DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF AN AXIAL-FLOW MILLET THRESHER

BY

AKINTAYO AFOLABI

DEPARTMENT OF AGRICULTURAL ENGINEERING

FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA

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JULY, 2015

DECLARATION

I declare that the work in this Thesis entitled Design, Construction and performance Evaluation of an Axial Flow Millet Thresher has been carried out by me in the Department of Agricultural Engineering under the supervision of Prof. D.D Yusuf and Dr. U. S Muhammed. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis has been previously presented for another degree or diploma at any institution.

Akintayo AFOLABI …… ……

M.Sc/ENG/1249/2011-2012 Signature Date

CERTIFICATION

This thesis entitled DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF AN AXIAL-FLOW MILLET THRESHER by Akintayo AFOLABI meets the regulations governing the award of the degree of Masters in Agricultural Engineering of the Ahmadu Bello University, and is approved for its contribution to scientific knowledge and literary presentation.

Prof. D. D Yusuf	…….	…….
Chairman, Supervisory Committee	(Signature)	(Date)
Dr. U. S Muhammed	…….	…….
Member, Supervisory Committee	(Signature)	(Date)
Prof. M. L Suleiman	…….	…….
Head of Department	(Signature)	(Date)
Prof. A. Z Hassan	…….	…….
Dean, School of Postgraduate Studies	(Signature)	(Date)

DEDICATION

This work is dedicated to all those who at one moment or the other have shown concern and interest in the work and to all those who have contributed in making the work successful.

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ABSTRACT

Existing millet threshers have not been performing up to expectation. Based on this, the physical properties of pearl millet grains were determined and used to design an axial-flow millet thresher. The length, width, thickness, geometric diameter, sphericity, surface area of the grains were found to decreased with decrease in moisture content of the grains from 11.6 to 7.8 %. The bulk and true densities of the grains were gotten as 0.73 and 1.14 kg m^{-3} respectively and the coefficient of friction of the grains on sheet metal and aluminium were obtained as 0.35 and 0.36 respectively. The thresher was made from locally available materials and evaluated at 3 levels of crop moisture content of 7.8, 9.7 and 10.3 % (dry basis), 4 levels of manual feed rates of 60, 90, 120 and 150 kg hr^{-1} and 4 levels of cylinder speeds of 5.5, 7.3, 9.2 and 11.0 ms^{-1}. The collected data were analyzed using analysis of variance and Duncan multiple range test. The thresher had 96.5 % and 95.2 % threshing and cleaning efficiencies respectively. The mechanical grain damage and scatter loss from the thresher were 2.65 % and 27.6 % respectively. The throughput capacity of 60 kg hr^{-1} was obtained at 9.7 % crop moisture content and 150 kg hr^{-1} feed rate. The analysis of variance showed that for threshing efficiency, cleaning efficiency, grain mechanical damage, scatter loss and throughput, there was no significant difference at 1 % level of confidence in the interactions of the three independent variables. But the analysis showed that the main effects of crop moisture, cylinder speed and feed rate had high significant differences on each of the performance indices evaluated. The Duncan multiple range test showed that the best crop moisture content for threshing was 7.8 %. It yielded 38kg per hour throughput, 94.8 % threshing efficiency, 94.4 % cleaning

efficiency and grains damage of 2.5 %. The highest feed rate (150 kg hr^{-1}) and the two uppermost speeds gave best results.

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CHAPTER ONE

1.0 Introduction

1.1 Agriculture and the World Population

Food is a very important component of human existence. Agriculture plays a vital role in the sustenance and continuous existence of man and his domestic animals. With the world population of seven billion and growing at the rate of 1.1 % per annum (www.worldmeters.org), there is the constant need to increase food production. The continuous increase in the world population would invariably increase the competition on food, land and other resources for agriculture (www.mapsofworld.com). For example, lands that were once used for farming are now used for either residential building or some other non-agricultural based industries. This has led to the need to increase the use of technology in order to feed the ever increasing population and to make maximum use of available resources to feed the population.

Cereals and legumes are some of the essential and most consumed food by man (www.fao.org/docrep). Cereals are widely consumed and utilized by man. They serve as raw materials for food and drug industries. This can be observed by the large metric tonnes of each of them reserved in silos and grains reserves world over (Mckee, 2011). Cereals are also used as animal feed and their stalks are as well useful to man in building temporary fence and as thatch for roofing of mud houses in villages (Mula *et al.,* 2009). Thus the importance of cereals to man cannot be over emphasized.

Millet is a kind of cereals that is widely grown in Africa and India. Millets are extremely important in the semi arid tropics of Africa and produced in 18.50 hectares by 28 countries covering 30 % of the continent (Obilana, 2007). According to DAFF (2011),

global production of millet grains probably exceeds 10 million tonnes a year, to which India contributes nearly half. It also said that, at least 500 million people depend on millet for their lives. Approximately one-third of world millets are grown in Asia and Africa. About 70 % of the amount produced in Asia and Africa is grown in West Africa. Major producing countries in Africa include Nigeria, Niger, Burkina Faso, Chad, Mali, Mauritius and Senegal in the West Africa and Sudan and Uganda in the East Africa (DAFF, 2011). The crop is draught resistant and thus can be planted in areas with low rainfall (Plaza-Wuthrich and Tadele, 2012).

There are nine species of millet among which four are produced significantly in Africa. The four species significantly planted in Africa are pearls millet, finger millet, teff millet, and furio millet. In Nigeria, the pearl millet (*pennisetum glacum*) is the most widely grown specie. And Nigeria accounts for 40 % of the millet production in Africa (Obilana, 2007). Millet is generally used as a staple food in homes almost across Africa. The crop is being used for making of traditional dishes like *tuwo, ogi* and *eko* and for some local dessert such as *kunu*, *fura* and so forth. Millet is also used for making of other beverages and drinks. As compared to other cereal crops, Obilana (2007) reported that millet has an equivalent or superior nutritional value.

1.2 Growth, Development and Adaptation of Millet

Millet is entirely a subsistent crop, generally grown without fertilizer or chemical protection. Perhaps, the ability of millet to thrive in drought-prone places makes it widely grown in areas with low rainfall in the range of 200 to 800 mm per annum (Bidinger *et al.*, 1981). Millet appears to have relatively fast root development, sending extensive root profile to take advantage of available soil moisture and nutrient (Robert, 2013). The

adaptive feature of millet makes it possible for it to be planted in shallow or sandy soil which has very low water retention. Millet can thrive relatively well in some other adverse condition such as in acidic soil, and when available soil moisture and fertility are low (Robert, 2013). Millet can also do well in areas where sorghum can adapt; it can be more drought-tolerant and can withstand lower soil pH than sorghum. Millet has early maturity than sorghum (Robert, 2013).

Kowal and Kassam (1978) reported that the regions where millet are often planted have short annual rainy season of 2 to 4 months and high mean daily temperatures, high potential evapotranspiration rates and shallow or sandy soils. The height of mature millet may vary from 90 to 180 cm depending on the variety and other agronomic conditions. The crop is primarily cross pollinated. The early maturing variety of millet matures in 70 to 75 days (Robert, 2013), while other varieties may mature in 80 to 90 days after planting (Mula *et al.,* 2009). Beside the drought tolerance and short maturity which characterize millet, low input requirement, suitability of its intercropping with crop plantation like mango and good stover yield are some of the reasons that encourage the cultivation of millet by farmers (Mula *et al.,* 2009). Millet has no significant pests and diseases. However, birds can cause damage to millet fields. The birds perch on the stalks to peck away the grains (Robert, 2013).

