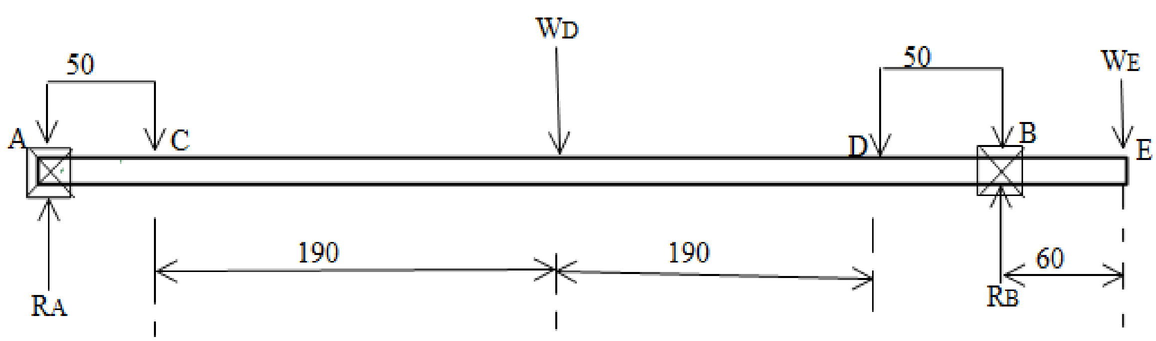

Figure 3.17. The drum shaft showing forces acting on it (dimensions are in mm).

Where: R_A-Reactions at the support (N)

R_B - Reactions at the support (N)

W_E - weight at the drum pulley (N)

W_D - total weight of shelling drum (N)

3.6.1. The reaction forces developed on shaft at both sides of the Shelling drum

The reaction forces developed on shaft at both the sides of the cylinder were shown at points A and B. These reaction forces were calculated by using equations (Khurmi and Gupta, 2005).Considering, the total upward force = Total downward force

$R_A + R_B = W_D + W_E$ …………………………………………………………………. (3.55)

$R_A + R_B = 333.3$ N

$R_B = 333.3 - R_A$ …………………………………………………………………... (3.56)

Considering, Moments at LHS of B = Moments at RHS of B

$(282.3 \times 60) = (R_A \times 480) + (51 \times 240)$

$RA = \frac{16938}{480} = 35.3\text{N}$

So, putting the R_A value in the above equation 3.56, we get

$R_B = 333.3 - 35.3\text{N} = 298\text{N}$

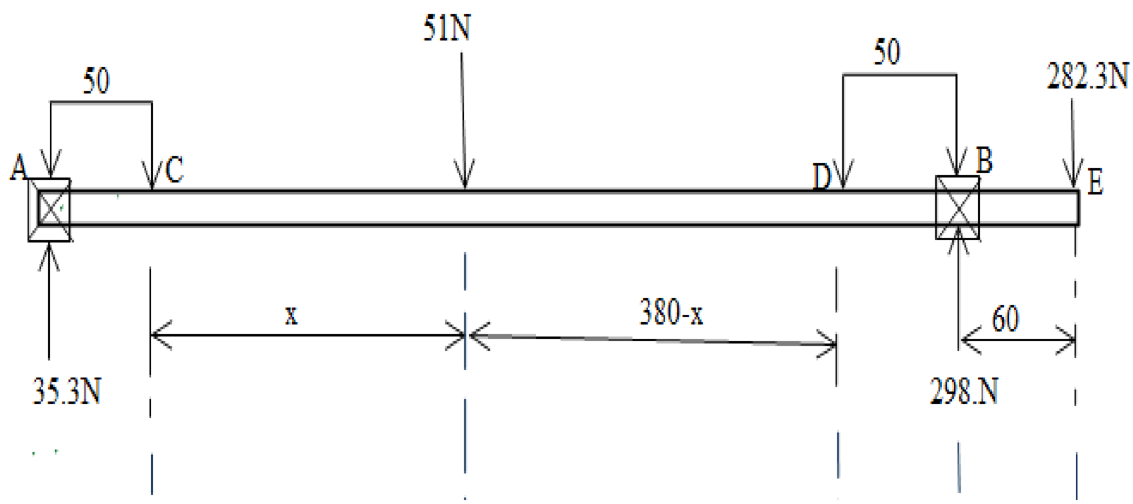

Figure 3.18. All the forces acting on drum shaft (dimensions are in mm)

3.6.2. Shearing force and bending moment on the drum shaft

The share force on the shaft was computed using Figure 3.19 as follows

F_E = 282.3N

F_B = 282.3-298N = -15.7N

F_D = -15.7N

F_C = - 15.7+51 = 35.3N

F_A = 35.3 N

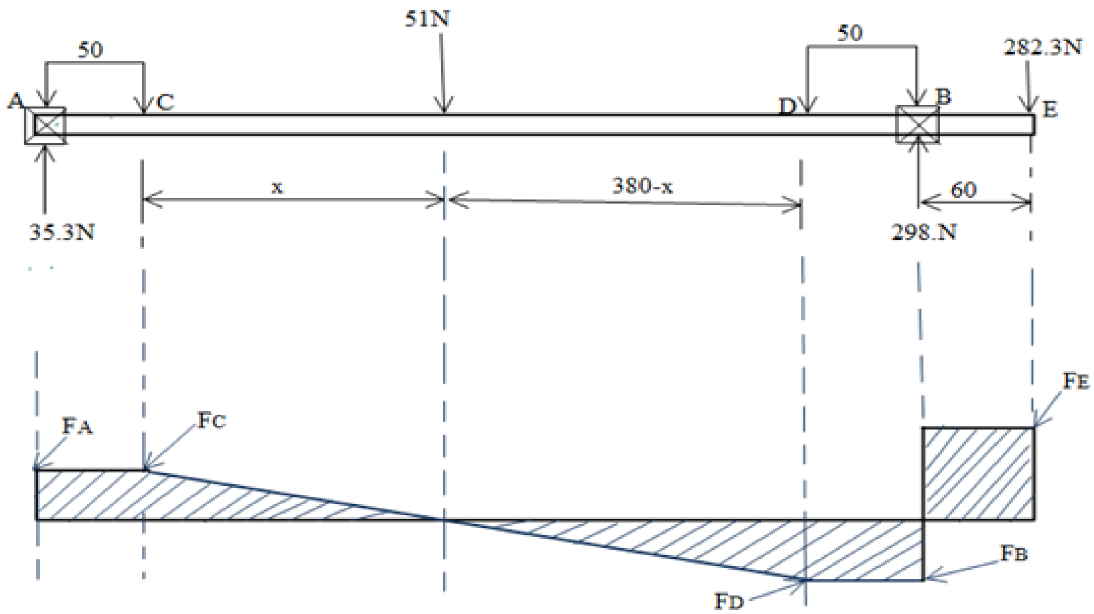

Figure 3.19. Vertical shear force distribution on the shelling drum shaft

The maximum vertical bending moments (M_V) on the shaft were computed using figure 3.20 as follows

BM at E = 0Nmm

M_B = - (282.3×60) = - 16938Nmm

M_D = - (282.3×110) + (298×50) = - 16153Nmm

M_C = - (282.3×490) - (51 ×190) + (298×430) = -19877Nmm

M_A =0Nmm

The possibility of bending moment occur at A, P and B, where the shared force changes the sign. To know the shear force moment at a point P, let *x* be the difference between C and P. considering the symmetry triangles in the geometry From Figure. 3.20, the distance between the P and D will be

$$\frac{15.7}{35.3} = \frac{x}{380 - x}$$

$$15.7(380 - \mathrm{x}) = 35.3\mathrm{x}$$

$$5966 – 15.7x = 35.3x$$

X $=\frac{5966}{51} = 117\text{mm},$ distance between the C and P.

So, the distance between the P and D will be,

380-x = 380-235.435mm = 263mm

The bending moment at the point P will be,

M_P = (-282.3×373) + (298×313) - (35.3N×117) = 7893.8Nmm

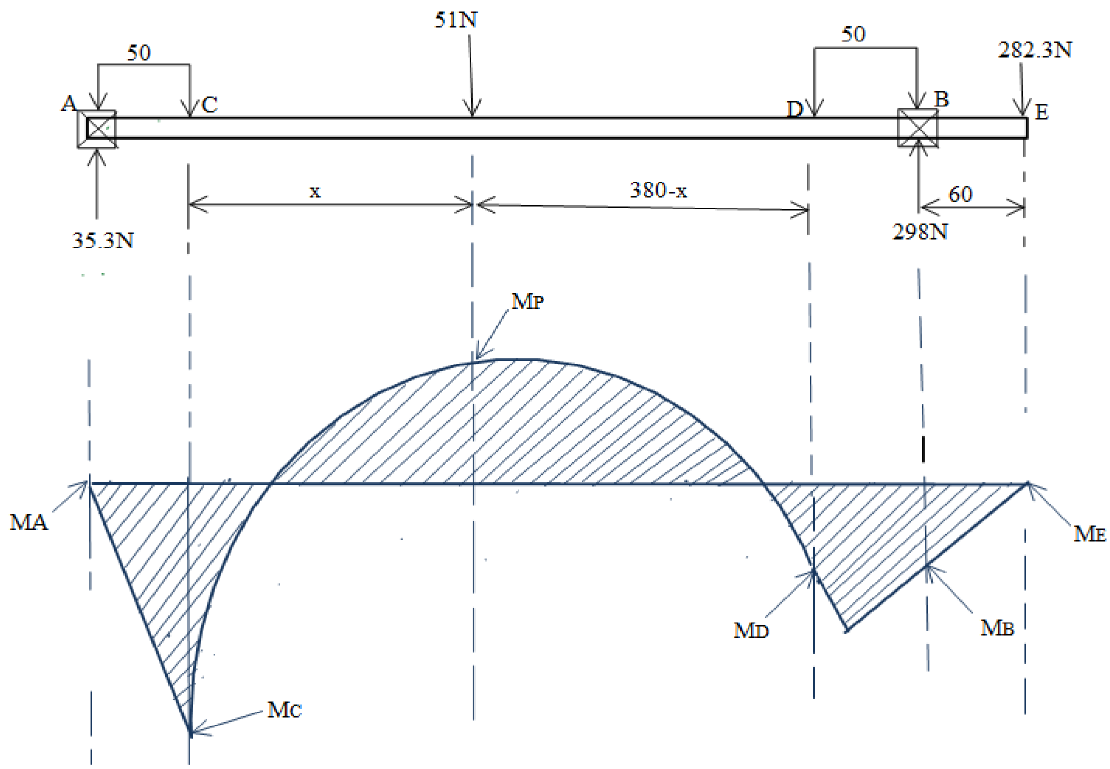

Figure 3.20. Vertical bending moment distribution

3.6.3. Shaft design

The shaft of this machine has a shelling unit attached to it (by welding) at two opposing sides and a pulley mounted on it and supported on bearings. The required diameter for a solid shaft having combined bending and torsional loads is obtained from ASME code equation (Hall et al; 1983).

$$d^3 = \frac{16}{\pi Ss}\left[(KbMb)^2 + (KtMt)^2\right]^{\frac{1}{2}} \quad \text{(3.57)}$$

Where d - diameter of shaft (mm)

Mt - torsional moment (Nm)

Mb - bending moment (mm)

Kb - combined shock and fatigue factor applied to bending moment

Kt - combined shock and fatigue factor applied on torsional moment

Ss- allowable stress for shaft without key way (MN/m^2)

For rotating shafts, when load is suddenly applied (minor shock): Kb = 1.5 to 2.0; Kt = 1.0 to 1.5. For shaft without key-way; Ss (allowable) = $55MN/m^2$.

3.6.3.1. Design of shaft when subjected to twisting moment

Design for diameter of the shelling drum shaft to mount driven pulley was done considering twisting moment (or torque) only. The diameter of the shaft was determined by following equation (Hall et al., 1988).

$$\frac{T}{J} = \frac{\tau}{r} \quad \text{(3.58)}$$

Where: T - Twisting moment (or torque) acting upon the shaft (Nm)

J - Polar moment of inertia of the shaft about the axis of rotation (m^4)

τ - Torsional shear stress (42 MPa taken for mild steel,).

r - Distance from neutral axis to the outer most fibre = d/2

d - diameter of the shaft (mm)

We know that for round solid shaft, polar moment of inertia,

$$J = \frac{\pi d^4}{32} \qquad (3.59)$$

$$\frac{T}{\frac{\pi d^4}{32}} = \frac{\tau}{d/2} \qquad (3.60)$$

$$d^3 = \frac{16T}{\pi\tau} \qquad (3.61)$$

$$T = \frac{P \times 60 \times 1000}{2\pi N} \qquad (3.62)$$

Where: T = Torque on driven pulley shaft (Nm)

N = revolution of the cylinder shaft (rpm)

$$T = \frac{1.492 \times 60 \times 1000}{2 \times 3.14 \times 874N} = 23.98Nm$$

Putting T value in equation 3.62 above

$$d^3 = \frac{16 \times 23980}{3.14 \times 42} = 14.3mm$$

3.6.3.2. Design of shaft when subjected to bending moment

When the shaft is subjected to a bending moment only, then the maximum stress (tensile or compressive) is given by the bending equation. The maximum bending moment on the Shaft was determined from the following expressions (Khurmi and Gupta, 2005).

$$M_b = \left(M_V{}^2 + M_h{}^2\right)^{1/2} \qquad (3.63)$$

Where: M_v - vertical bending momentum (Nm)

M_h - horizontal bending momentum (Nm)

The maximum horizontal bending moment is given as

$$M_H = \frac{\sigma_b \times I}{Y} \qquad (3.64)$$

$$I = \frac{\pi d^4}{64} \qquad (3.65)$$

$$y = \frac{d}{2} \qquad (3.66)$$

Where: M_H- horizontal bending moment

I- Moment of inertia of cross-sectional area of the shaft about the axis of rotation

σ_b - Bending stress (100 Nmm).

y- Distance from neutral axis to the outer-most fire.

$$\sigma_b = \frac{MH \times \frac{d}{2}}{\frac{\pi d^4}{64}} \qquad (3.67)$$

$$d^3 = \frac{32M}{\pi \times \tau} = \frac{32 \times 15570}{3.14 \times 100Nmm} = 1586.75mm$$

d =11.66mm

From above considerations, the designed shaft diameter when shaft subjected to twisting and bending moment was found to be 14.3mm and 11.66 mm. By considering factor of safety, 20% and availability the designed shaft diameter of 20mm diameter was selected for shelling drum shaft.