1.3 Economic Importance of Millet

Millet is key to maintenance of food security in the developing world since it is a major food, feed and fodder source for the people and their livestock (Plaza-Wuthrich and Tadele, 2012). Like rice, edible millet (especially pearl millet) is the main source of calories and protein for the people who depend on it (Bidinger *et al.,* 198I). Millet is

widely consumed as stable food across Africa and in India. It is prepared in various forms of food. Millet is prepared in the form of porridge from flour called ‘tuwo’, as dessert called ‘dan wake’ and as sundry drinks in the forms of pap, ‘ogi’ and ‘kunu.’ Millet contains high amount of vitamin, calcium, iron, potassium, magnesium and zinc (Leder, 2004). Hence, millet is considered to be a nutritious and healthy food. Its grains do not contain gluten, a substance that causes celiac disease or other forms of allergies (Plaza-Wuthrich and Tadele, 2012). Rather, it has been shown to have anti-proliferative property and might have a potential in the prevention of cancer initiation (Chandrasekara and Shahidi, 2011).

Although, millet has been grown as subsistence crop, but recently, it is becoming more market oriented crop owing to the change in its utilization from mainly food crop to other alternative uses such as animal and poultry feeds and drinks. The grain of millet is largely used as poultry feed in America (Robert, 2013) and its stalks as feed for draft and milch animals world-over (Krishnappa *et al.,* 2009). There is a growing interest in millet because of the technological possibilities of its utilization in such industrial application as starch production. Therefore, consequent on the large scale production of the crop (Ojediran *et al.,* 2010), is the need to development an efficient machine for the threshing of the crop.

1.4 Classification and Types of Millet in Nigeria

Generally, millets are classified into two primary groups, namely the small millets and the pearls millet. The small millets include all the other species of millet except the pearls millet (Seetharam *et al.,* 1989). Examples of the small millet are the fonio (*Digitaria ibura)* and teff (*Eragrostis teff*). While some of the small millets are cultivated as food,

others are planted as feed and fodder for birds and other farm animals. The pearls millet (*Pennisetum glaucum*), on the other hand, is the commonest species of millet planted for food across Africa and India (Kamble *et al.,* 2003). According to Ikwella (1998), pearls millet is second important only to sorghum as a staple food in Nigeria.

There are three types of pearls millet based on the maturity dates (Ikwella, 1998). These are *gero, maiwa* and *dauro*. *Gero* is photoperiod neutral and early maturing (70 -100 days). It is cultivated in the Northern Guinea, Sudan savanna and in the Sahel. *Gero* is grown on about 80 % of the total area under millet and predominates in Sahel (Ikwella, 1998). *Gero* is usually the earliest maturing cereal in Nigerian savanna and fills the hunger gap between the depletion of preceding year's harvest and the availability of the next one (Ajayi and Uvah, 1988). *Maiwa* is photoperiod sensitive and late maturing. It is mostly grown in Southern and Northern Guinea savanna areas. It flowers at the end of rains and yields much lower than *gero.* While *dauro,* the transplanted millet, is photoperiod sensitive and late maturing. It is cultivated in restricted scale in parts of Kaduna, Kebbi, Plateau and Nasarawa States of Nigeria (Ikwella, 1998).

1.5 Problem Statement

The majority of millet farmers in Africa are small-holder farmers which have very little capital to run their enterprises. They are often characterized by possessing a small-sizeable land (Kothari *et al,* 2005), and as such cannot afford the capital to purchase a combine for the harvesting and threshing of their produce. Thus the threshing of millet is oftentimes done manually by pounding of the crop in mortar using pestle or by its flailing on threshing floor using sticks by farmers. These traditional methods of threshing of the crop are not only time-consuming but also laborious and of very low output (Joshi, 1981).

The long hours of day labour of these "human threshers" is not anything to write home about as an average woman can only thresh about 10 kg per day (www.fao.org/docrep). Thus, the traditional methods are arduous and slow. Kamble *et al.,* (2003) reported that while an impressive progress has been made in the design and development of wheat thresher, no acceptable thresher is yet available for millet as at 2003. Thus, powered wheat threshers are being used for the threshing of millet with low efficiency and high losses (Robert, 2013). According to Robert (2013) where combine harvester is used for the harvesting of millet, it is difficult to get good threshing and cleaning efficiencies.

The manual threshing of millet on the threshing floors invariably introduces a lot of foreign materials such as sands into the crop, thus reducing the market value of the crop and decreasing the quality of the crop for human consumption. Besides, the drudgery of threshing millet by pounding or flailing is one of the factors discouraging farming, encouraging rural-urban drift, causing the neglect of agriculture (Irtwange, 2009) and fostering unemployment.

In the years past, millets are commonly known as orphan- or neglected-crops due to too little attention given to them by researchers and scientists (Plaza-Wuthrish and Tadele, 2012). This may be premised on the facts that the crop is produced by subsistent farmers which expect little or no financial profit from the cultivation of the crop, nor does the crop attract much foreign exchange in the international market. However, the crop is the major food for the subsistence farmers who farm it. Recently, there are increased efforts to improve the production of millet and to produce varieties which would be more drought-tolerant and disease-resistant by many researchers and institutions (Plaza-Wuthrish and Tadele, 2012). These efforts must be complemented by the engineers who

work with the scientists and technologists to improve on the lot of millet farmers in the regions where the crop is produced.

1.6 Justification

Knowing the importance of millet in Africa, it becomes imperative to design a millet thresher capable of meeting the needs of the farmers in Nigeria. The development of the thresher would not only increase the standard of living of the farmers by increasing the market value of their produce but would also make life more comfortable for the farmers by alleviating the drudgery they undergo in the course of the manual threshing of their produce. The development of engine-operated thresher for millet would reduce the time consumed in threshing and also reduce the foreign materials inadvertently introduced by threshing on farm-floors using any of the traditional methods of threshing. The thresher would be developed from locally and readily available materials. This would make it affordable to the small-holder farmers in Nigeria. The rising need of local millet farmers for a mechanical thresher necessitated this work (Ndirika, 1994). The research is intended not only to encourage more production of the crop but would also enhance the economic value of the crop. It would also promote the availability of the crop as raw material for food and pharmaceutical industries and thus boosting the farmers' standard of living and contributing to Nigeria's Gross Domestic Product (GDP).

The mechanical threshing of millet would improve on the cleaning processes and add value to the final produce. This would invariably increase the wholeness and worthiness of the crop for human consumption. Also, the mechanization of the process would ensure the availability of the crop in good quantity and quality as soon as they can be produced on the field. The efficiency of threshing and cleaning would be improved upon where the

threshing process is fully mechanized. According to Kamble *et al.*, (2003) the cost of operation and use of machine is sometimes much cheaper than the cost of using manual labour for such task as threshing. They observed that in peculiar cases, the cost of paying labourers and the time consumed in carrying out such activities exceed what would be incurred when the process is carried out using the engine-operated thresher. Thus, the thresher would increase the timeliness and efficiency of threshing of the crop.

The amount of energy expended to thresh a reasonable quantity of millet is enormous and the exercise is also time-consuming and the output per person per day is extremely low (Irtwange, 2009). Thus this research is important in order to overcome all these challenges and improve the living standards of the farmers and their families. It would also allow the farmers some spare time to engage themselves in other important activities.

1.7 Objectives

The aim of this research is to develop an affordable millet thresher for small-scale farmers.

The objectives of the project are:

i. to determine basic physical properties of pearl millet grains;
ii. to design and construct an axial-flow millet thresher from readily available local materials;
iii. to evaluate the performance of the developed thresher.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Species of Millets and its Areas of Production

According to Kothari *et al.,* (2005), millet embraces ten genera and at least fourteen species (Table 2.1). The species are in alphabetical order of their botanical names. Ojediran *et al.,* (2010) reported that Crowford and Lee (2003) rated the most widely cultivated species in order of the worldwide production as pearls millet (*Pennisetum glaucum*), foxtail millet (*Setaria italia*), proso millet (*Panicum miliaceum*) and finger millet (*Eleusine coracana*) in that order. Obilana (2007) stated that four species are produced significantly in Africa namely pearls millet, finger millet, teff millet

Table 2.1 List of millet species

Species	**Common names**
Brachiaria ramose	Browntop millet
Coix lachryma jobi	Job's tears
Digitaria exilis	Hungry rice
Digitaria ibura	Fonio or Hungry rice
Echinochloa colona	Jungle rice
Echinochloa decompositum	Australian millet
Echinochloa frumentacea	Japanese barnyard millet
Eleusine coracana	Finger millet
Eragrostis teff	Teff
Panicum miliaceum	Proso millet
Panicum miliare	Little millet
Paspalum notatum	Bahia grass
Paspalum scrobiculatum	Kodo millet
Pennisetum glaucum	Pearls millet
Setaria italica	Foxtail millet

Source: Kothari *et al.,* (2005)

(*Eragoastica teff*) and furio millet (*Digitaria ibura*). He also reported that in Nigeria, pearls millet is the most widely grown specie and that Nigeria account for forty percent of this millet production in Africa. Thus, pearls millet was used for the evaluation of the machine (on completion) because it is the most widely grown specie of millet.