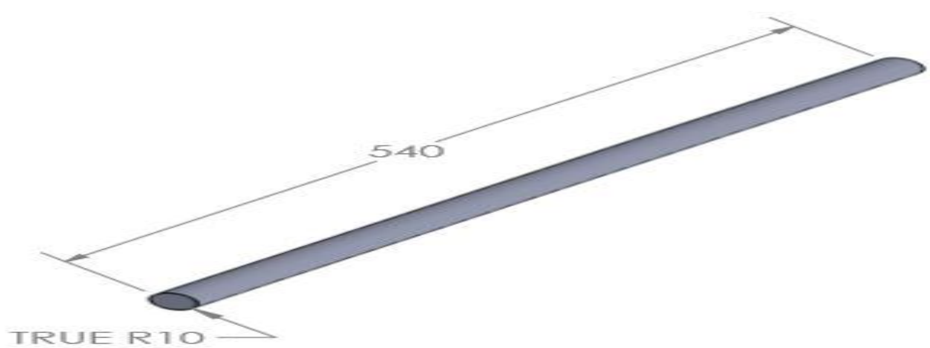

Figure 3.21. Drum shaft of the maize sheller prototype (dimensions in mm).

3.7. Force required for shelling maize along the length of the shelling drum

3.7.1. Centrifugal force

The rotational motion from the prime mover (electric motor shaft) is transmitted to the driven shaft carrying the drum with rotary spikes. The shelling spikes which are attached to the shelling drum rotate with the shaft, giving rise to centripetal force and given by (Hannah and Stephens, 1970).

$$F = m\omega^2 r \qquad (3.68)$$

$$\omega = \frac{2\pi N}{60} \qquad (3.69)$$

Where: F - centrifugal force (N)

m -mass of threshing spikes (kg)

ω -angular velocity

N - revolution of the cylinder shaft (rpm)

r -maximum radius of threshing arm and it is given (0.008m, assumed)

$$\omega = \frac{2\pi N}{60} = \frac{2 \times 3.14 \times 950}{60} = 99.43\ \text{rad}^{-s}$$

$$F = 1.1\ \text{kg} \times 99.43^2 \times 0.08 = 870\text{N}$$

3.7.2. Determination of shelling torque

The value of torque developed by a rotational body is given as the product of the force causing the motion multiplied by the radius of rotation and given by (Hannah and Stephens 1970).

$$T = F \times r \qquad (3.70)$$

Where: F - available centripetal force

r - Distance from neutral axis of shaft = d/2

$$T = 870\text{N} \times 0.01 = 8.7\ \text{Nm}$$

3.7.3. Determination of the power delivered by drums shaft

As the torque transmitted by the shaft was known, the power developed by a torque moving at ω is calculated by using the formula (Adesuyi, J., 1983).

$P = T\omega$ ……………………………………………………………………………...… (3.71)

Where: P - power delivered by drums shaft (Watt.)

T-torque (Nm)

ω -angular velocity shelling drum ($rads^{-1}$)

$$P = 8.7\text{Nm} \times 99.43 \text{ rad s}^{-1} = 865\text{watt.}$$

3.7.4. Determination of torsional moment

Torsional moment on the shaft was calculated using the following equation (Ryder, 1989).

$M_t = \frac{P \times 60}{2\pi N}$……………………………………………………………………………….. (3.72)

Where: Mt - torsional moment (Nm)

P -Power (watts)

N - Speed (rpm)

$$M_t = \frac{865 \times 60}{2 \times 3.14 \times 950} = 8.7\text{N}$$

3.7.5. Torsional Stress

According to Black and Adams (1968) torsional stress is determined as follow.

$$\tau xy = \frac{M_t \times r}{J} = \frac{16M_t}{\pi d^3} \quad \text{.......... (3.73)}$$

$$J = \frac{\pi d^4}{32} \quad \text{.......... (3.74)}$$

Where: τxy - Torsional stress Nm^{-2}

M_t- torsional moment (Nm)

r -radius of shaft (m)

J - Polar moment of area (m^4)

d -diameter of shaft (m)

$$J = \frac{3.14 \times 0.02^4}{32} = 1.5 \times 10^{-8} m^4$$

$$\tau xy = \frac{8.7 \times 0.01}{1.5 \times 10^{-8}} = \frac{5800000N}{m^2} = 5800Kpa$$

3.7.6. Torsional rigidity

Torsional rigidity of a shaft is based on permissible angle of twist. The amount of twist Permissible depends upon the particular application and varies from 0.3 degree per meter for a machine tools shaft to about 3 degree per meter for line shafting (Black and Adams, 1968).

$$\theta = \frac{584\ M_t L}{Gd^4} \quad \text{.......... (3.75)}$$

Where: θ - angle of twist (degree)

L -length of shaft (m)

M_t-torsional moment (Nm)

G -torsional modulus of rigidity (Nm^{-2})

d -diameter of shaft (m)

$$\theta = \frac{584 \times 8.7 \times 0.54}{84 \times 10^9 \times 1.6 \times 10^{-7}} = 0.204rad$$

$$\theta = 0.204rad \times \frac{180}{\pi} = 0.204rad \times \frac{180}{3.14} = 11.7^o$$

3.7.7. Lateral rigidity

The lateral rigidity of a shaft is based upon the permissible lateral deflection for proper bearing, Operation, accurate machine tool performance; shaft alignment .Amount of deflection can also be calculated by two successive integrals of the formula (Black and Adams , 1968).

$$d^2y / xd^2y = Mb / EI \qquad (3.76)$$

Where: Mb - bending moment Nm

E - Modulus 'of elasticity (Nm^{-2})

I - Moment of inertia (m^4)

$$d^2y / xd^2y = \frac{15570000}{380 \times 10^9 \times 7 \times 10^{-9}} = 0.0000000885m^{-4}$$

3.7.8. Shear stress

The shear stress on the shaft is determined by the formula below (Black and Adams , 1968).

$$\tau = \frac{16T}{\pi d^3} \qquad (3.77)$$

Where: τ- Shear stress

T- torque (Nm)

d - diameter of shaft (mm)

$$\tau = \frac{16 \times 8.7}{3.14 \times 0.02^3} = 5541401.274Nm^{-2}$$

3.8. Construction and principle of operation of the maize sheller prototype

The maize sheller prototype was constructed based on dimension obtained from the design using software (CAT IAV5). The prototype consist frame, drum with spike, shaft, concave, outer cover, hopper, outlet, belt, pulley and motor.

3.8.1. Construction of the maize sheller prototype

The detailed parts and materials for construction of the maize sheller is shown in table 3.1
Frame: it was designed with an angle iron of 40mm cut to length of 420 x 400mm to form the top resting platform for shelling drum and bearings. The same angle iron was cut to a length of 600mm to form standing legs for the frame. The operations are cutting, welding and drilling.

Drum: The drum was made from a mild steel of 30mm. The metal sheet was rolled with the rolling machine to form a drum of length 380mm and diameter 130mm. Faceplates were marked out as 130mm circles and cut out. They were then welded to the drum and the right centers were drilled to accommodate the shaft. The operations cutting, bending and welding.

Spikes: They were made from a mild steel rod of10mm diameter. They were cut to give 40mm length and were welded unto the drum. The operations were cutting and welding.

Shaft: A mild steel rod of 20mm diameter was used as the power transmission shaft. The operations carried out were mainly facing, cutting and welding.

Concave: It was constructed using four half round rings on which mild steel rods of 10×380mm are welded at spacing of 15mm based on the linear dimensions of maize grain. The concave was designed to screen the seeds and the cobs of maize during shelling.

Hopper: The hopper was made up of mild steel sheet of 1mm thickness; it serves as inlet for the maize grain. The mild steel sheet was cut to dimensions 480mm×400mm with height, 50 mm. The operations carried out was cutting and welding.

Outer cover: The outer cover was made of a 1mm thick mild steel sheet of 480mm by 400mm. It was rolled to form a half cylinder of 400mm diameter, both sides were bent and holes were drilled to permit bolting to the frame.

A face plate was marked out and cut to give 400mm diameter which was divided into two halves and were welded to both sides of the cylinder giving space for the shaft to pass through. The operations carried out was cutting, bending and welding.

Outlet: The outlet was made of mild steel sheet of 1mm thickness cut to give rectangle of 520mm by 400mm.The same metal sheet was cut to 430 mm×302 mm×150mm and welded at both sides. The operation are cutting and welding. The outlet is designed to collect all the grains from the concave and direct into a receiver.

Pulley: The pulley for this prototype maize sheller, the motor drives pulley of 0.08cm diameter and the diameter of pulley shaft of 0.12was selected based on velocity relationship and horse power rating of the electric motor.

Selection of belt: The procedure for selecting a V-belt drive is dependent on the motor horse power and the speed (rpm) rating. V-belt of a cross section viz., density, cross sectional area and allowable tensile stress (σ) were taken as $1000\mathrm{Kg/m^3}$,$104\mathrm{mm^2}$ and 2.5MPa was chosen.

Selection of motor: For this maize shelle prototype, a three phase motor (2hp) was chosen based on the load conditions. The electric motor was mounted on the main frame by using two pairs of MS angles and provision was made to slide the motor to get desired tension on belt.

3.8.2. Principle of operation of the maize sheller prototype

The machine was designed and constructed to remove maize from its cob; this is achieved by the rotary motion of the shelling drum. A 2 hp electric motor provides drive through belt connections to drive the pulley on shelling drum. The maize cobs were introduced to the machine through the hopper and passed through the restricted concave clearance between the shelling units.

The spikes teeth feed the maize through the shelling unit and at the same time shell the maize by rolling, impact and crushing action against the concave and each other. Because the spikes are arranged in a zig-zag form, the whole maize moves along the length of the sheller in the forward direction until they reach the cob exit spout. Under the shelling drum there is the perforated concave which allows the grains to drop easily out of the shelling unit. The outlet is designed to collect grains from all sides of the concave into a receiver.

3.9. Performance evaluation

Performance evaluation of the constructed motor driven maize sheller was carried out at Adama Science and Technology University, Mechanical System and Vehicle Engineering Department with commonly grown BH 660 and BH540 maize variety in accordance with procedures prescribed below.

3.9.1. Pre-test observations

The moisture content and grain to cob ratio were determined in the laboratory prior to performance evaluation of maize sheller. The constructed sheller was tested for combination of various treatments. Before starting the actual testing, belt tension, direction of rotation of pulleys were checked. The clearance between shelling drum and the concave was determined using vernier caliper. The shelling drum speed was also recorded using a tachometer. After preliminary set up, machine was placed at an angle equal to or greater than angle of repose for maize, so that maize movement took place properly inside the sheller, then the motor was started and the speed was adjusted at particular rpm using speed cone as per treatment combination planned.

3.9.2. Test at no-load

Before commencing the test, the machine was running for 20minutes at different speeds and feed rate. This test was conducted to know the soundness and quality of construction of different component of the machine.

3.9.2.1. Power consumption

The machine was installed on level hard surface and operated at different shelling drum speed and feed for 10 minutes. A three phase wattmeter was connected to prime mover circuit to measure power consumption at no load condition and the consumption of different component of the machine under no-load condition were noted and presented in the Appendix $E_{1.}$

3.9.2. 2. Visual observations

During and after the power consumption test, the observations were made with respect to slippage of belts, presence of knocking or rattling sound, slackness of any components and presence of any oscillation in the machine during the operation.

3.9.3. Test at load

The experiments were conducted at different levels of independent parameters such as, shelling drum peripheral speed and feed rate at 12%moisture content (w.b). The details about independent parameters are given below. In order to shell the maize cobs greater than1000 kghr^{-1} the required cylinder peripheral velocity is greater than 9 m s^{-1} (Singh et al., 2011). So, this study from sheller for capacity of 1000 to 2000 kghr^{-1}the shelling drum peripheral speed of 9 to 11m s^{-1}at 12%moisture content (w.b) was selected.

Table 3.5 Independent variables/treatments at different level

Independent variables/treatments	Levels	Description	Value
		S_1	9.2
shelling drum speed (m s^{-1})	3	S_2	9.6
		S_3	10.1
		F_1	1000
Feed rate (kg h^{-1})	3	F_2	1500
		F_3	2000

The results pertaining to the effect of operational parameters, shelling drum peripheral speed, feed rate and crop parameter like moisture content on the performance parameters of the maize sheller were tested as described below.