Bidinger *et al.,* (1981) have compared rice with pearls millet. They said that like rice, millet is the main source of calories and protein for the people who depend on it. Most of this people are in arid and semi-arid areas where no major cereal is as well adapted as millet. More than ninety-five percent of the world's millet crop is grown in Africa and South Asia, principally in the Sahelian-Sudan zones of West Africa and the semi-arid regions of the east and southeast of the Thar Desert in India. These areas of adaption of millet species are clearly defined by the mean annual rainfall isohyets of 200 to 600 mm (Bidinger *et al.,* 1981). Ikwella *et al.,* (1993) rated pearl millet as the most important cereal in the southern Sudan and the northern guinea.

2.2 Reviews on the Physical Properties

The knowledge of physical properties of crops are critical to the design of equipment for harvesting, threshing, handling, conveying, cleaning, separation, packaging, storing, drying and processing of agricultural products (Baryer, 2002 and Davies, 2009). For the development of agricultural machines such as thresher, planter, seed grader and so on, the physical properties of the crop to be handled must be determined in order to design adequate equipment for the crop. Some physical properties of crops which have been investigated by researchers (Davies, 2009; Pradhan *et al.,* 2013) include axial dimensions (length, width and thickness), geometric diameter, sphericity, surface area, 1000 grain mass, bulk and true densities, angle of repose of grains and coefficient of friction between

the grains of the crops and diverse engineering materials. Jain and Bal (1997) investigated the physical properties of a certain pearls millet variety (*pennisetum typhoides*), Baryeh (2002) evaluated the physical properties of another variety of pearl millet (*pennisetum gambience*). Ndirika (1994) and Ojediran *et al.*, (2010) determined the physical properties of *pennisetum glaucum.* However, Ndirika (1994) did not evaluate the coefficients of friction of the crop on engineering materials such as plywood and galvanized metal. And Ojediran *et al.,* (2010) left out the determination of geometric diameter, surface area and volume of the crop. Other researchers (Davies, 2009; Pradhan *et al.,* 2013) have investigated the physical properties of other crops like maize, groundnut, sorghum for the purpose of adopting the findings for the design of machines to process the crops.

2.3 Trends in Development of Threshers

From medieval time, before the development of machine and technology, threshing of crops has been done in the traditional ways. The traditional ways of threshing cereals and pulses have being by flailing manually with sticks, treading by animals on the threshing floor (Culprin, 1947 and Irtwange, 2009). Abolaji (1980) reported that the first step in the mechanization of threshing was in the seventeenth century when farming mills were developed. According to him, Sir John Van Berg was the first to develop a mechanical thresher which consists of several flails operated by cranks. The first work on the development of thresher in America is probably the one by Hiram and John Pitts of Winthrop. Their machine was able to thresh, separate and winnow the crop in one go. Irtwange (2009) on his part stated that Andrew Meikles in 1976 built a thresher which combined the blow of flails with the robbing action of the threshing floor. The beaters

were fastened to the revolving drum forcing the grains against the ribs of a concave sieve placed below the drum. Irtwange (2009) avowed that the machine was the prototype of the present day threshers.

However, since the 1960s to date, there has been a lot of improvement in the development of machines for threshing different crops (Irtwange, 2009). While new threshers are been developed daily for various crops, works are still on going to improve on the existing ones (Joshi, 1981). In recent time, the combine harvester is used for the cutting (or harvesting of crops), feeding, threshing, separation and cleaning of some crops like rice, corn and soyabeans (Hunts, 1983). The initial cost of obtaining the combine harvester and even the cost of owning and maintaining the machine is beyond the means of the average small holder farmers in Africa (Irtwange, 2009).

2.4 Developments in Millet Thresher

There has being efforts geared towards the development of millet thresher. Wagami (1979) designed and fabricated an axial flow millet thresher. Abolaji (1980) reported that the output capacity of Wagami's thresher was low (25 kg hr^{-1}) and that the thresher has no winnowing unit to clean the threshed millet in the same machine. Thus the product had to be cleaned manually after threshing in the machine. However, Abolaji (1980) was able to incorporate a winnowing unit into Wagami's work but did not bother about increasing the capacity. While an impressive progress has been made in the design and development of wheat and barley threshers, no acceptable thresher is available for millet crop (Kamble *et al.*, 2003). Therefore, according to Kamble *et al.*, (2003), wheat power threshers are being used for the threshing of millet with low efficiency and high losses. Joshi (1981) also made a comprehensive review on works on threshers; he described how

concerted effort has been made on the development of wheat and barley threshers but was altogether silent on works on millet thresher. This may be due to the relatively low amount of work that has so far been done in this regards as stated by Kamble *et al.*, (2003).

A study was conducted by Singhal and Thierstein (1987) with pearl millet crop on modified axial flow thresher. At 12 % moisture content the threshing efficiency, cleaning efficiency, blown up grain (scatter loss) and output capacity of the thresher were observed to be 8 %, 86 %, 5 % and 400 kg hr^{-1}, respectively. Also in India, another study on millet threshing carried out by Kamble *et al.,* (2003) gave the obtained highest threshing efficiency as 98.6 %, the lower grain damage of 2.75 %, and 2.1 % total grain loss as the machine's best output. They also evaluated the germination of the crop threshed by the machine and found it to be 87 %.

2.5 Demerits of Traditional Methods of Threshing

Wherever the planting of cereals and grains are done the task of threshing of the crops is seen as a herculean task but also as essential component of the production of the crop (Danilo and Beverly, 1999). Danilo and Beverly (1999) reported that the time required for threshing of crops depends on the variety of the crop, the degree of dryness of the grains, and the method of threshing. They further stated that in India, the common practice for threshing grains is to place them on the road for vehicles to run over. They stated that approximately 1.2 tonnes of grains can be threshed on the road in one day and that 35 labourers are required for the monitoring of the crops in this process. Jianqiu and Yuxue (1999) stated that 250 kg of grains may be threshed by flailing by a person in one day, but agreed that flailing to thresh is inefficient and labour intensive and therefore

discourage its use as a method of threshing. They added that the most popular method of threshing in China is the use of animals to thresh. The animals are made to pull a stone roller over some spread crops on the floor to thresh. The process of running the roller over the crop is repeated until the heads of the crop are satisfactorily threshed. The output per day per person for this method was given as 1000 kg (Jianqiu and Yuxue, 1999). Jianqiu and Yuxue (1999) went on to say that mechanical threshing is still preferred to other methods because it has higher efficiency, clean threshing and low *glumaceous* rate. They however did not state these advantages in numerical quantity.

2.6 Factors Affecting the Performance of Threshers

According to Kepner *et al.,* (1972), the performance of any thresher is dependent upon the moisture content of the crop, the peripheral speed of the cylinder, the clearance between concave and cylinder as well as the feed rate of the machine. Based on these factors, many previous works (Abolaji, 1980; Kamble *et al.,* 2003; Abarchi, 2011 and Gbabo *et al.,* 2013) have been done to determine the optimum moisture content, the best peripheral speed of cylinder, the ideal clearance of drum and cylinder and the most adequate feed rate of various machines and crops to achieve the best result of the threshing of the different crops. Also, rasp-bar and spike cylinder have been used for threshing different crops and the thresher in which they are used evaluated. Kamble *et al.,* (2003) used spike bar for threshing of millet and obtained a threshing efficiency range of 78.10 to 96.80 % for the different levels of test variables. They reported that an increase in threshing efficiency with increase in the peripheral speed was expected due to an increase in impact energy and rubbing shear action on the crop. They were able to obtain an optimum clearance of 10 mm for millet. Nonetheless, it is commonly reported that the

clearance between the cylinder and concave would determine the amount of mechanical grains damage (Joshi, 1981). Also, the moisture content of the crop would affect both the scatter loss and the required energy needed for its threshing. Joshi (1981) reported that Klein and Harmond (1966) studied the effect of varying cylinder speed and clearance on three different threshing cylinders namely; spike tooth, rubber covered angle bar and rubber covered flat bar and got optimum peripheral speed and clearance ranges of 1253 to 1545 meter per minute and 8 to 40 mm respectively.