3.9.3. 1. Testing Procedures

300kg of unshelled maize was purchased from the rural farmers of East Shoa Zone Adami Tullu district at field and the moisture content was tested and sun dried to 12% (w.b). The testing of the machine was done at this moisture content and three different shelling drum peripheral speeds and feed rates in three replications as shown in appendix tables F_1, F_2 and F_3. Two laborers were engaged for these operations one for feeding maize cobs at hopper and the other for collecting the grains at the outlet. The materials were fed into the hopper in each test at three different feed rates (1000kghr^{-1}, 1500kghr^{-1}and 2000kghr^{-1}) the shelled materials fall through the concave drum by gravity down to the outlet. Weight of whole grains, broken grains and unshelled cobs were recorded (separately), and time of operation to calculate output and efficiency were also recorded. The procedure was repeated for all the combinations of treatments and the following parameters were recorded:

- Weight of grains fed through the hopper (kg)
- Weight of grains shelled at main grain outlet (kg)
- Weight of damaged grains (kg)
- Weight of unshelled grains at outlet (kg)
- Scattered grains (kg)
- Weight of shelled cobs(kg)
- Time of operation (hr)

The performance evaluation of maize sheller was carried out one hour duration at specified moisture content, shelling drum speeds and feed rates. During the evaluation, a sample was collected from main grain outlet for further analysis. The various performance evaluation parameters were calculated from the measured values made on each treatment and dependent parameters on each treatment combinations.

The definitions and calculations of these parameters were shown according to (Andeh, 1992).

3.9.3. 2. Input capacity

The input capacity was evaluated from equation

$$\mathrm{Ci} = \frac{\mathrm{Wu}}{\mathrm{t}} \quad \ldots\ldots (3.78)$$

Where: Ci - input capacity ($kghr^{-1}$)

Wu - weight of unshelled maize fed into the machine (kg)

t - time taken to thresh the maize grain (hr)

3.9.3. 3. Output capacity

Machine Output Capacity is the quantity of maize crop shelled in a given time by the machine and is given as

$$\mathrm{Co} = \frac{\mathrm{M_C}}{\mathrm{t}} \quad \ldots\ldots (3.79)$$

Where: C - output capacity ($kghr^{-1}$)

$\mathrm{M_C}$ - mass of the maize shelled in the machine (kg)

t - time taken (hr)

3.9.3. 4. Shelling efficiency

Shelling efficiency is the ratio of the mass of the shelled maize to the total mass of the maize expressed in percentage as follows

$$\mathrm{S_e} = \frac{\mathrm{m_s}}{\mathrm{m_t}} \quad \ldots\ldots (3.80)$$

Where: $\mathrm{S_e}$ - the shelling efficiency (%)

$\mathrm{m_s}$- mass of the shelled maize (kg)

$\mathrm{m_t}$- total mass of the maize (kg)

3.9.3. 5. Unshelled grain

Unshelled grain is the ratio of quantity of unshelled maize to the initial mass of the sample expressed in percentage and given as follows;

$$U_g = \frac{M_u}{M_t} \times 100 \quad \ldots\ldots (3.81)$$

Where: U_g - unshelled grain (%)

M_u - mass of the unshelled grain (kg)

M_t- total mass maize sample (kg)

3.9.3. 6.Percentage damage

The percentage damage is the ratio of quantity damaged to the total quantity of the sample, calculated as follows

$$P_d = \frac{Q_d}{M_t} \times 100 \quad \ldots\ldots (3.82)$$

Where: P_d- Percentage damage (%)

Q_d - Quantity of damage seeds (kg)

M_t-total mass of the sample (kg)

3.9.3. 7.Percentage loss

Percentage loss is the quantity of maize kernel loss from the total quantity of maize expressed in percentage and was computed as follows

$$P_L = \frac{M_l}{m_t} \times 100 \quad \ldots\ldots (3.83)$$

Where: P_L - percentage losses (%)

M_l -mass of the loss seeds (kg)

m_t- total mass of the maize crop (kg).

3.9.3. 8.Seed recovery

Seed recovery is the quantity of shelled maize obtained from the maize cob. It is expressed as Percentage of shelled kernels including damaged seeds and computed as follows;

$$S_r = \frac{M_s}{M_t} \times 100 \quad \text{.......} \quad (3.84)$$

Where: S_r- Seed recovery (%)

M_s - Mass of the shelled kernels (kg)

M_t- Total mass of the maize crop (kg)

Figure 3.22. Performances testing of the constructed maize sheller prototype

3.10. Statistical analysis

The data collected from the performance test for different treatments of maize sheller were analyzed using descriptive statistics of the mean and standard deviations of the parameters were estimated with Analysis of Variance (ANOVA) and Least Significant Difference (LSD) were used to determine the significant differences among treatments and to form regression equation. Levels of significance were used in F-test at ($P<0.05$) for the statistical conclusion.

3.11. Economics of the motor driven maize sheller prototype

The methodology pertaining to determination of total production cost, cost of operation, Return per year and profit are presented below.

3.11.1. Construction cost of the maize sheller prototype

The construction cost of the prototype maize sheller was calculated by using the following cost parameters, cost of raw material, cost of fabrication process and cost of labour. The detailed calculations of production cost of the maize sheller prototype are given in AppendixG_{2}.

3.11.2. Cost of operation

The cost of operation of the maize sheller prototype for maize includes the fixed cost and the variable cost. The fixed cost generally includes depreciation, interest on investment, insurance, taxes and housing. The operating cost includes the cost of repairs and maintenance, electricity charge and labour wages (Ojha and Michael, 2009).

Total processing or operation cost = Fixed cost + Operating cost .. …………………...... (3.85)

Return per year = Capacity × No. of working hours per year × Cost for shelling……...... (3.86)

Profit = Return per year - total operating cost per year………………………………...… (3.87)

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

The results pertaining to engineering properties of maize, design and construction of different components of maize sheller, testing and evaluation of maize sheller were presented and analyzed. The economics of maize sheller were also presented in this chapter.

4.1. Engineering properties of maize

The various engineering properties of maize were determined using the standard procedures as explained in section 3.3 of chapter 3. All physical properties of maize grains were evaluated at a moisture content of 12% (w.b). The average dimensions and other related parameters for the selected maize varieties are given in table 4.1 below.

Table 4.1. Parameters and properties of maize variety selected for the study

Particulars		Mean values of varieties		SD	mean
		BH660	BH540		
Length of un-shelled cob, mm		149.335	151.975	1.866762	150.655
Diameter of unshelled cob, mm		46.9275	48.75	1.288702	47.83875
Weight of un-shelled cob, g		189.385	194.25	3.440074	191.8175
Linear dimensions of maize grains	length	10.475	9.5475	0.655842	10.01125
	Width	7.0425	6.215	0.585131	6.62875
	thickness	3.84	3.695	0.10253	3.7675
No. of grain lines in cobs		13.5	14	0.353553	13.75
No. of grains in one line of cob		42.5	46.25	2.65165	44.375
Min. diameter of cob without grains, mm		20.685	21.1975	0.362392	20.94125
Max. diameter of cob without grains, mm		24.3625	25.9375	1.113693	25.15
Avg. length of shelled cob, mm		40.9625	145.0275	2.874389	142.995
Shape		Oval flattened			

4.1.1. Physical properties

Table 4.2. Physical properties of both maize grain varieties.

	Mean values of varieties			
	BH660	BH540	SD	Mean
Roundness	0.25	0.33	0.04	0.28
Arithmetic mean diameter (mm)	7.96	7.61	0.175	7.785
Geometric mean diameter (mm)	7.64	7.10	0.27	7.37
Spherecity	0.64	0.68	0.02	0.66
Surface area (mm^2)	198.89	182.04	8.425	190.465
Bulk density ($^{g}/_{cm^3}$)	0.78	0.77	0.005	0.775
True density ($^{g}/_{cm^3}$)	1.11	1.04	0.035	1.075
Test weight (g)	317.60	314.83	1.385	316.215
Grain cobs ratio	3.16	2.88	0.14	3.02

4.1.2. Frictional properties

Table 4.3. Frictional properties of maize both maize varieties

Properties		Mean values of varieties			
		BH660	BH540	SD	Mean
Angle of repose, degree		21.16	23.24	1.471	22.2
Coefficient of friction of grains with	Grains	0.29	0.31	0.0141	0.3
	MS sheet	0.42	0.46	0.0283	0.44

4.2. Performance evaluation of motor driven maize sheller

Prior to the actual performance evaluation of sheller, pretest observations were recorded. The performance of sheller was evaluated under no load and load condition and the results were provided below.

4.2.1. Pre-test observations

The pre-test observations such as moisture content and the mean grain to dry matter ratio were measured and found to be12% and 3.02. During 20minutesprototype run under no load conditions, no breakdown or loosening of parts were observed but vibration due to motor was found. In order to reduce the vibration the motor was tightened to the motor set and bolted to bottom back of the frame.

4.2.2. Test at no-load

Results pertaining to performance of the maize sheller at no-load and visual observations are presented below.

4.2.2.1. Power consumption

The average power consumption of sheller was found to be 305 watts, in that 43.54%, 35.25% and 21.21. % consumed by the motor, threshing drum and other miscellaneous under no-load condition.

4.2.2.2. Visual observations

The observations of machine during the operation were made on slippage of belts, presence of undue knocking or ratting sound, slackness of any components and presence of any oscillation. The results were presented in appendix $E_{2.}$

4.2.3. Performance evaluation at load condition

The results pertaining to the effect of operational parameters, shelling drum peripheral speed, and feed rate on the performance parameters of the maize sheller are presented below.

4.2.3.1. Input capacity

The input capacity was calculated by using the equation 3.78. The mean C_i with respect to F_1, F_2 and F_3 feed rateswas1053.1, 1629.3 and 2175.4kgh^{-1}, respectively. Among all the different feed rates, the C_i was maximum in high shelling drum speed (S_3) condition whereas lowest in lower shelling drum speed (S_1) was recorded. The C_i was influenced by shelling drum peripheral speed and feed rates of 1000, 1500 and 2000 kg and their relation is shown in the Figure 4.1. At all the feed rates, the C_i increased for increasing shelling drum speed.

The ANOVA table 4.5 shows that all the first level factors and interaction of S and F factor were significant at $p < 0.05$. The interaction effects of S*F factors were non-significant for C_i. The best fit equation was developed to establish the relation between C_i of different feed rates with respect to S factors. The linear trend equation was found as best fit relation with highest R^2 value and the values of the same along with equations are shown in the table 4.6.

Table 4.4. Input capacities at different feed rate and shelling drum peripheral speeds

Treatments	Feed rate (F)														
	F_1 =1000 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F_2 =1500 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F_3 =2000 kg hr^{-1} Shelling drum speed (S), m s^{-1}				
	S_1	S_2	S_3	mean	SD	S_1	S_2	S_3	mean	SD	S_1	S_2	S_3	mean	SD
T_1	1016.9	1083.0	1127.8	1075.9	55.8	1621.6	1744.2	1694.9	1686.9	61.7	2069.0	2112.7	2381.0	2187.5	169
T_2	1000.0	1045.3	1107.0	1050.8	53.7	1428.6	1522.8	1657.5	1536.3	115.0	1954.4	2362.2	2409.6	2242.1	250
T_3	983.6	1027.4	1087.0	1032.7	51.9	1538.5	1648.4	1807.2	1664.7	135.1	1935.5	1973.7	2381.0	2096.7	247
mean	1000.2	1051.9	1107.3	1053.1		1529.6	1638.5	1719.9	1629.3		1986.3	2149.5	2390.5	2175.4	
SD	16.7	28.4	20.4			96.8	111.0	77.9			72.2	196.9	16.6		

Table 4.5. ANOVA table for input capacity at different feed rate and shelling drum peripheral speeds

Source	Sum of squares	Degree of freedom	Mean Square	F value	
S-Peripheral speed	82202.427	2	41101.213	0.129	significant
F-Feed rate	1889788.94	2	944894.47	53.15	significant
S*F	24465.773	4	6116.443	0.019	Non-significant
Total	1996457	9			

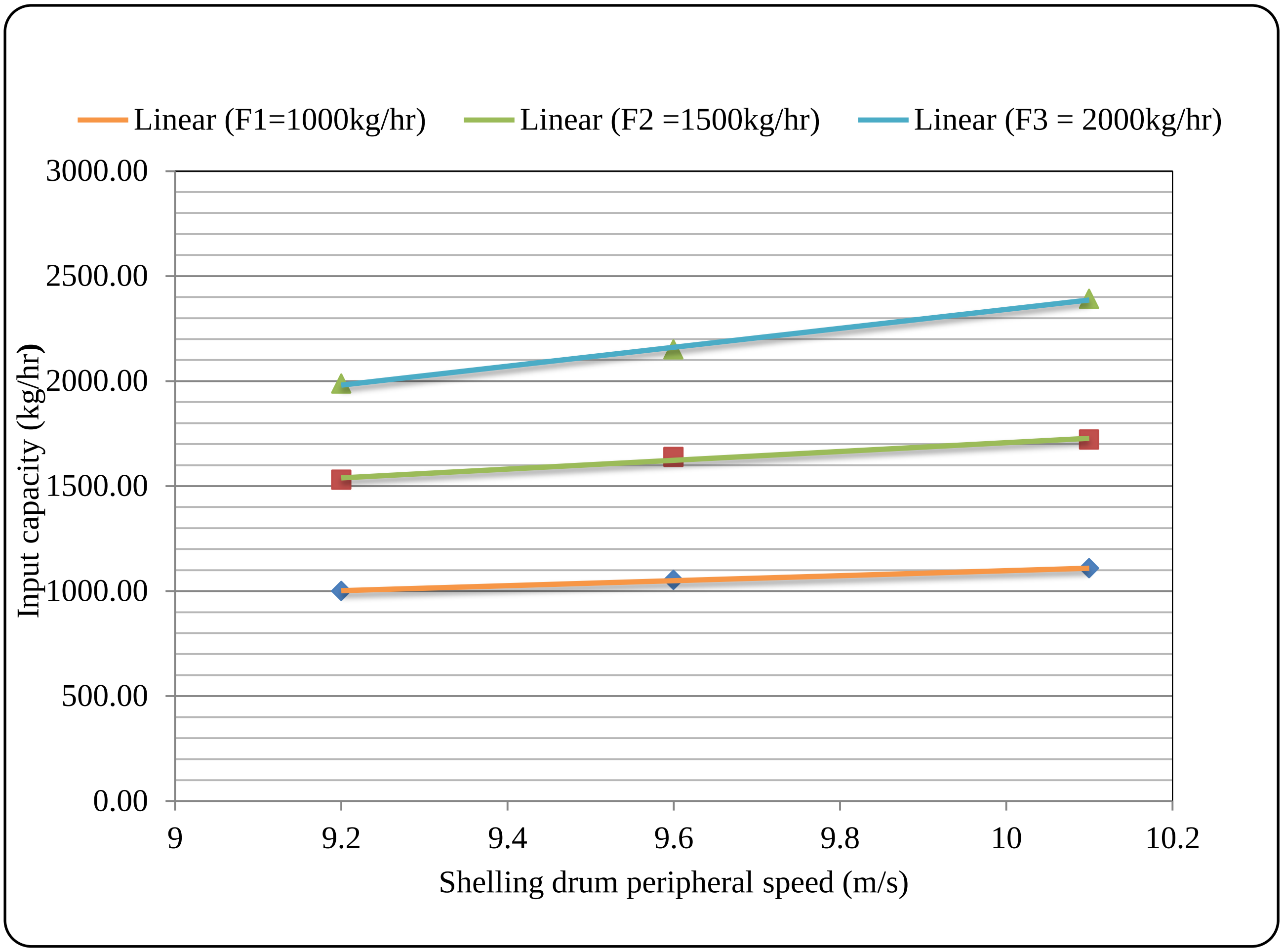

Figure 4.1 Effect of shelling drum peripheral speed on input capacity for different feed rates.

Table 4.6. Equations for input capacity (y) at different levels of feed rate and shelling drum peripheral speeds.

Feed rate	Shelling drum peripheral speeds (x)	CD
F_1 = 1000 $kghr^{-1}$	y = 118.64x-89.742	R^2= 0.998
F_2 = 1500 $kghr^{-1}$	y = 209.47x-388.59	R^2= 0.9785
F_3 =2000$kghr^{-1}$	y= 450.49x-2164.3	R^2= 0.9978

CD: Coefficient of determination

4.2.3.2. Output capacity

The output capacity (C_o) was calculated by using the equation 3.79. The mean $C_o$with respect to F_1, F_2 and F_3 feed rates was797.7, 1238.9 and 1658.1 kgh^{-1}, respectively. Among all the different feed rates, the C_o was maximum in high shelling drum speed (S_3) condition whereas lowest in lower shelling drum speed (S_1) was recorded. The C_o was influenced by shelling drum peripheral speed and feed rates of 1000, 1500 and 2000 kg and their relation is shown in the figure 4.2. At all levels of the feed rates, the C_o increased for increasing shelling drum peripheral speed.

The ANOVA table 4.8 shows that all the first level factors and interaction of S and F factor were significant at $p<0.05$. The interaction effects of S*F factors were non-significant for C_o. The best fit equation was developed to establish the relation between C_o of different feed rates with respect to S factors. The linear trend equation was found as best fit relation with highest R^2 value and the values of the same along with equations are shown in the table 4.9.

Table 4.7. Output capacity at different feed rate and shelling drum peripheral speeds.

Treat ments	Feed rate (F)														
	F1 = 1000 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F2 = 1500 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F3 = 2000 kg hr^{-1} Shelling drum speed (S), m s^{-1}				
	S_1	S2	S_3	mean	SD	S_1	S_2	S_3	mean	SD	S_1	S_2	S_3	mean	SD
T_1	767.9	808.6	862.9	813.1	47.7	1225.8	1327.2	1298.1	1283.7	52.2	1565.6	1609.2	1813.6	1662.8	132.4
T_2	754.7	794.1	846.5	798.4	46.1	1079.3	1158.1	1268.8	1168.7	95.2	1478.1	1798.3	1846.5	1707.7	200.2
T_3	741.1	779.3	824.5	781.6	41.7	1160.5	1251.6	1381.0	1264.4	110.8	1470.2	1509.1	1832.4	1603.9	198.8
mean	754.6	794.0	844.6	797.7		1155.2	1245.6	1316.0	1238.9		1504.6	1638.9	1830.8	1658.1	
SD	13.4	14.7	19.3			73.4	84.7	58.2			52.9	146.9	16.5		

Table 4.8. ANOV A table for output capacity at different feed rate and shelling drum peripheral speeds.

Source	Sum of squares	Degree of freedom	Mean Square	F value	
S-Peripheral speed	55620.469	2	27810.234	0.148	significant
F-Feed rate	1110588.936	2	555294.468	47.044	significant
S*F	15201.604	4	3800.401	0.020	Non-significant
Total	1181411	9			

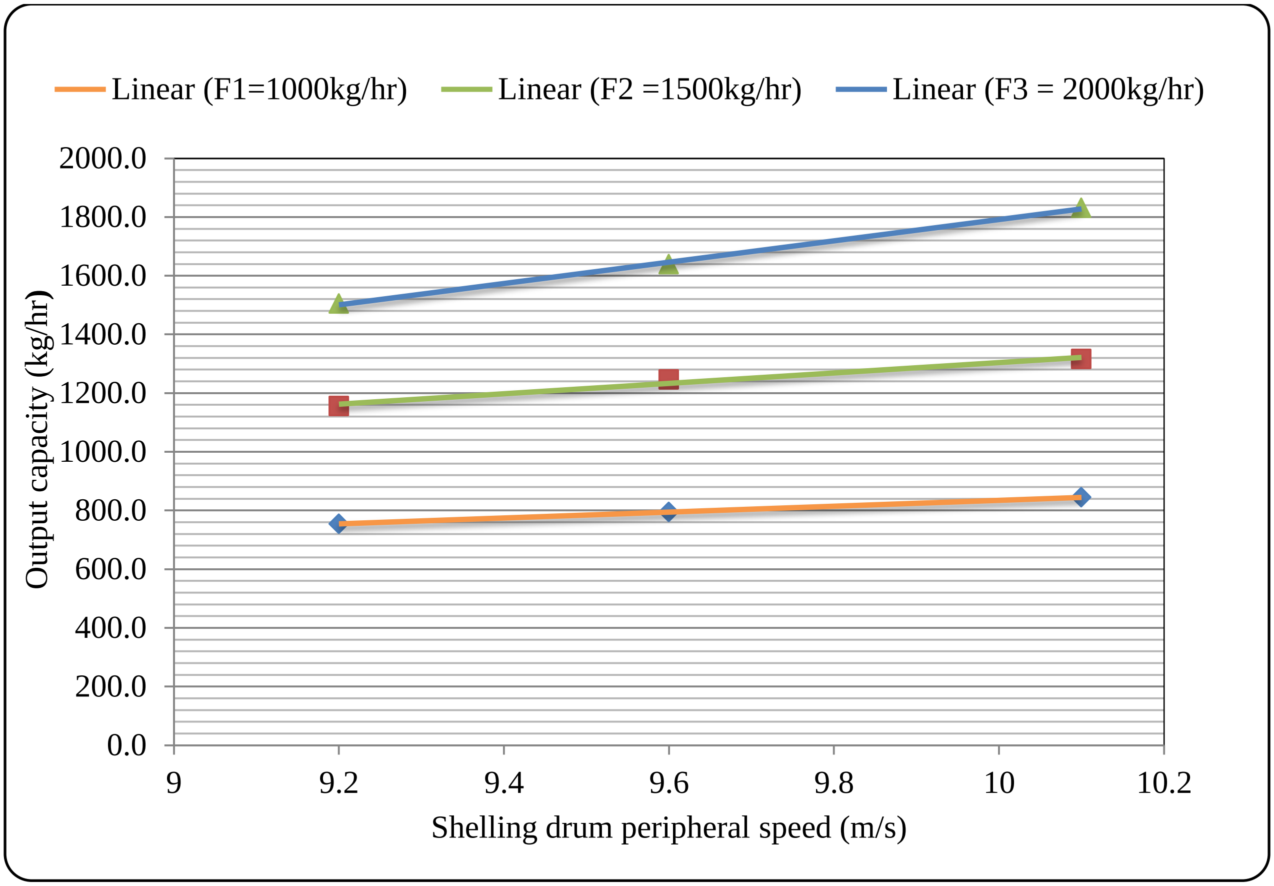

Figure 4.2. Effect of shelling drum peripheral speed on output capacity for different feed rates.

Table 4.9. Equations for output capacity (y) at different levels of feed rate and shelling drum peripheral speeds.

Feed rate	Shelling drum peripheral speeds (x)	``CD
F_1 = 1000 $kghr^{-1}$	y = 100.1x-166.56	R^2= 0.9999
F_2 = 1500 $kghr^{-1}$	y = 177.11x- 467.21	R^2= 0.9816
F_3 =2000kg hr^{-1}	y = 363.31x-1841.8	R^2= 0.9986

CD: Coefficient of determination

4.2.3.3. Shelling efficiency

The effect of different shelling drum peripheral speeds and feed rate at 12% (w.b) moisture contents were presented in table 4.10 and it was observed that the highest shelling efficiency of 98.78% was obtained for S_3F_3 treatment combination where as it was lowest (94.20%) for S_1F_1 treatment combination. The mean shelling efficiency with respect to F_1, F_2 and F_3 feed rate were 95.5%, 96.39% and 97.22%, respectively. At the feed rate of 1000 kg hr^{-1}, the shelling efficiency was in the range of 94.2 to 97.08% where it was 95.0 to 97.93% and 95.80to 98.78% for 1500 and 2000 kg per hour feed rate respectively.

The shelling efficiency relation with respect to the shelling drum peripheral speeds and feed rate is shown in the figure 4.3. The shelling efficiency, for all feed rates, increased with the increase in shelling drum peripheral speeds. The effect of cylinder peripheral speed on shelling efficiency at different level of feed rates was shown in the figure 4.3. The shelling efficiency increased with increase in the cylinder peripheral speed. The increase in the shelling efficiency was more as the cylinder peripheral speeds increased from 9.2 to 9.6 ms^{-1}, thereafter the shelling efficiency decreased after 10.1ms^{-1}.

The ANOVA table 4.11 shows that all the first level factors and interaction of S and F factor were significant at ($p<0.05$). The interaction effects of S*F factors were non-significant for S_e. The best fit equation was developed to establish the relation between S_e of different feed rates with respect to S factors. The polynomial trend equation was found as best fit relation with highest R^2 and the values of the same along with equations are shown in the table 4.12.

Table 4.10. Shelling efficiency at different feed rate and shelling drum peripheral speeds

Treatments	Feed rate (F)														
	F_1= 1000 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F_2 = 1500 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F_3 = 2000 kg hr^{-1} Shelling drum speed (S), m s^{-1}				
	S_1	S2	S_3	mean	SD	S_1	S_2	S_3	mean	SD	S_1	S_2	S_3	mean	SD
T_1	94.80	95.40	95.46	95.22	0.36	95.60	96.20	96.88	96.23	0.64	96.40	97.10	97.70	97.07	0.65
T_2	94.20	94.80	95.47	94.82	0.63	95.00	95.60	96.28	95.63	0.64	95.80	96.50	97.10	96.47	0.65
T_3	95.80	96.50	97.08	96.46	0.64	96.70	97.30	97.93	97.31	0.62	97.50	98.10	98.78	98.13	0.64
mean	94.93	95.57	96.00	95.50		95.77	96.37	97.03	96.39		96.57	97.23	97.86	97.22	
SD	0.81	0.86	0.93			0.86	0.86	0.84			0.86	0.81	0.85		

Table 4.11. ANOVA table for shelling efficiency at different feed rate and shelling drum peripheral speeds

Source	Sum of squares	Degree of freedom	Mean Square	F value	
S-Peripheral speed	2.186	2	1.093	1.470	significant
F-Feed rate	4.439	2	2.220	6.036	significant
S*F	0.021	4	0.005	0.0136	Non-significant
Total	83591	9			

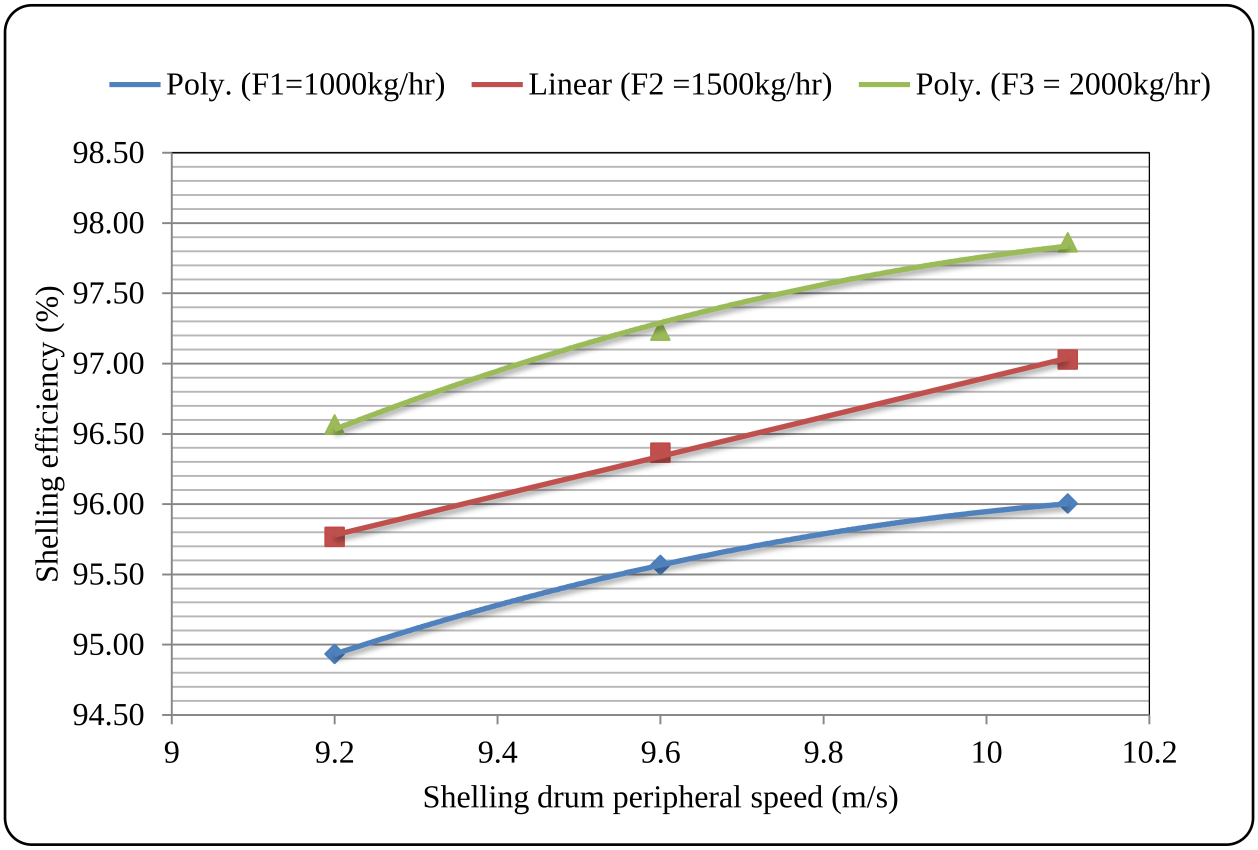

Figure 4.3. Effect of shelling drum peripheral speeds on shelling efficiency for different feed rates.