Vas and Harrison (1969) studied the effects of selected mechanical parameter on kernel damages and threshability of wheat. They reported that concave clearance have less effect on the damage of wheat kernel as compared with the cylinder speed, while an increase in the feed rate results in a decrease in the mechanical damage which was described as a result of the cushioning effect at higher feed rate. Table 2.2 shows the recommended cylinder peripheral speeds and concave clearance of various crops.

2.7 Essential Components of Threshers

Essentially, a modern thresher would have an inlet (often a hopper)-through which the crop to be threshed is fed into the machine, the threshing chamber-where the actual task of threshing the crop takes place, the cleaning unit-where separation of kernel from chaff is done, and possibly separate outlets for the kernel and chaff. The amount of scatter losses is greatly influenced by the design and shape of inlet hopper for most threshers (Joshi, 1981). The threshing chamber is made of drum (cylinder) and the concave. The drum beats the pinnacles of the crop against stationary concave and forces out the kernels

Table 2.2 Recommended cylinder speed and concave clearances for various crops

Crops	Details of Cylinder	Peripheral speed(m/min)	Concave Clearance(mm)	Moisture content (%)
Barley	Spike-tooth	1524-1828	4.0 (lateral)	_
	Rasp-bar	1524-1828	9.5- 12.7	_
	Robber faced bar	1524-1828	12.7-15.9	_
Maize		750-1220	22-30	_
Rice	Spike-tooth, 48 cm diameter and 59 cm length having 63 spikes of 13x3.5x 0.4 cm size	950	40-70	13.2 % grain 11.0 % straw, wet base
	Spike tooth, 50.5 cm diameter and 122 cm length having 52 pegs of 1.1 cm diam. x 7.6 cm length	800	38	16.0 % grain 17.4 % straw, wet base
	Wire loop type pegs, 40 cm diameter and 90 length	500	Without concave	_
	Rasp-bar, 28.5 cm diameter and 32 cm length	450	_	_
	Spike-tooth, 68 cm diameter and 140 cm length having 120 pegs of 1.8 cm diameter x 15 cm length	1100	25	20.0 % grain 47.0 % straw, dry base
Soya beans	Rasp-bar, 52 cm diameter and 100 cm length having eight rasp-bars	490-820		10-16 % grain, wet base
Sunflower	Fixed hammer type, 20 hammers of 31 x 2.5 x 2.5 cm each welded on 9.0 cm diameter shaft at 25 cm length	650	11.5	10-18 % grain wet base
Wheat	Spike-tooth, 68 cm diameter and 140 length having peg of 1.8 cm diameter x 15 cm length	1190	25	10.5 to 14.3 % grain, 3.6 to 7.5 straw, wet base
	Straight beater types, 66 to 89 cm diameter and 230 to 270 cm length	1075-1450	20-45	_
	Chaff-cutter type, 840 cm diameter and 50-85 cm length with cutting blades	726	40	_
	Spike-tooth, 30 to 43 cm diameter and 27 to 33 cm length with 1.3 to 1.6 cm diameter x 7.6 cm pegs with end threaded	760-848	25	_

Source: Joshi (1981)

from the pinnacle. Often, the concave is perforated to enable the threshed product to drop by gravity into some sort of a collector and channelled out through the outlet. The cleaning unit in most mechanical threshing uses the difference in the aerodynamic properties of chaff and grain to separate between the two (Henderson and Perry, 1979).

2.8 Types of Mechanical Threshers

Different mechanical threshers have been developed by diverse researchers for threshing of various crops (Joshi, 1981). The types of threshers depend on the crop to be threshed. For rice, various throw-in threshers have been developed (De Datta, 1981). Also many handheld rice threshers are in existence (IRRI, 1974). In the throw-in threshers, the whole pinnacle is thrown into the machine. While in the handheld type, the pinnacle is held against the cylinder by hand. Some of the handheld threshers are pedal powered by the holder of the panicle, thus they use human power to operate.

For cereals, mechanical threshers are classified into axial-flow and cross-flow threshers. In the axial-flow threshers, the crop is made to flow along the longitudinal length of the cylinder. This is to allow for multiple impacts between the cylinder and the concave as the crop is moved along the length of the cylinder. This is said to improve the threshing efficiency of the thresher (Simonyan and Imokheme, 2008). However, in the cross-flow threshers, the crop is threshed as they are forced to transversally move between the cylinder and the concave.

Threshers may also be categorized on the basis of the cylinder type. The cylinder may be spike toothed or rasp bar (Kepner *et al.*, 1972). In the spike-tooth thresher, an array of

spikes are arranged along the cylinder which impact the crop on the concave (Simonyan and Imokheme, 2008). But in the rasp bar, a flat-surface cylinder runs above the concave and the centrifugal force of the cylinder causes the crop to be threshed.

The number of operators and the source of power to run a thresher would depend on the capacity of the machine and its design (De Datta, 1981). While some threshers are pedal-type or hand operated using human power, other are powered by chemical energy from internal combustion engines. Not only that, there are effort to study thresher which are powered by electricity via electric motor (Kamble *et al.,* 2003). Harrington (1970) designed a multicrop thresher having spike-toothed cylinder and fixed concave on the basis of acceptance of the Japanese paddy threshers and American wheat threshers which used spike toothed cylinder. The clearance was kept at 2.5cm. The losses in paddy and wheat were both 3 %. The thresher was not suitable for straw making as it normally reduced wheat straw to 25-50 % of the original length depending upon cylinder speed and moisture condition.

2.9 Energy Needs for Threshing of Crops

Threshing of any crop can be done in any of three ways, namely, manually by human energy, by the drive of animal to tread on the crop to thresh or mechanically by means on an engine-powered machine. The kernels of the crops are bonded to the crop head by some forces which needed to be overcome in order to separate the kernel from the head. Esmay *et al.,* (1979) stated that the force needed to cause this detachment is dependent upon the kind of crop, the degree of ripeness of the crop and the kernel moisture content. They reveal that the retention forces vary with the size, form and structure of the plant tissue holding the kernels.

Casem and Khan (1968) stated that the force needed to separate the kernel/grains from the head can be given by:

$$F = KW_gRN^2 \quad 2.1$$

where:

F = threshing force in newton,

W_g = grain weight in kg,

R = average radius of head in m,

N = revolutions per second of the cylinder, and

K = coefficient of threshing depending on crop.

2.10 Limitations of Existing Threshers

The limitations of the currently existing threshers for diverse crops are scatter losses, damages and breakage of kernels and imperfection in the cleaning and threshing processes (Joshi, 1981 and Kamble *et al.,* 2003). De Datta (1981) stated that threshing losses vary with the thresher used and that some un-threshed grains are held either in the machine or discarded together with the straws. Joshi (1981) reported that in wheat threshing at 700 rpm and 63.5 mm peg spacing, the threshing efficiency, external damage, cleaning efficiency and separation losses were 99.63, 0.47, 96.47 and 2.4 % respectively. Verma *et al.,* (1978) conducted a survey on human accident in (wheat) threshers. They reported that accidents were highest for drum-type threshers. The number of accidents on spike-toothed threshers was the minimum. They suggested that an

improved design of feeding chute for safe feeding of the crop in threshers. Joshi (1981) reported that in a study by Ramos (1975) five types of threshers were evaluated; the types are:

i. single drum-no blower-no no separator type,
ii. double drum- single blower with oscillating separator type,
iii. double drum-single blower without oscillating separator type,
iv. axial flow thresher, and
v. single drum-single blower with oscillating screen type

In the test, according to Joshi (1981), un-threshed loss was high in threshers type I, II and V. At IRRI (1963), a cone-type thresher was designed, fabricated and tested which showed that the principle of cone-type thresher was sound and gave a maximum output of 300kg per hour using a 6 horsepower engine. The centrifugal nature of the cone thresher resulted in increased friction on the screen and drag on the drum, creating a high power requirement. Complete threshing was achieved, but even a 4.5 square meter screen did not fully separate the grains from the straw. Efforts were made to improve the cone thresher (IRRI, 1970, 1973, 1974). The cone thresher gave a high threshing output but the grain cleaning performance was not satisfactory (Joshi, 1981).