Table 4.12. Equations for shelling efficiency (y) at different levels of feed rate and shelling drum peripheral speeds.

Feed rate	Shelling drum peripheral speeds (x)	CD
F_1 = 1000 $kghr^{-1}$	$y = 0.78961x^2+16.428+10.627$	R^2= 0.9999
F_2 = 1500 $kghr^{-1}$	$y = -1956x^2- 5.1764x+64.695$	R^2= 0.9816
F_3 =2000$kghr^{-1}$	$y = 0.457x^2+10.25x+40.868$	R^2= 0.9986

CD: Coefficient of determination

4.2.3.4. Unshelled grain percentage

The percentage of unshelled grain during shelling operation was calculated by using the equation 3.81 and observations were shown in the table 4.13. From the table, it was found that mean percentage of unshelled grain at F_1, F_2 and F_3 feed rates were 4.50%, 3.57% and 2.78%, respectively. Among all the treatments, the percentage of unshelled grain was maximum of (5.80%) in F_1S_1 treatment combination and minimum unshelled grain percentage of 1.22% was recorded in F_3S_3 treatment combination.

The unshelled grain percentage trends at the different shelling drum peripheral speeds for feed rate of 1000, 1500, 2000 kg per hour is shown in the figure 4.4. It was found that the unshelled grain percentage increased with decrease in the shelling drum peripheral speed for all the feed rate tested and the maximum percentage of unshelled grain were obtained at 1000kg feed rate for all the shelling drum peripheral speeds while it was minimum for 2000kg feed rate. The percentage of the unshelled grain was decreased significantly as the feed rate increased from 1000kg to 2000kg.

The effect of shelling drum peripheral speed on unshelled grain percentage at all level of feed rates, the shelling drum peripheral speed increased from 9.2 to 9.6 m s^{-1}, the percentage of unshelled grain decreased for all the feed rate levels. Among the different feed rates, 1000kg feed rate resulted in maximum unshelled grain percentage whereas 2000kg feed rate gives minimum unshelled grain percentage for all the shelling drum peripheral speeds. The relation between the shelling drum peripheral speeds and percentage of unshelled grain at all level of the feed rate, shelling drum peripheral speed increased, the unshelled grain percentage decreased.

The ANOVA table 4.14 shows that all the first level factors and interaction of S and F factor were significant at $p<0.05$. The interaction effects of S*F factors were non-significant for P_u.The best fit equation was developed to establish the relation between P_u of different feed rates with respect to S factors. The linear trend equation was found as best fit relation with highest R^2 and the values of the same along with equations are shown in the table 4.15.

Table 4.13. Unshelled grain percentage at different feed rate and shelling drum peripheral speeds

Treatments	Feed rate (F)														
	F_1 = 1000 kg h^{-1}					F_2 = 1500 kg h^{-1}					F_3 = 2000 kg h^{-1}				
	Shelling drum speed (S), m s^{-1}					Shelling drum speed (S), m s^{-1}					Shelling drum speed (S), m s^{-1}				
	S_1	S2	S_3	mean	SD	S_1	S_2	S_3	mean	SD	S_1	S_2	S_3	mean	SD
T_1	5.20	4.60	4.54	4.78	0.36	4.40	3.80	3.12	3.77	0.64	3.60	2.90	2.30	2.93	0.65
T_2	5.80	5.20	4.53	5.18	0.63	5.00	4.40	3.37	4.26	0.82	4.20	3.50	2.90	3.53	0.65
T_3	4.20	3.50	2.92	3.54	0.64	3.30	2.70	2.06	2.69	0.62	2.50	1.90	1.22	1.87	0.64
Mean	5.07	4.43	4.00	4.50		4.23	3.63	2.85	3.57		3.43	2.77	2.14	2.78	
SD	0.81	0.86	0.93			0.86	0.86	0.70			0.86	0.81	0.85		

Table 4.14. ANOVA table for unshelled grain percentage at different feed rates and shelling drum peripheral speed

Source	Sum of squares	Degree of freedom	Mean Square	F value	
S-Peripheral speed	2.331	2	1.166	1.559	significant
F-Feed rate	4.447	2	2.224	5.631	significant
S*F	0.038	4	0.010	0.025	Non-significant
Total	124.54	9			

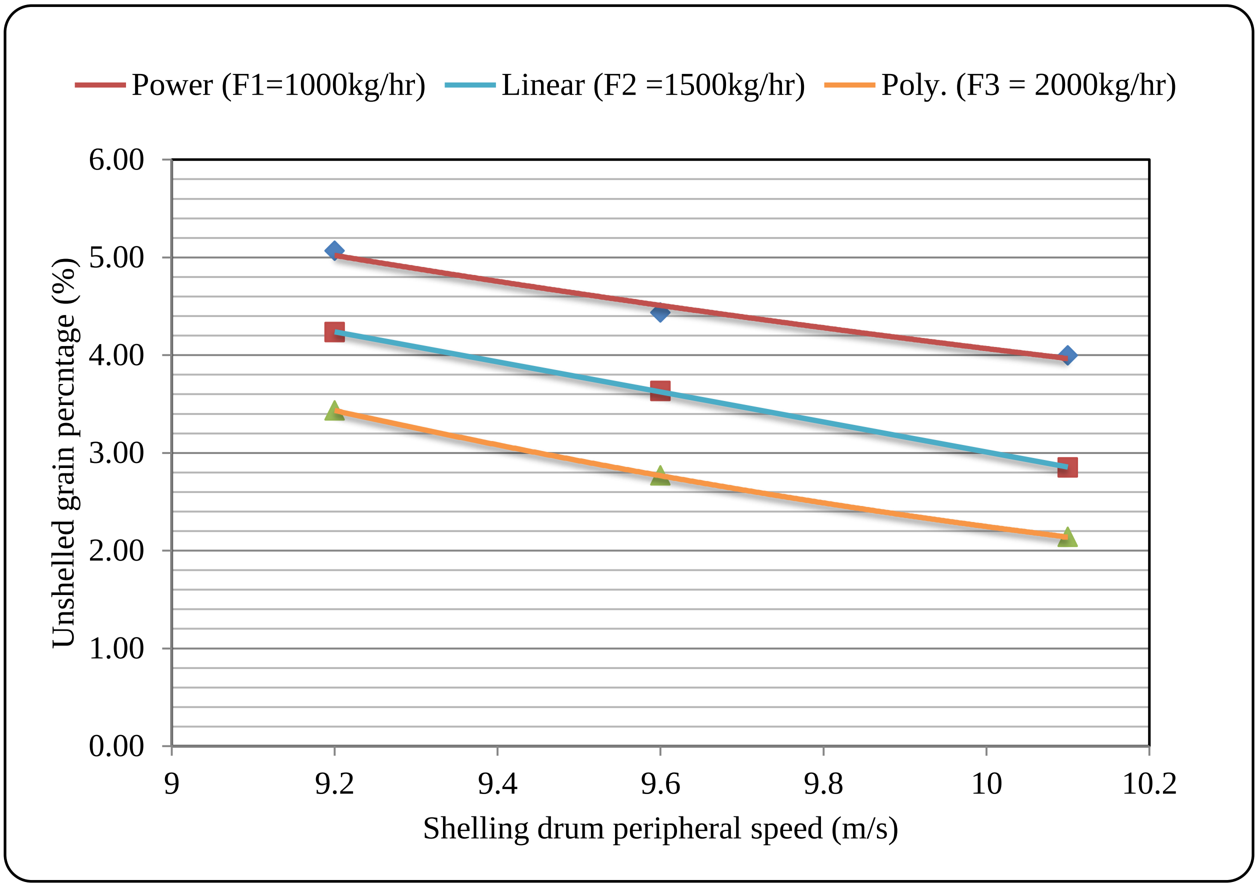

Figure 4.4. Effect of shelling drum peripheral speeds on unshelled grain percentage for different feed rates.

Table 4.15. Equations for unshelled grain percentage (y) at different levels of feed rate and shelling drum peripheral speeds.

Feed rate	Shelling drum peripheral speeds (x)	CD
$F_1 = 1000$ kghr^{-1}	y = -1.1756x+15.824	R^2= 0.9714
$F_2 = 1500$ kghr^{-1}	y = -1.5371.11x+18.38	R^2= 0.9999
F_3 =2000 kghr^{-1}	y = -1.4307x+16.562	R^2= 0.9934

CD: Coefficient of determination

4.2.3.5. Percentage of damaged grains

The percentage of damaged grains during shelling operation was calculated by using the equation 3.82 and observations were shown in the table 4.16. From the table, it was found that mean percentage of damaged grains at F_1, F_2 and F_3 feed rates were 3.105%, 3.085% and 3.043%, respectively. Among all the treatments, the percentage of damaged grains was maximum of (3.345 %) in F_1S_3 treatment combination and minimum damaged grain percentage of 2.6% was recorded in F_3S_1treatment combination.

The damaged grains percentage trends at the different shelling drum peripheral speeds for feed rate of 1000, 1500, 2000 kg per hour are shown in the figure 4.5. It was found that the grain damaged percentage increased with increase in the shelling drum peripheral speed for all level of feed rates tested and the maximum percentage of damaged grains were obtained at 2000kgfeed rate for all the shelling drum peripheral speeds while it was minimum for 1000kg feed rate for all the shelling drum peripheral speeds.

The relation between the shelling drum peripheral speeds and percentage of damaged grains at all level of the feed rate, shelling drum peripheral speed increased from 9.2 to 9.6ms^{-1}, the damaged grains percentage increased. There after the damaged grains percentage decreased after 10.1ms^{-1}.

The effect of different factors on damaged grain percentage was analyzed statically and it was shown in table 4.17. It was observed that all the first level factors were significant at 5% level. The interaction effects of S*F, treatment combination found as non-significant for grain damaged percentage. The best fit equation was developed to establish the relation between P_d of different feed rates with respect to S factors. The polynomial trend equation was developed to establish the relation between grains damaged percentage at different feed rate levels with shelling drum peripheral speed levels. The values of the same along with equations are shown in the table 4.18.

Table 4.16. Damaged grains percentage at different feed rate and shelling drum peripheral speeds

Treatments	Feed rate (F)														
	F1 = 1000 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F2 = 1500 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F3 = 2000 kg hr^{-1} Shelling drum speed (S), m s^{-1}				
	S_1	S2	S_3	mean	SD	S_1	S_2	S_3	mean	SD	S_1	S_2	S_3	mean	SD
T_1	2.700	3.300	3.319	3.106	0.352	2.600	3.300	3.314	3.071	0.408	2.600	3.200	3.309	3.036	0.382
T_2	2.700	3.300	3.371	3.124	0.369	2.700	3.300	3.345	3.115	0.360	2.600	3.300	3.320	3.073	0.410
T_3	2.600	3.300	3.353	3.084	0.420	2.600	3.300	3.306	3.069	0.406	2.600	3.200	3.260	3.020	0.365
mean	2.667	3.300	3.348	3.105		2.633	3.300	3.322	3.085		2.600	3.233	3.296	3.043	
SD	0.058	0.000	0.026			0.058	0.000	0.021			0.000	0.058	0.032		

Table 4.17. ANOVA table for damaged grains percentage at different feed rates and shelling drum peripheral speed

Source	Sum of squares	Degree of freedom	Mean Square	F value	
S-Peripheral speed	0.892	2	0.446	382.352	significant
F-Feed rate	0.006	2	0.003	0.21	significant
S*F	0.001	4	0.000	0.000	Non-significant
Total	86.14	9			

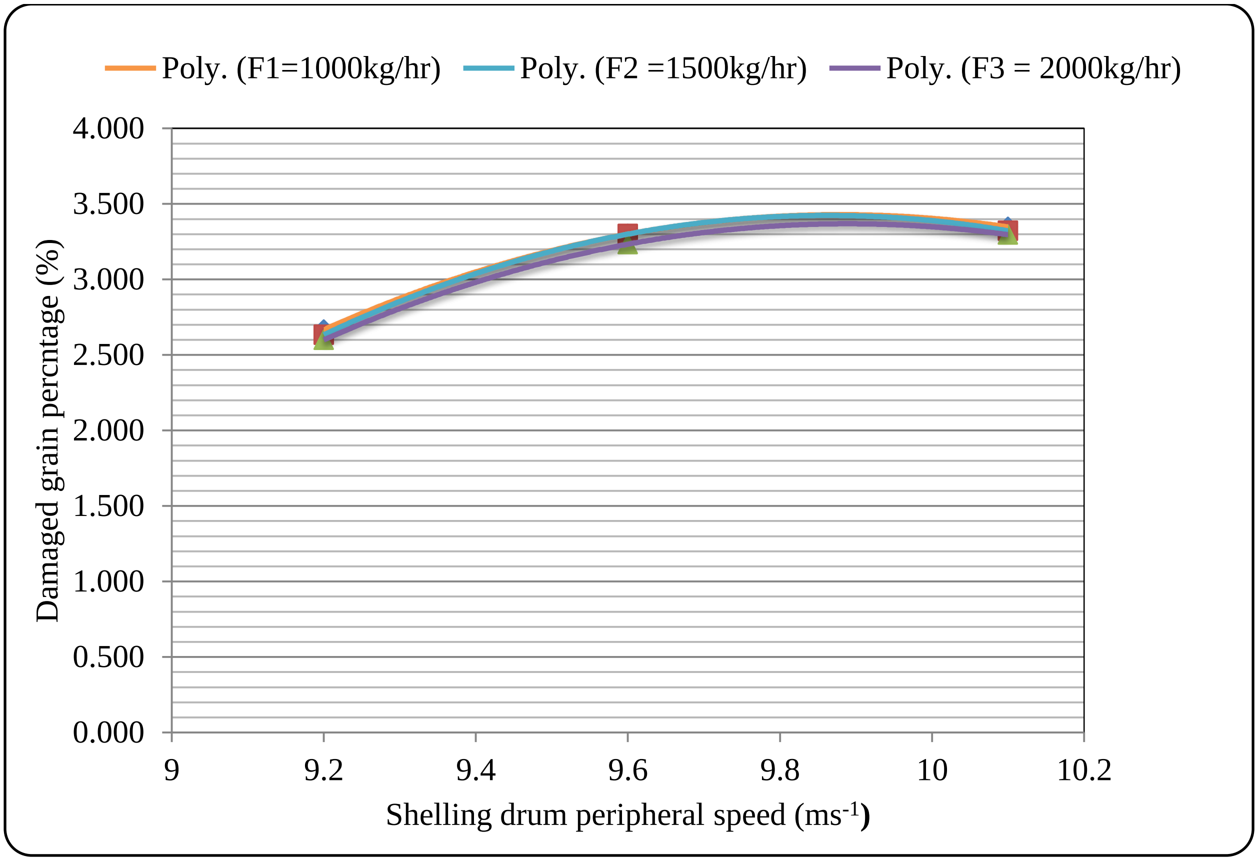

Figure. 4.5. Effectof shelling drum peripheral speed on damaged grains percentage for different feed rates.

Table 4.18. Equations for damaged grains percentage (y) at different levels of feed rate and shelling drum speeds.

Feed rate	Shelling drum peripheral speeds (x)	CD
F1 = 1000kghr^{-1}	$y = -1.6533x^2+32.666x-157.92$	R^2= 0.999
F2 = 1500 kghr^{-1}	$y = -1.693x^2x+32.025x-154.98$	R^2= 0.998
F3 =2000 kghr^{-1}	$y = -1.8037x^2+35.576x-172$	R^2= 0.9934

CD: Coefficient of determination

4.2.3.6. Percentage of grain losses

The percentage of grain losses was calculated by using the equation 3.83. Among all the different treatments, the percentage of grain losses was maximum of (12.40%) in S_3F_1 treatment combination and lowest grain loss of 8.60% was recorded in F_3S_1 treatment combination. The mean percentage of grain losses with respect to F_1, F_2 and F_3 feed rate were found to be 11.36%, 10.79% and 9.76%, respectively.

The influence of shelling drum peripheral speed on grain loses at feed rates of 1000, 1500 and 2000 kg per hour were shown in the figure. 4.6. For all the feed rates, percentage of grain losses increased as shelling drum peripheral speed increased. The minimum percentage of grain losses was observed for 9.2ms^{-1}shelling drum peripheral speed whereas it was maximum for 10.1ms^{-1}, shelling drum peripheral speed. The lowest percentage of grain losses achieved at feed rate of 2000 kghr^{-1}.

The effect of factors, S and F on the percentage of grain losses of the prototype maize sheller were analyzed statistically and presented in table 4.20. From the ANOVA table it was observed that all the first level factors and interaction effect of S and F were significant at $p<0.05$. The interaction effect of S*F was also-significant on percentage of grain loss. The best fit equation was developed to establish the relation between P_L of different feed rates with respect to S factors. The linear trend equation was developed with highest R^2 value for $F_1$and F_3 and polynomial equation was developed for F_2 feed rate. The values of the coefficient of determinant along with equations are shown in the table 4.21.

Table 4.19. Percentage of grains loss at different feed rate and shelling drum peripheral speeds

Treat ments	Feed rate (F)														
	F_1 = 1000 kg h^{-1} Shelling drum speed (S), m s^{-1}					F_2 = 15000 kg h^{-1} Shelling drum speed (S), m s^{-1}					F_3 = 2000 kg h^{-1} Shelling drum speed (S), m s^{-1}				
	S_1	S2	S_3	mean	SD	S_1	S_2	S_3	mean	SD	S_1	S_2	S_3	mean	SD
T_1	11.10	11.50	11.80	11.47	0.35	10.40	10.80	11.13	10.78	0.37	9.60	10.00	10.40	10.00	0.40
T_2	11.60	12.00	12.40	12.00	0.40	10.90	11.30	11.66	11.29	0.38	10.10	10.00	10.87	10.32	0.48
T_3	10.20	10.60	11.03	10.61	0.42	9.40	11.30	10.20	10.30	0.95	8.60	8.90	9.33	8.94	0.37
mean	10.97	11.37	11.74	11.36		10.23	11.13	11.00	10.79		9.43	9.63	10.20	9.76	
SD	0.71	0.71	0.68			0.76	0.29	0.74			0.76	0.64	0.79		

Table 4.20. ANOVA table for percentage of grains loss at different feed rate and shelling drum peripheral speed

Source	Sum of squares	Degree of freedom	Mean Square	F value	
S-Peripheral speed	0.53	2	0.268	0.471	significant
F-Feed rate	3.058	2	1.529	10.359	significant
S*F	0.350	4	0.088	0.1596	significant
Total	1006.5	9			

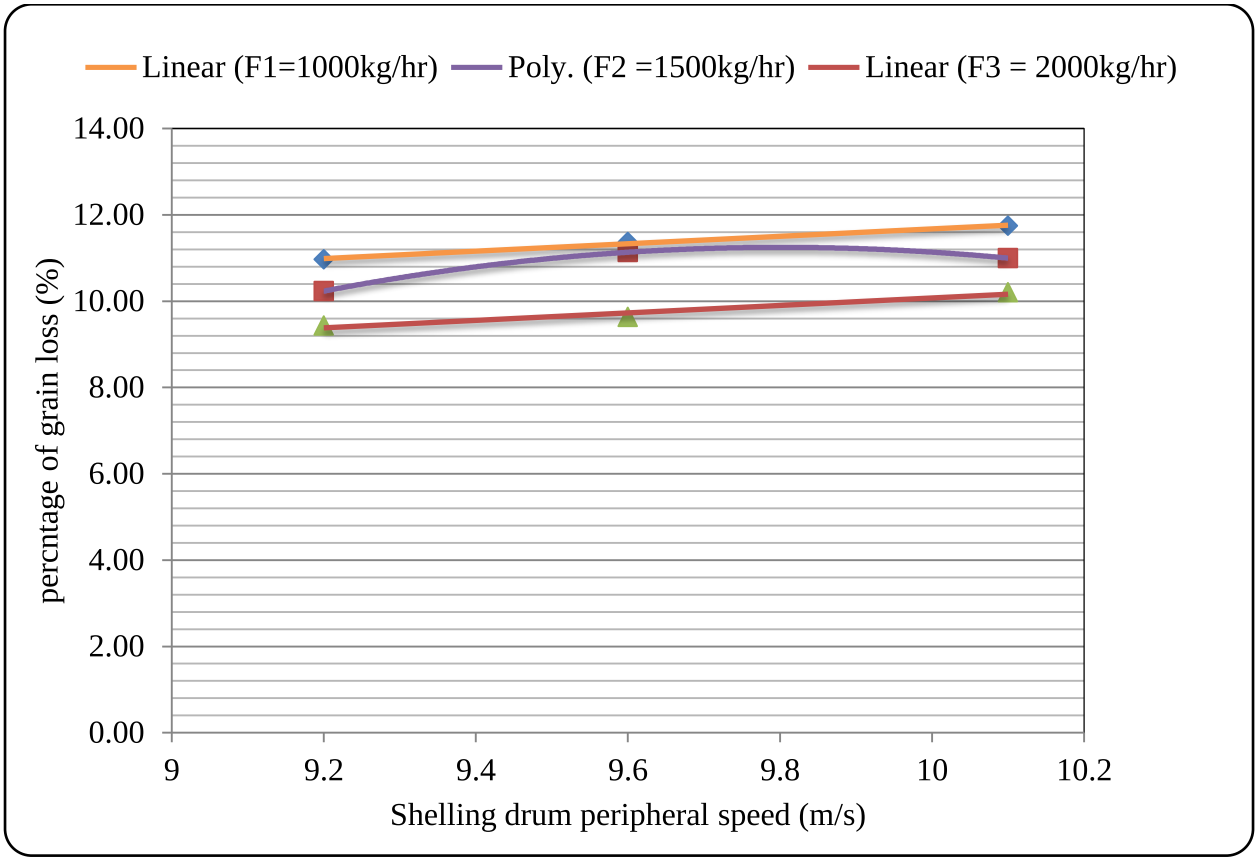

Figure 4.6.Effect of shelling drum peripheral speed on percentage of grains loss for different feed rates.

Table 4.21. Equations for percentage of grains loss (y) at different levels of feed rate and shelling drum peripheral speeds

Feed rate	Shelling drum peripheral speeds (x)	CD
F_1 = 1000kghr^{-1}	y = 0.8596 + 3.0782	R^2= 0.9935
F_2 = 1500kghr^{-1}	y = -2.8037x^2 +54.96x-258.09	R^2= 0.9999
F_3 =2000kghr^{-1}	y = 0.657x + 1.4168	R^2= 0.9581

CD: Coefficient of determination

4.2.3.7. Percentage of grain recovery

The percentage of grain recovery was calculated by using the equation 3.84. Among all the different treatments, the percentage of grain recovery was maximum of (91.40%) in S_1F_3 treatment combination and the minimum percentage of grain recovery of 87.6% was recorded in F_1S_3treatment combination. The mean percentage of grain recovery with respect to F_1, F_2 and F_3 feed rate were found to be 89.39%, 90.20% and 91.06%, respectively.

The influence of shelling drum peripheral speed on percentage of grain recovery at feed rates of 1000, 1500 and 2000 kg per hour were shown in the figure 4.7. For all the feed rates, percentage of grain recovery decreased as shelling drum peripheral speed increased from 9.2 to 10.1 ms^{-1}.

The effect of factors S and F on the percentage of grain recovery of the prototype maize sheller were analyzed statistically and presented in table 4.23. From the ANOVA table it was observed that all the first level factors and interaction effect of S and F was significant at 5%. The interaction effect S*F was non-significant on percentage of grain recovery. The best fit equation was developed to establish the relation between S_r of different feed rates with respect to S factors. The linear trend equation was developed with highest R^2value. The values of the coefficient of determinant along with equations are shown in the table 4.24.