CHAPTER THREE

3.0 MATERIALS AND METHODS

The materials used and methods followed in the determination of physical properties of pearl millet grains and the design and performance evaluation of the developed thresher are as described in this chapter.

3.1.0 Determination of physical properties of grains

To determine the size of millet grains, 50 units grains were randomly selected from each sample of the cleaned grains at the moisture contents of 7.8, 9.7, 10.3 and 11.6 %. For each grain selected, three principal linear dimensions were measured using a vernier calliper of sensitivity of 0.01 mm. From the length (L), width (W) and thickness (T) of the grains measured, the geometric mean diameter (D_g) was determined from the equation given by Mohsenin (1980) and Baryeh (2002) as:

$$D_g = (LWT)^{\frac{1}{3}} \quad 3.1$$

where D_g = geometric mean diameter in mm,

L = Length of grains in mm,

W = width of grains in mm and,

T = grains thickness in mm.

The sphericity was determined from the equation given by Mohsenin (1980) and Baryeh (2002) as:

$$\varphi = \frac{D_g}{L} \quad 3.2$$

where φ = Sphericity,

D_g = geometric mean diameter in mm and,

L = grain length in mm.

The surface area (S) was found from the equation given by McCabe *et al.,* (1986) and Baryeh (2002) as:

$$S = \pi D_g^2 \quad 3.3$$

where S = surface area in mm^2 and

D_g = geometric mean diameter in mm.

The computation of volume (V) of grains was done using the equation given by Mohsenin (1980) as:

$$V = \frac{\pi}{6} D_g^3 \quad 3.4$$

where V = volume in mm^3.

The 1000 unit mass (M_{1000}) was determined using mettle electronic balance of accuracy of 0.01g. One thousand unit grains were carefully counted out from a cleaned sample of millet grains at 9.7 % grain moisture content and weighed in the balance. The process of determining the 1000 unit mass (M_{1000}) was repeated three times and the average of the masses was found.

3.1.1 Determination of densities of the millet grains

Bulk density of millet grains was determined by weighing the mass and measuring the height and diameter of an empty container. The mass was taken using an electronic balance of sensitivity of 0.01 gramme. The mass and volume of the empty container were found to be 24 gramme and 500 cm^3 respectively. The weighed container was then filled with cleaned millet grain from a height of 150 mm above the top of the container. The mass of filled container was also taken and the procedure repeated five times and the average calculated. The bulk density was determined from the equation given by Alonge and Adegbulugbe (2005) as:

$$\rho_b = \frac{M_1 - M_2}{V} \qquad 3.5$$

where ρ_b = bulk density in g cm^{-3},

M_1 =mass of filled container in gramme,

M_2 = mass of empty container in gramme, and

V = calculated volume of container in cm^3.

The true density (ρ_t) of the grains was determined by the water displacement method as described by Mohsenin (1980). The weight of the container containing distilled water was measured and recorded as W. The weighted grain was gently filled into the container of water, allowing the water to spill in to a basin. The experiment was done as snappy as possible to minimize the absorption of water by the grains. The true density was found as the ratio of the mass of grain to the volume of water displaced (Pradhan *et al.*, 2013).

The porosity of the grains was determined based on the relationship given by Mohsenin (1980) and Baryeh (2002) as:

$$\rho_O = 1 - \frac{\rho_b}{\rho_t} \quad 3.6$$

where ρ_O = porosity,

ρ_b =bulk density in g cm^{-3}, and

ρ_t =true density in g cm^{-3}.

3.1.2 Determination of angle of repose of grains

The angle of repose of the grains was determined by using an open ended cylinder of 150 mm diameter and 500 mm height in accordance to the procedure given by Bart-Plange and Baryeh (2002) and Pradhan *et al.,* (2013). The open container was filled with millet grains on a smooth concrete surface. The container was gradually raised so that a conical heap of the grain was formed on the surface. The height and diameter of the cone were determined using a vernier's calliper of sensitivity of 0.01 mm. The procedure was repeated five times and the angle of reposed (θ) was calculated from the relation given by Davies (2009) as:

$$\theta = \tan^{-1}\{\frac{2H}{D}\} \quad 3.7$$

where θ = angle of repose in degree,

H = vertical height of conical heap of grains in mm, and

D = the diameter of base of cone formed.

3.1.3 Coefficient of friction of grains with difference materials

The coefficients of friction of millet grains with respect to four surfaces namely wood, glass, metal sheet and aluminium were determined. The materials were selected because they are often used in the design of equipment and machines for handling and processing the grains. Each of the surfaces (in turns) was put in a rectangular box and sample of grains packed on the surface. The platform on which the surface was placed was gradually inclined until the grains started to slide down. The angle of tilt (α) was read from the scale attached to the side of the platform according to the procedure used by Davies (2009). The coefficient of friction is the inverse of tangent of the angle of tilt (α).

3.2 Design Considerations

The following factors were put into consideration in the design of the thresher

i. Diesel engine of 4.25 horsepower was used to power the thresher after completion. The choice of diesel engine was to give room for the usage of the thresher in the remotest villages where main supply is not yet available and to make the use of the machine possible in case of power outage in places connected to national grid.
ii. The materials used for the construction of the thresher were available in the local market so that the developed thresher was made affordable to peasant farmers. However, engineering standards and specifications were by no means or in any way compromised in the design and construction of the machine
iii. Technical conditions were dependent on the moisture content of the crop, the peripheral speeds of the cylinder and the blower and the feed rate of the thresher

iv. Emphases were placed on the impact-force required to thresher the kernels of the millet from the pinnacles while the differences in aerodynamic properties of the kernels and chaff were utilised to separate the kernels from the chaff.

v. The optimum reciprocating frequency of the shaker for millet cleaning was considered as 500 rpm in accordance to Kamble *et al.,* (2003) and Gbabo *et al.,* (2013).

vi. The required force for detaching kernels from pinnacles was deemed achievable by the mere robbing and squeezing actions of the crop between the cylinder and the concave along the axis of the cylinder.

vii. The total height of the machine was chosen as 1.2 m so as to allow for its convenient operation by an average height person.

viii. The size and total weight of the machine were considered for easy loading into a tractor trailer and other similar transportation facilities.

ix. The feeding chute was made in such a way as to minimise accident on the fingers of the operator as the thresher is being feed manually.

3.3 Selection of Materials for the Thresher

The machine was designed and constructed from locally available materials. The selection of materials for the construction of the thresher was based on the design considerations. The components of the machine were constructed from mild steel materials of various sizes and shapes. These materials were selected based on the strength and rigidity that is required by each component and also on the availability of the material in local market. Mild steel metal of gauge 16 was used for the shaker, while the blower blade and casing were constructed from mild steel sheet metal of gauge 18.

Standard mesh wire gauze of size 4 mm openings was used in making the sieve. The used mesh gauze was simply the available size in the market with openings approximate to the dimensions of millet grain. Pulleys sizes were selected based on the speed ratio requirement.

3.4 Instrumentation and Test Materials

The quartz stopwatch was used for measurement of time during the performance evaluation of the machine. A digital tachometer (*DT 2235B*) was used to determine the peripheral speed of the cylinder and electronic balance of sensitivity of 0.01 kilogrammes was used in weight measurements. The commonest available variety of pearl-millet (Ex-Borno) commonly called "gero" in Nigeria was used for the evaluation. Ex-Borno was used because it is one of the varieties often planted by local farmers (Ojediran *et al.*, 2010).