Table 4.22. Percentage of grain recovery at different feed rate and shelling drum peripheral speeds

Treatments	Feed rate (F)														
	F_1 = 1000 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F_2 = 1500 kg hr^{-1} Shelling drum speed (S), m s^{-1}					F_3 = 2000 kg hr^{-1} Shelling drum speed (S), m s^{-1}				
	S_1	S2	S_3	mean	SD	S_1	S_2	S_3	mean	SD	S_1	S_2	S_3	mean	SD
T_1	88.90	88.50	88.18	88.53	0.36	89.60	89.20	88.87	89.22	0.37	90.40	90.00	89.60	90.00	0.40
T_2	88.40	88.00	87.60	88.00	0.40	89.10	88.70	88.34	88.71	0.38	89.90	89.50	89.13	89.51	0.39
T_3	89.80	89.40	88.97	89.39	0.42	90.60	90.20	89.80	90.20	0.40	91.40	91.10	90.67	91.06	0.37
mean	89.03	88.63	88.25	88.64		89.77	89.37	89.00	89.38		90.57	90.20	89.80	90.19	
SD	0.71	0.71	0.68			0.76	0.76	0.74			0.76	0.82	0.79		

Table 4.23. ANOVA table for percentage of grain recovery at different feed rates and shelling drum peripheral speed

Source	Sum of squares	Degree of freedom	Mean Square	F value	
S-Peripheral speed	0.630	2	0.315	0.436	Significant
F-Feed rate	4.270	2	2.135	18.439	Significant
S*F	0.065	4	0.016	0.022	Non- Significant
Total	72009.53	9			

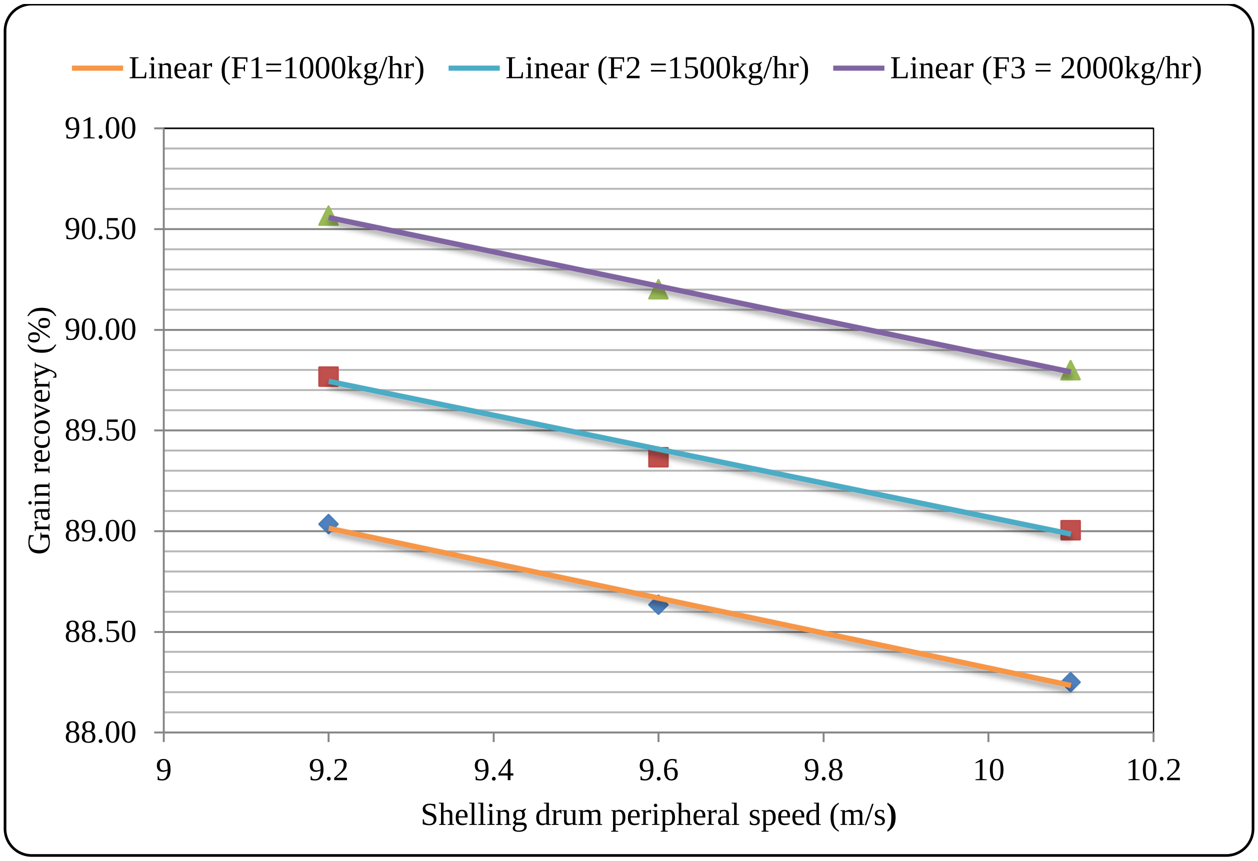

Figure 4.7.Effect of shelling drum peripheral speed on percentage of grain recovery for different feed rates.

Table 4.24. Equations for percentage of grain recovery (y) at different levels of feed rate and shelling drum peripheral speeds

Feed rate	Shelling drum peripheral speed (x)	CD
F_1 = 1000 $kghr^{-1}$	y = -0.8673x+96.993	R^2= 0.9943
F_2 = 1500 $kghr^{-1}$	y = -0.8432x+97.501	R^2= 0.9916
F_3 =2000 $kghr^{-1}$	y = -0.852x+98.396	R^2= 0.9986

CD: Coefficient of determination

CHAPTER FIVE

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5. 1. Summary

This study was undertaken at the Department of Mechanical System and Vehicle Engineering, School of Mechanical, Chemical and Materials Engineering, Adama Science and Technology University on important issues of shelling of maize cob with specific objectives study of engineering properties of the two selected maize varieties, design, construct and performance evaluation of motor driven maize sheller.

In this study two main varieties of maize, BH60 and BH540 were selected. The engineering properties (size, shape, spherecity, true density, bulk density, surface area, angle of repose and coefficient of friction) of the selected maize grains varieties were determined using standard procedures. Various components of the sheller prototype were designed and the machine components were constructed in in Mechanical Engineering Workshop. The prototype was operated by three phase electric motor with power rating of 2hp.

For optimizing the operational parameters of prototype for efficient performance, the performance evaluation of the sheller were carried out with major influencing factors, feed rates (F_1 = 1000 kg h^{-1}, F_2 = 1500 kg h^{-1} and F_3 = 2000kg h^{-1}) and cylinder peripheral speeds (S_1 = 9.2 ms^{-1}, S_2 = 9.6 $ms^{-1}$and S_3= 10.1 m s^{-1}) at 12% moisture content of maize grain (w.b).

The performance of the sheller was evaluated with commonly grown BH450 maize variety bought from the farmer at East Shoa, Adami Tullu district. The various parameters are input capacity(kgh^{-1}), output capacity (kgh^{-1}), shelling efficiency (%), unshelled grain percentage(%), damage/broken grain(%), percentage grain loss(%) and grain recovery(%)were determined and analyzed.

5.2 Conclusions

The sheller is simple, less bulky and requires low electrical energy for its working and its capital investment is also low compared to the existing power operated methods of shelling. The sheller can help to substantially reduce the human labour involved in shelling at an affordable cost and also reduces the time used for shelling operation on small farms considering the deduced fact that energy requirements is low. It will also improve the production and processing of maize in Ethiopia because the sheller is affordable, easy to maintain and simple to operate; more so, it was constructed with locally available materials making the spare parts easily/readily available for repair and /or replacement of parts if broken down. There is no doubt that the sheller will ease the long term problem of maize shelling especially for the small scale farmers.

5.3. Recommendations

The performance evaluations made indicated that the sheller prototype can be used successfully for small and medium scale farmers. Nonetheless, the following issue must be addressed to make the sheller popular, adaptable and usable among the farmers.

- There is need to create awareness among the farming communities on adoption of developed low cost power operated sheller for shelling of maize cobs and to change the traditional method of shelling maize.
- The constructed maize sheller prototype can be modified for multi crop thresher by altering shelling drum and concave clearance.
- Incorporation of the removable handle and balance weight the machine can be operated by human labour so that the machine can be used without depending on the electricity or diesel engine incase power source is the factor to adopt this technology.
- Incorporation of cleaning and separation device for the removal of unwanted material which is more efficient and less cost than manual cleaning.
- Addition of wheels to enhance the movement within shelling area and transportation from farms.
- There is a need for development of low cost power operated high efficiency maize sheller for small and marginal farmers therefore; this study can be used as a reference for future work.

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APPENDIX

Appendix A: Details of the construction features of motor operated maize sheller prototype

No	Components/parts	Materials	dimensions
1	Frame (Length x top &bottom x height) , mm	Angle bar Mild Steel	420 x (400 &500) x600
2	Shelling drum (length x diameter), mm	mild steel	380 x 210
3	Spike (length x diameter),mm	mild steel rod	40 x 12
4	Drum shaft (length x diameter), mm	mild steel rod	540 x 20
5	Concave (length x radius), mm	mild steel rods and flat	40 x140
	MS flat bars (length x width x thickness), mm	mild steel flat bars	440 x 40 x 1
	Round bars mounted on flat bars (diameter x length),mm	mild steel rods	10 x 400
8	MS Top drum cover (length x thickness x diameter),mm	Metal sheet	630 x 400
9	Feeding hopper length x width x height mm	Metal sheet	480 x400 x50
10	Outlet (length x width x thickness), mm	Metal sheet	570 x400 x1
11	Frame of the electric motor (length x width), mm	Angle bar Mild Steel	30 x 20
2	Size of the motor drive pulley (groove x diameter), mm	Mild Steel	20 x 80
13	Driven pulley on Drum shaft (groove x diameter), mm	Mild Steel	20 x 120
14	V-Belt (Width x Thickness),mm	Black rubber	22 x 18
15	Prime mover: electric motor (capacity), kW	3 phase electric motor	2.22kw

Appendix B: Parameters and properties of maize variety selected for the study

Measurements		BH660 Maize varieties REPLICATIONS 1	2	3	mean	SD	BH540 maize varieties REPLICATIONS 1	2	3	mean	SD
Length of un-shelled cob, mm		152.10	159.60	140.30	150.67	9.730	157.30	164.00	137.60	152.97	13.723
Diameter of unshelled cob, mm		46.00	48.31	45.56	46.62	1.477	48.00	50.10	47.20	48.43	1.498
Weight of un-shelled cob, g		176.20	187.22	195.32	186.25	9.597	179.20	191.42	208.66	193.09	14.801
No. of grain lines in cobs		15.00	13.00	14.00	14.00	1.000	13.00	13.00	14.00	13.33	0.577
No. of grains in one line of cob		52.00	28.00	47.00	42.33	12.662	56.00	32.00	51.00	46.33	12.662
Min. diameter of cob without grains, mm		18.35	21.37	23.13	20.95	2.418	20.13	19.30	23.10	20.84	1.998
max.diameter of cob without grains, mm		26.72	23.27	25.33	25.11	1.736	24.67	26.13	25.12	25.31	0.748
length of shelled cob, mm		132.70	140.43	149.55	140.89	8.435	138.41	142.25	148.40	143.02	5.039
Length of un-shelled cob, mm		152.10	159.60	140.30	150.67	9.730	157.30	164.00	137.60	152.97	13.723
Linear dimensions of	length	11.41	10.2	9.87	10.49	0.811	10.13	9.60	10.05	9.93	0.286
maize grains	Width	8.14	7.08	5.72	6.98	1.213	6.96	5.82	7.43	6.74	0.828
	thickness	4.31	3.96	3.07	3.78	0.639	3.84	3.72	4.15	3.90	0.222

Appendix C: Physical properties of maize variety selected for the study

Properties	BH660 Maize varieties REPLICATIONS			mean	SD	BH540 maize varieties REPLICATIONS			mean	SD
	1	2	3			1	2	3		
Roundness	0.26	0.24	0.25	0.25	0.01	0.32	0.33	0.34	0.33	0.01
Arithmetic mean diameter (mm)	7.82	7.61	8.08	7.84	0.24	7.97	7.76	8.82	8.18	0.56
Geometric mean diameter (mm)	7.56	8.02	7.48	7.69	0.29	7.65	8.30	7.84	7.93	0.33
Spherecity	0.72	0.64	0.62	0.66	0.05	0.74	0.72	0.68	0.71	0.03
Surface area (mm2)	196.63	178.00	214.60	196.41	18.30	202.30	180.80	218.70	200.60	19.01
Bulk density (g cm-3)	0.76	0.74	0.78	0.76	0.02	0.82	0.78	0.84	0.81	0.03
True density (g cm-3)	1.13	0.96	1.02	1.04	0.09	1.24	1.20	1.14	1.19	0.05
Test weight (g)	312.40	314.62	298.16	308.39	8.93	316.22	302.18	318.26	312.22	8.75
Grain straw ratio	3.21	2.98	3.34	3.18	0.18	3.14	3.29	3.36	3.26	0.11

Appendix D: Frictional properties of the selected maize grains varieties

Properties		BH660 Maize varieties REPLICATIONS			mean	SD	BH540 maize varieties REPLICATIONS			mean	SD
		1	2	3			1	2	3		
Angle of repose		20.12	22.24	21.63	21.33	1.091	21.74	23.46	24.23	23.14	1.041
Coefficient of	Grains	0.28	0.30	0.30	0.29	0.011	0.30	0.32	0.32	0.31	0.009
friction)	MS sheet	0.34	0.32	0.34	0.33	0.012	0.33	0.34	0.34	0.34	0.006

Appendix: E Data sheet for test at no load

Appendix E_1: Power consumption

SI.No.	Particulars		Details
1	Source of power		3 phase electric motor
2	Rated power (kW)		2.2
3	Rated speed (rpm)		950
4	Type of drive		V-belt
5	Total time run (min)		20 minutes
		Total power (watt)	305
6	Average power consumption	Motor (%)	43.54%
		Shelling drum (%)	35.25%
		Miscellaneous (%)	21.21%

Appendix E_2: testing Observations at no load

SI.No	Particulars	Details
1	Slippage of belts	No
2	Presence of undue knocking or sound	Concave
3	Slackness of any components (20 minute)	Top most part of hopper
4	Presence of any oscillation	No
5	Raise in temperature	No

Appendix F: Performance evaluations of the maize sheller at different shelling drum peripheral speed and feed rates

Appendix F_1: Performance evaluation of the maize sheller at $9.2ms^{-1}$ cylinder speed with different feed rate

Measurements	$1000kghr^{-1}$				$1500kghr^{-1}$				$2000kghr^{-1}$			
	REPLICATIONS				REPLICATIONS				REPLICATIONS			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
Wt. of maize feed (kg)	10	10	10	10	10	10	10	10	10	10	10	10
Grain output (kg)	7.551	7.547	7.535	7.544	7.56	7.555	7.54	7.553	7.567	7.56	7.596	7.576
Unshelled grain (kg)	0.414	0.463	0.328	0.402	0.35	0.39	0.26	0.335	0.279	0.33	0.195	0.268
Wt. of damaged grains (kg)	0.212	0.216	0.208	0.212	0.21	0.212	0.20	0.208	0.204	0.21	0.2	0.204
Wt. of shelled cobs (kg)	1.23	1.14	1.19	1.187	1.27	1.185	1.23	1.232	1.320	1.23	1.280	1.276
Wt. of grains loss (kg)	0.886	0.933	0.802	0.874	0.82	0.867	0.74	0.807	0.751	0.79	0.667	0.738
Time (min)	0.59	0.60	0.61	0.60	0.37	0.42	0.39	0.393	0.29	0.30	0.31	0.302
Input capacity (kg/hr)	1017	1000	983.6	1000	1621	1428	1538	1538.5	2069	1954	1935	1984.6
Output capacity (kg/hr)	768	754.7	741.2	754.4	1226	1079	1160	1162	1565	1478	1470	1505.2
Shelling efficiency (%)	94.8	94.2	95.8	94.9	95.6	95	96.7	95.8	96.4	95.8	97.5	96.6
Unshelled grain (%)	5.2	5.8	4.2	5.1	4.4	5	3.3	4.2	3.6	4.2	2.5	3.4
Damaged grains (%)	2.7	2.7	2.6	2.7	2.6	2.7	2.6	2.6	2.6	2.6	2.6	2.6
Percentage Loss (%)	11.1	11.6	10.2	11	10.4	10.9	9.4	10.2	9.6	10.1	8.6	9.4
Seed recovery (%)	88.9	88.4	89.8	89	89.6	89.1	90.6	89.8	90.4	89.9	91.4	90.6

Appendix F_2: Performance evaluation of the maize sheller at 9.6ms^{-1} cylinder speed with different feed rate

Measurements	1000kghr^{-1}				1500kghr^{-1}				2000kghr^{-1}			
	REPLICATIONS			Average	REPLICATIONS			Average	REPLICATIONS			Average
	1	2	3		1	2	3		1	2	3	
Wt of feed (kg)	10	10	10	10	10	10	10	10	10	10	10	10
Grain output (kg)	7.601	7.6	7.58	7.599	7.609	7.60	7.593	7.602	7.62	7.61	7.65	7.63
Unshelled grain (kg)	0.364	0.41	0.28	0.388	0.297	0.35	0.211	0.285	0.229	0.279	0.14	0.22
Wt. of damaged grains (kg)	0.262	0.27	0.26	0.264	0.258	0.26	0.254	0.258	0.25	0.26	0.25	0.25
Wt. of shelled cobs (kg)	1.234	1.14	1.19	1.189	1.28	1.19	1.239	1.236	1.32	1.23	1.28	1.28
Weight of grains loss (kg)	0.916	0.96	0.83	0.94	0.85	0.89	0.766	0.837	0.78	0.83	0.70	0.77
Time (min)	0.564	0.57	0.58	0.569	0.344	0.3	0.364	0.3673	0.28	0.25	0.30	0.28
Input capacity (kg/hr)	1083	1045	1027	1054.5	1744	1523	1648.3	1634.88	2113	2362	1974	2135.23
Output capacity (kg/hr)	808.	794.	779	801.3	1327	1158	1251.6	1242.8	1609	1798	1509	1628.1
Shelling efficiency (%)	95.4	94.8	96.5	95.1	96.2	95.6	97.3	96.4	97.1	96.5	98.1	97.2
Unshelled grain (%)	4.6	5.2	3.5	4.9	3.8	4.4	2.7	3.6	2.9	3.5	1.9	2.8
Damaged grains (%)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.2	3.3	3.2	3.2
Percentage Loss (%)	11.5	12	10.6	11.8	10.8	11.3	9.8	10.6	10	10.5	8.9	9.8
Seed recovery (%)	88.5	88	89.4	88.2	89.2	88.7	90.2	89.4	90	89.5	91.1	90.2

Appendix F_3: Performance evaluation of the maize sheller at 10.1ms^{-1} cylinder speed with different feed rate

Measurements	1000kghr^{-1}				1500kghr^{-1}				2000kghr^{-1}			
	REPLICATIONS			Average	REPLICATIONS			Average	REPLICATIONS			Average
	1	2	3		1	2	3		1	2	3	
Wt. of feed (kg)	10	10	10	10	10	10	10	10	10	10	10	10
Grain output (kg)	7.651	7.647	7.585	7.627	7.659	7.655	7.643	7.652	7.617	7.663	7.696	7.658
Unshelled grain (kg)	0.364	0.363	0.228	0.318	0.247	0.296	0.161	0.235	0.179	0.229	0.095	0.167
Wt of damaged grains (kg)	0.266	0.27	0.262	0.266	0.262	0.266	0.258	0.262	0.258	0.262	0.254	0.258
Wt of shelled cobs (kg)	1.274	1.184	1.234	1.231	1.319	1.229	1.279	1.276	1.364	1.274	1.274	1.304
Weight of grains loss (kg)	0.946	0.993	0.862	0.934	0.88	0.927	0.796	0.867	0.811	0.858	0.727	0.798
Time (min)	0.532	0.542	0.552	0.542	0.354	0.362	0.332	0.349	0.252	0.249	0.252	0.251
Input capacity (kg/hr)	1127.82	1107.011	1086.957	1107.077	1694.915	1657.459	1807.229	1719.198	2380	2409.639	2380.952	2390.438
Output capacity (kg/hr)	862.9	846.5	824.5	844.317	1298	1268.7	1381	1309.513	1813	1846	1832.	1830.598
Shelling efficiency (%)	95.46	95.5	97.08	95.997	96.87	96.277	97.93	97.02	97.70	97.1	98.78	97.866
Unshelled grain (%)	4.541	4.532	2.918	3.967	3.124	3.372	2.057	2.98	2.296	2.902	1.219	2.134
Damaged grains (%)	3.319	3.371	3.353	3.348	3.314	3.345	3.306	3.322	3.309	3.32	3.26	3.297
Percentage Loss (%)	11.80	12.39	11.03	11.756	11.13	11.659	10.2	10.993	10.40	10.87	9.331	10.198
Seed recovery (%)	88.18	87.60	88.97	88.244	88.87	88.341	89.8	89.007	89.59	89.13	90.67	89.802

Appendix G: performance analysis of the prototype sheller using software (SPSS 16)

Source	Dependent Variable	Sum of Squares	df	Mean Square	F
Feed rate(F)	Input capacity of maize	1889788.940	2	944894.470	53.15
	Output capacity of maize grain	1110588.93	2	555294.468	47.044
	Shelling efficiency	4.439	2	2.220	6.036
	Usheelled grain percentage	4.447	2	2.224	5.631
	Damaged grain percentage	.006	2	.003	0.21
	Percentage of grain loss	3.058	2	1.529	10.359
	Seed recovery percentage	4.270	2	2.135	18.439
Drum speed(S)	Input capacity of maize	82202.427	2	41101.213	0.129
	Output capacity of maize grain	55620.469	2	27810.234	0.148
	Shelling efficiency	2.186	2	1.093	1.470
	Usheelled grain percentage	2.331	2	1.166	1.559
	Damaged grain percentage	.892	2	.446	382.352
	Percentage of grain loss	.536	2	.268	0.471
	Seed recovery percentage	.630	2	.315	0.436
F *S	Input capacity of maize	24465.773	4	6116.443	0.019
	Output capacity of maize grain	15201.604	4	3800.401	0.020
	Shelling efficiency	.021	4	.005	0.0136
	Usheelled grain percentage	.038	4	.010	0.025
	Damaged grain percentage	.001	4	.000	0.00
	Percentage of grain loss	.350	4	.088	0.1596
	Seed recovery percentage	.065	4	.016	0.022
Total	Input capacity of maize	2.560E7	9		
	Output capacity of maize grain	1.483E7	9		
	Shelling efficiency	83591.238	9		
	Usheelled grain percentage	124.540	9		
	Damaged grain percentage	86.154	9		
	Percentage of grain loss	1006.510	9		
	Seed recovery percentage	72009.531	9		

Appendix H: Materials, specification and costing for the maize sheller prototype

Component	Types Material	Specifications	Quantity	Unit price (ETB)	Total price(ETB)
Frame	Angle iron	420×400×600mm	1	150.00	150.00
Shelling drum	Metal sheet	Ø130mm×380mm	1	200.00	200.00
Spike	Mild steel rod	Ø10mm×40mm	32	2.00	64.00
Drum shaft	Mild steel rod	Ø20mm×540mm	1	36.00	36.00
Concave	Mild steel rod	Ø10mm×140mm	22	110.00	110.00
	Mild steel flat	20mm×440mm	4	10.00	40.00
Top cover	Metal sheet	Ø400mm×400mm	1	150.00	150.00
Hopper	Metal sheet	480mm×400mm×50mm	1	150.00	150.00
Bolts and nuts	Mild steel	M12	12	3.00	18.00
Ball bearings	Mild Steel	P 206	2	50.00	100.00
Motor pulley	Mild steel	Ø20mm×80mm	1	40.00	40.00
Drum pulley	Mild steel	Ø20mm×120mm	1	60.00	60.00
Electrodes		Gauge 12	1	150.00	150.00
Abrasives		2 mm Thick	1	100.00	100.00
Paint		1 liter	1	200.00	200.00
Belt	Black rubber	A 22 x 18	2	50.00	100.00
Motor		3 phase electric motor	1	10,000.00	10,000
Sub-total					**11668.00**
Labour cost	13% of material cost (assumed)				1517.00
Machine Cost	15 % of material cost (assumed)				1750.00
Grand Total					**15752.00**

1. **Fixed cost**

Cost of materials + construction cost, 15752.00 ETB

Salvage value @ 10% total cost of machine, 1575.2ETB

Number of labour used for construction work = Two @75.00ETB per day

Working hours per day = 8 h

Number of working days = 10 days

Cost of labour for construction work: 2 × 10 × 75 = 1500ETB

Assume cost of machines as 15 % of material cost

Cost of electricity = 15/100 ×11668=1750ETB

Total Construction cost of the Prototype maize Sheller

= Cost of raw material + Cost of labour for construction + Cost of machines

= 11668 +1500 +1750=14918ETB

The construction cost of the Prototype maize Sheller was, 15752.ETB

2. Cost of operation

The following assumptions were considered for determining the cost of the maize sheller proto type.

Useful working hours =1600

Useful life years =8

No. of labours per day =1

No. of working hours per year = 200hr

Salvage value @ 10% total cost of sheller

Rate of interest on fixed capital = 12 % of total cost of sheller

Taxes per annum = 2 % of total cost of machine

Housing =1 % of total cost of machine

Repair and maintenance = 4% per annum of total cost of sheller

Production cost of the maize sheller prototype = 15752.00ETB

Fixed cost

Salvage value $= \frac{10 \times 15742}{100} = \text{ETB}.\,1575.2.\,\text{ETB}$

Deprecation $= \frac{15752 - 1575.2}{8} = \text{ETB}.\,1772.\,\text{ETB}$

Interest $= \frac{15752 + 1575.2}{2} \times \frac{12}{100} = 1040.\,\text{ETB}$

Taxes $= \frac{15752 \times 2}{100} = 315.\,\text{ETB}$

Housing $= \frac{15752 \times 1}{100} = 157.52.\,\text{ETB}$

Repair and maintenance $= \frac{15752 \times 4}{100} = 630.\,\text{ETB}$

Total Fixed cost = 5490.ETB.Per annum

Operating cost

Repair and maintenance $= \frac{15752 \times 4}{100} = 630.\,\text{ETB}$

Labour charge $= 75 \times 1 \times \frac{1600}{8} = 15000.\,\text{ETB}$

Energy/electricity/fuel charge per annum $= 1600 \times 1.492 \times 5 = 11936.\,\text{ETB}$

Total operating cost$= 630 + 1500 + 11936 = 27566.\,\text{ETB}$

Total processing /operation cost = Fixed cost + Operating cost

$= 5490 + 27536$ =33056.ETB

$$\text{Hourly cost operation} = \frac{\text{Total operation cost}}{\text{No. of working dayper year} \times \text{per day working our}}$$

Hourly cost operation $= \frac{33056}{1600} = 20.66.\,\text{ETB}$ per hour

Expected return per year = Capacity × No. of working hours per year × Cost for shelling

= $1500 \times \frac{1600}{8} \times 0.2 = \text{ETB}45000$ per annum

Profit = Return per year - total operating cost per year

= 45000 – 33056 = 11944.ETB per year

Apendix I: Basic static and dynamic capacities of various types of radial ball bearings.

Bearing No.	*Basic capacities in kN*							
	Single row deep groove ball bearing		*Single row angular contact ball bearing*		*Double row angular contact ball bearing*		*Self-aligning ball bearing*	
	Static (C_0)	*Dynamic (C)*	*Static (C_0)*	*Dynamic (C)*	*Static (C_0)*	*Dynamic (C)*	*Static (C_0)*	*Dynamic (C)*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
200	2.24	4	—	—	4.55	7.35	1.80	5.70
300	3.60	6.3	—	—	—	—	—	—
201	3	5.4	—	—	5.6	8.3	2.0	5.85
301	4.3	7.65	—	—	—	—	3.0	9.15
202	3.55	6.10	3.75	6.30	5.6	8.3	2.16	6
302	5.20	8.80	—	—	9.3	14	3.35	9.3
203	4.4	7.5	4.75	7.8	8.15	11.6	2.8	7.65
303	6.3	10.6	7.2	11.6	12.9	19.3	4.15	11.2
403	11	18	—	—	—	—	—	—
204	6.55	10	6.55	10.4	11	16	3.9	9.8
304	7.65	12.5	8.3	13.7	14	19.3	5.5	14
404	15.6	24	—	—	—	—	—	—

Appendix J: Photographs of the sheller component parts and testing activities

a. Traditional maize shelling method b. Measuring physical properties

c. Design of the sheller d. Construction of the maize sheller prototype

e. Motor driven maize sheller prototype f. Performance test