3.5 Determination of Moisture Content

The moisture contents of the millet were determined using the standard oven-dried method in accordance with the ASAE (1998). The initial and final weights of the millet before and after oven drying were measured using the electronic balance. The threshed millet grains were oven dried at 105 °C to 24 hours (Ndirika, 1994). Three levels of crop moisture contents were used for the performance evaluation of millet thresher. The moisture contents were 7.8, 9.7 and 10.3 % dry basis. These moisture contents were the natural moisture contents of the crop at the time the thresher was ready for evaluation on completion of its construction. The highest moisture content of 10.3 % (dry based) was the moisture content of crop during the three days of the performance test of the thresher.

The other two crop moisture contents of 7.8 and 9.7 % were the moisture content of the crop at two and a week after the first moisture contents respectively. The entire crop used for the evaluation was bought from local farmers at Shanono local government area of Kano state.

The expression used for the determination of the moisture contents as give by Mohsenin (1980) is:

$$M = \frac{W_1 - W_2}{W_2} X\ 100 \qquad 3.8$$

where, M = crop moisture content (%),

W_1 = weight of grains before oven-drying in grammes

W_2 = weight of grains after oven-drying in gramme.

3.6 Determination of Cylinder Speed

The cylinder speeds of the thresher during its evaluation were determined using the tachometer. This tachometer has the sensitivity of one revolution per second. The thresher was evaluated at four levels of cylinder speed of 300, 400, 500 and 600 revolutions per minute; these correspond to peripheral speed of 5.5, 7.3, 9.2 and 11.0 ms^{-1} respectively. This range was selected based on the speed required to cause threshing of the crop without unnecessary overrunning the thresher. Running the thresher at a speed below 5.5 ms^{-1} would not achieve effective threshing of the crop. And running it at speed above 11.0 ms^{-1} may only cause wastage of energy without corresponding increase in threshing efficiency but would also accelerate depreciation of the thresher.

3.7 Determination of Feed Rate

The feed rate of the developed thresher was determined by measuring out 1.0, 1.5, 2.0 and 2.5 kilogrammes of the unthreshed pearls millet at the moisture contents considered. These masses of the unthreshed crop were measured using the E200 electronic balance. The times to feed in the various masses of the pearl millet were measured by using a quartz stopwatch and each was converted into kilogramme per hour. The feed rates of 60, 90, 120 and 150 kg hr^{-1} were therefore used for the evaluation of the thresher. These feed rates were selected based on the mass of unthreshed crop that a man can manually feed into the thresher through the chute per unit time.

3.8 Concave Clearance and Sieve Size

Concave clearance of 5 mm was used in the design of the thresher and the same cylinder-concave was maintained throughout the performance evaluation of the thresher. This is in accordance with the recommendation of Kamble *et al.,* (2003) of 5 mm cylinder clearance for the best output in millet threshing. Also the sieve size of 4 mm opening was used for the thresher based on available gauze size at the local market. Although the findings from the physical properties and also by Ojediran *et al.,* (2010) gave the largest axial dimension of millet as about 5 mm at the highest moisture content for which the thresher was evaluated.

3.9 Machine Design

In the design of the components of the machine, the following major components were considered.

3.9.1 Determination of pulley dimensions

For the determination of sizes of driving and driven pulleys, the equation 3.9 given by Hannah and Stephen (1984) was used as:

$$N_1 D_1 = N_2 D_2 \qquad 3.9$$

where:

N_1 = speed of drive pulley in rpm

N_2= speed of driven pulley in rpm

D_1 =diameter of drive pulley in mm and

D_2 =diameter of driven pulley in mm.

Four pulleys were used on the thresher: there are two pulleys on the cylinder-drum shaft, one pulley each on the fan and the reciprocating shafts. Based on equation 3.9 and the pulley sizes on the cylinder-drum, the fan and the reciprocating shaker shafts were determined as shown below based on the schematic diagram of the transmission.

3.9.1.1 *Determination of the cylinder shaft driven pulley size*

From the Figure 3.1:

$$N_1 D_1 = N_2 D_2$$

$$D_2 = \frac{N_1 D_1}{N_2}$$

where;

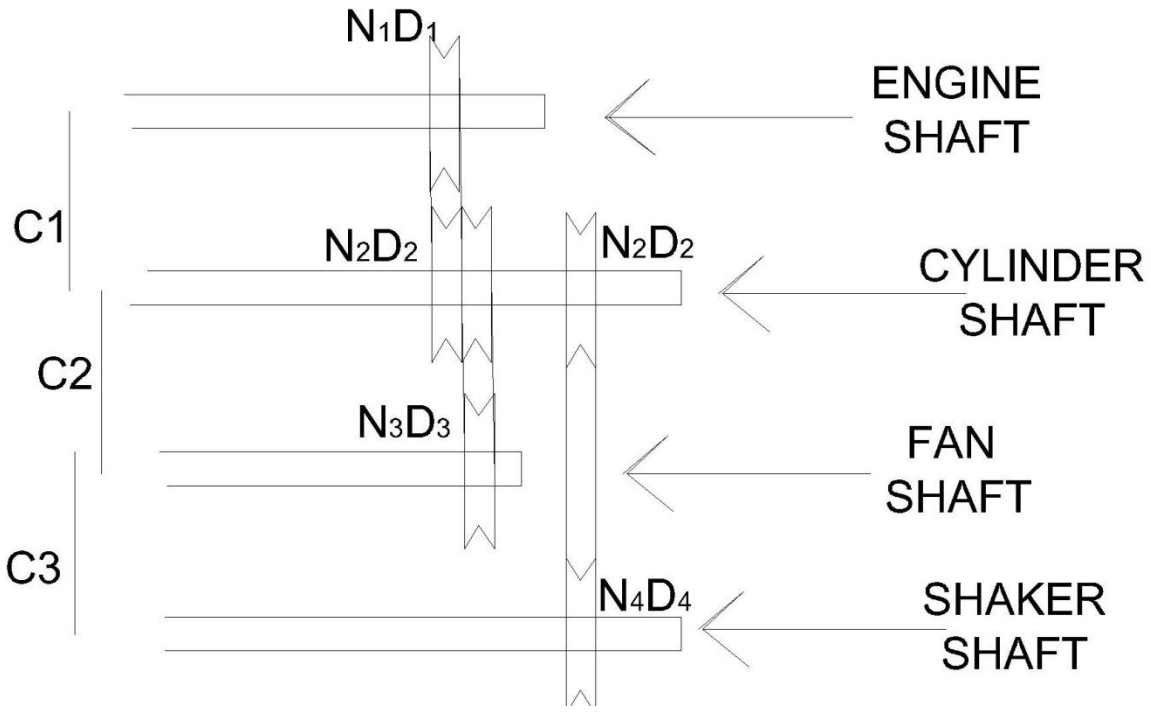


Figure 3.1 Schematic diagram of the machine transmission system

N_1 = 2000 rpm

N_2 = 900 rpm

D_1 = prime mover pulley size = 104 mm

Therefore D_2 = diameter of pulley on cylinder = 231 mm

But a pulley of 230 mm diameter was used on the cylinder shaft.

3.9.1.2 *Determination of the fan shaft driven pulley size*

$N_2D_2 = N_3D_3$

$$D_3 = \frac{N_2D_2}{N_3}$$

where;

N_3 = 1900 rpm

D_3 = diameter of pulley size on fan shaft = 109 mm

But a pulley of 110 mm diameter was used on the fan shaft.

3.9.1.3 *Determination of the shaker shaft driven pulley size*

$$D_5 = \frac{N_4 D_4}{N_5}$$

where :

N_4 = 2000 rpm

D_4 = 30 mm

N_5 = 300 rpm

D_5 = diameter of pulley size on shaker shaft = 200 mm

But a pulley size of 205 mm was used because it was the size found in local market.

3.9.2 Determination of belt length

The lengths (L) of belts used in the design of the thresher were obtained as (Khurmi and Gupta, 2007):

$$L = \frac{\pi}{2}(D + d) + 2C + \frac{(D - d)^2}{4C} \qquad 3.10\ A$$

$$L = \frac{\pi}{2}(D + d) + 2C + \frac{(D + d)^2}{4C} \qquad 3.10\ B$$

where:

C = distance between drive and driven pulleys in mm

D=diameter of drive pulley in mm and

d= diameters of the driven pulleys in mm.

The equations 3.10 A and 3.10 B above were used for the determination of the length of belts used on the thresher. While equations 3.10 A was used for calculating length of open belts, equation 3.10 B was used for the crossed belt. A cross belt was used between the prime mover and the cylinder-drum in order to get the desired direction of rotation of the cylinder-drum so as to minimize scatter losses of threshed grain from the hopper.

3.9.2.1 *Length of cross belt between prime mover and cylinder pulleys*

From the schematic diagram (Fig 3.1)

$$L_1 = \frac{\pi}{2}(D_1 + D_2) + 2C_1 + \frac{(D_1 + D_2)^2}{4C_1}$$

D_1 = diameter of prime mover pulley = 104 mm

D_2 = diameter of cylinder shaft pulley = 230 mm

C_1= distance between the centres of prime mover and cylinder pulley = 550 mm substituting

$$L_1 = \frac{\pi}{2}(104 + 230) + 2x450 + \frac{(230 + 104)^2}{4x450}$$

L_1 = 1486.62 mm

L_1= cross belt between prime mover and cylinder = 1486.62 mm (A57´ Belt obtained from market was used).

3.9.2.2 *Length of open belt between cylinder and fan pulleys*

$$L_2 = \frac{\pi}{2}(D_2 + D_3) + 2C_2 + \frac{(D_2 - D_3)^2}{4C_2}$$

D_2 = diameter of cylinder pulley = 230 mm

D_3 = diameter of fan pulley = 110 mm

C_2 = distance between the centres of cylinder and the fan pulleys = 645 mm

substituting,

$$L_2 = \frac{\pi}{2}(230 + 110) + 2x645 + \frac{(230 - 110)^2}{4x645}$$

L_2 = 1829.65 mm

L_2= open belt between cylinder-drum and fan pulleys = 1829.70 mm (A72´ Belt obtained from market was used).

3.9.2.3 *Length of open belt between cylinder and reciprocating unit's pulleys*

$$L_2 = \frac{\pi}{2}(D_4 + D_5) + 2C_2 + \frac{(D_5 - D_4)^2}{4C_2}$$

D_4 = diameter of small cylinder pulley = 30 mm

D_5 = diameter of shaker pulley = 205 mm

C_3 = distance between the centres of cylinder and the shaker pulleys = 880 mm

substituting,

$$L_3 = \frac{\pi}{2}(30 + 205) + 2x885 + \frac{(205 - 30)^2}{4x885}$$

L_3 = 2147.70 mm

L_3 = open belt between cylinder drum and reciprocation unit's pulleys =2147.70 mm (A85´ Belt was obtained from market was used)

3.9.3 Determination of angle of lap of belts on pulley

For the purpose of determining the angle of lap (θ) of belt on pulleys the equations below as given by Khurmi and Gupta (2007) were used as: While Equations 3.12A and 3.12B were used for open and cross belts respectively.

$$\theta = (180 - 2\alpha)\frac{\pi}{180} \qquad 3.11$$

$$\alpha = \sin(\frac{D-d}{2C}) \qquad 3.12A$$

$$\alpha = \sin(\frac{D+d}{2C}) \qquad 3.12B$$

where:

D = diameter of larger pulley in mm

d= diameter of the smaller pulley in mm and

C= the distance between the centre of the two pulleys in mm. Both open and cross belts were used in the design of the machine.

θ_1= angle of contact at the drum's pulley = 3.67 rad.

θ_2= angle of contact at the fan and the drum = 2.86 rad.

θ_3 = angle of contact at the cylinder and shaker= 3.79 rad.

3.9.4 Determination of belt tensions

For the determination of tensions in belt, the equations 3.13 and 3.14 below as given by Khurmi and Gupta (2007) were solved simultaneously as:

$$P = (T_1 - T_2)V \qquad 3.13$$

$$\frac{T_1}{T_2} = e^{\mu\theta \operatorname{cosec}\beta} \qquad 3.14$$

where:

T_1 and T_2 are the tension (in newton) on the tension and slack sides of the belt respectively N = speed of prime mover in rpm,

d = diameter of pulley in metre,

θ = angle of lap (in radian) as given by equation 3.11,

μ= coefficient of friction between belt and pulley materials were obtained from Kkurmi and Gupta (2007) and given on Table 3.1, and

β = 20 ° as given by Khurmi and Gupta (2007).

Where linear velocity V, is given as:

$$V = \frac{\pi dN}{60} \qquad 3.15$$

where N = number of revolution per minute.

Table 3.1 Values of coefficients of friction used between belts and pulleys

Pulley number	**Material from which pulley was make**	**Pulley Description**	**Coefficient of friction, μ**
1	Cast iron	Cylinder-drum Pulley driven by prime mover	0.27
2	Cast metal	Cylinder pulley driving the shaker system	0.27
3	Steel metal	Fan pulley drivien by Pulley 1 above	0.32
4	Cast metal	Shaker pulley driven by pulley 2	0.27

Source: Khurmi and Gupta (2007)

3.9.5 Determination of weight of fan

From Hannah and Stephen (1984) and Mohammed (2009), the weight of fan is given by

$$W = \delta g v \quad 3.16$$

where:

W = weight in newton

δ=density of fan blade material in kg m^{-3},

δ=7850 kg m^{-3}(as given by Khurmi and Gupta, 2007 for mild steel sheet material)

g = the acceleration due to gravity in ms^{-2} and

v = the volume of the material used for the fan construction in m^3

Four (4) blades each of volume 30 x 12 x 1.5 mm^3 was used in construction of the fan.

Thus, weight of fan W = 166 newtons ≈ 170 N

Similarly, the force required for reciprocating mechanism was gotten as 400 N.

3.9.6 Determination of fan air discharge rate

According to Joshi (1981), the air discharge (Q) by a blower is given by

$$Q = V \times D \times w \quad 3.17$$

where:

Q= air discharge in m^3s^{-1}

V= the air velocity in ms^{-1},

D= the depth of flow above the reference point in metre and

w = the width over which air is required in metre.

3.9.7 Determination of power required in fan and shaker mechanism

Power required in fan P_F = force x velocity (V_F)

$$= 170 \text{ X } V_F$$

Peripheral velocity of fan, $V_F = \pi DN/60$

$$= \pi \times 0.11 \times 1882 \div 60$$

$$= 10.84 \text{ ms}^{-1}$$

Therefore, Power in fan $P_F = 170 \times 10.84$

$$= 1800 \text{ W}$$

Peripheral velocity of shaker pulley $= \pi \times 0.21 \times 126 \div 60$

$$= 1.386 \text{ ms}^{-1}$$

Therefore power required for reciprocation $P_R = 400 \times 1.386$

$$= 554.4 \text{ W}$$

Total power required by fan and shaker reciprocation = 2354.4 W

3.9.8 Determination of total torque and power in thresher

The torque required for fan and shaker was gotten from the expression given by Khurmi and Gupta (2007) as:

$$T = \frac{60P}{2\pi N} \qquad 3.18$$

where;

T = Torque on fan and shaker pulley in Nm

P = power requires to drive fan and shaker in watt

N = speed of revolution in rpm

Torque in fan and shaker pulleys, $T = \frac{60 \times 2354.4}{2\pi\ x\ 900}$ = 25 Nm

$$\text{Power required in cylinder drum} = \frac{2\pi NT}{60}$$

$$= \frac{2\pi\ X\ 900\ X\ 25}{60}$$

= 2357.14 W

3.9.9 Determination of tensions in belts

Tension in fan belt is gotten by solving equation 3.13 and 3.14 simultaneously

where μ = 0.32, θ = 2.86 rad, V= 10.84 ms^{-1}, β =20° and P =1800 W

Therefore T_{F1}= 178.42 N and T_{F2} =12.28 N

where T_{F1} and T_{F2} are the tensions in the tight and slack sides of the belt linking cylinder shaft to fan shaft respectively. The belt driving the fan, on the developed thresher, was inclined at 63° to the horizontal. Thus the vertical component of the sum of the tensions of the blower belts is 169.91 N. And the horizontal component is 86.58 N.

Similarly, Tension in belt of Shaker mechanism is gotten from solving equation 3.13 and 3.14 simultaneously,

where $\mu = 0.27$, $\theta = 3.08$ rad, $V = 1.39\ ms^{-1}$, $\beta = 20°$ and $P = 554.4$ W

Therefore $T_{R1} = 437.29$ N and $T_{R2} = 38.46$ N

where T_{R1} and T_{R2} are the tensions in the tight and slack sides of the belt linking cylinder shaft to shaker shaft respectively.

Also, Tension in belt from prime mover is gotten from solving equation 3.13 and 3.14 simultaneously,

where $\mu = 0.27$, $\theta = 3.79$ rad, $V = 10.84\ ms^{-1}$, $\beta = 20°$ and $P = 2357.14$ W

Therefore $T_{M1} = 228.28$ N and $T_{M2} = 11.48$ N

where T_{M1} and T_{M2} are the tensions in the tight and slack sides of the belt linking the prime mover to the cylinder shaft respectively.

3.9.10 Determination of reactions in bearings supporting drum

Total vertical force on cylinder pulley = weight of pulley + summation of vertical tensions in all belts

= 20 + 169.91 + 38.46 + 437.29 + 11.46 + 228.28

= 905.4 N

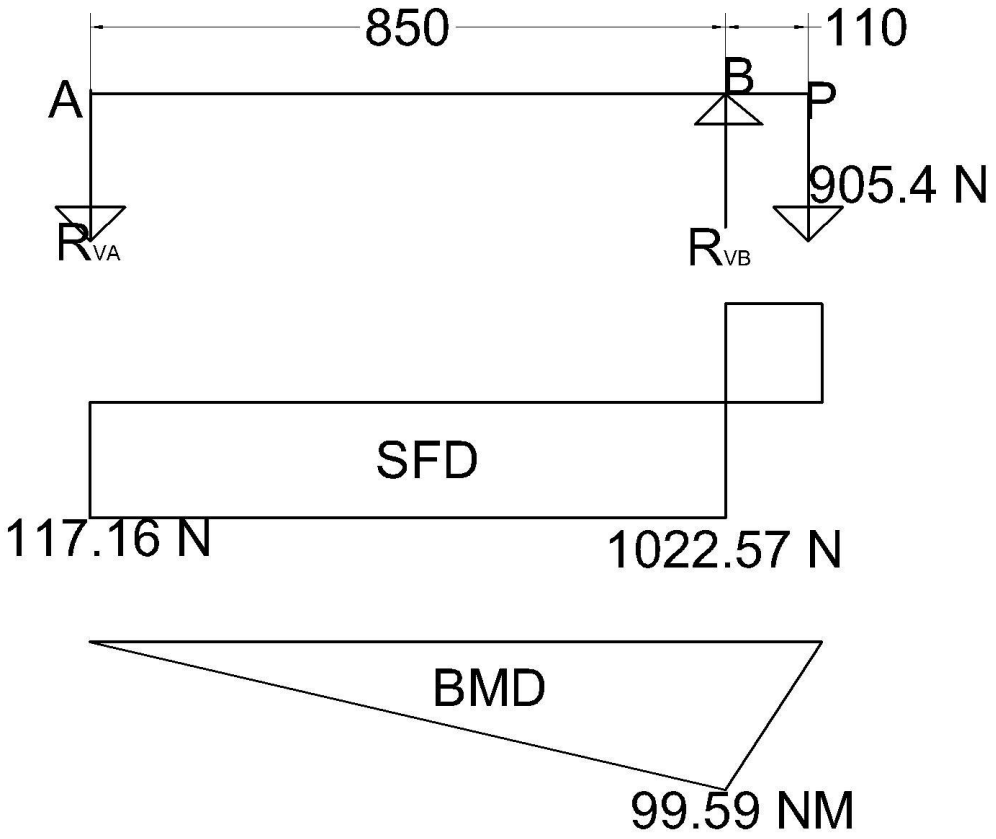


Figure 3.2 Schematic diagram of vertical forces on cylinder shaft, the SFD and BMD

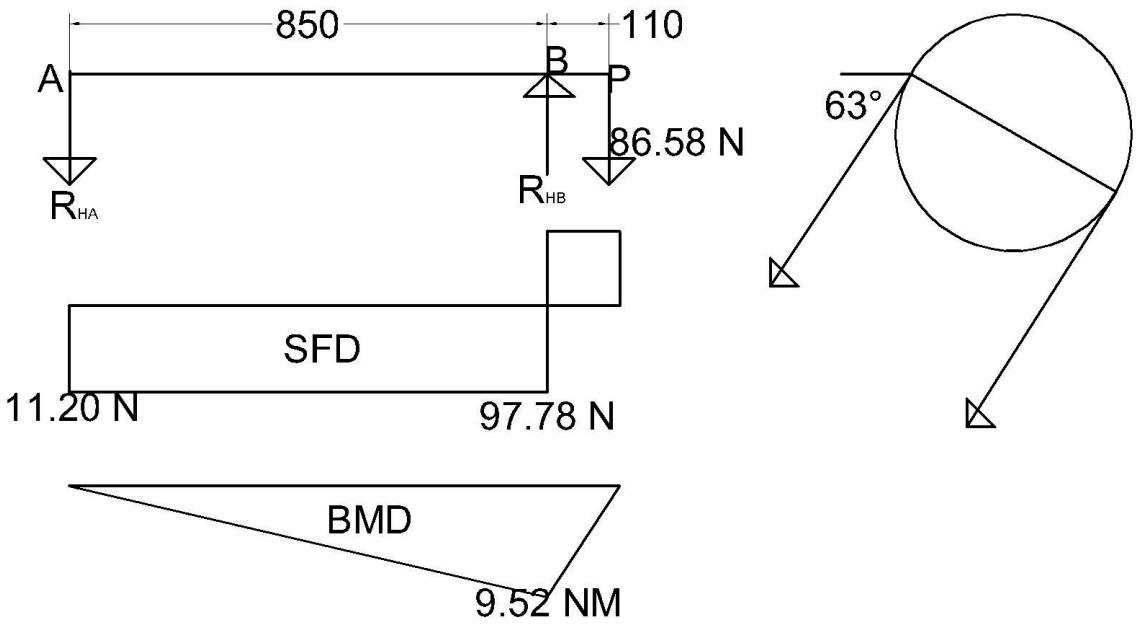


Figure 3.3 Schematic diagram of horizontal forces on the cylinder shaft, the SFD and BMD

3.9.10.1 *Vertical component of reactions on bearings*

Taking moment about A, and solving

R_{VA} = 1022.57 N and R_{VB} = 117.16 N

where, R_{VA} and R_{VB} are reactions at bearings A and B as shown in Figure 3.2

3.9.10.2 *Horizontal component of reactions on bearings*

Horizontal force was caused by the inclination of belt at 63° to the vertical.

The only horizontal force was cause by the inclination of the belt for fan = 190.70 N

Taking moment about A (Figure 3.3), the farther bearing from cylinder pulley P, and solving

R_{HA} = 11.20 N and R_{HB} = 97.78 N

3.9.11 Determination of bending and torsional moments

Resultant Moment $M_b = \sqrt{(9.52^2 + 99.59^2)}$

= 100.04 Nm

Torsional Moment $M_t = \frac{60P}{2\pi N}$ = 25 Nm

3.9.12 Determination of cylinder shaft diameter

In the determination of the shaft of thresher, which is a major component of the machine, its diameter was obtained using the equation 3.18 as give by Khurmi and Gupta (2007) as:

$$D^3 = \frac{16}{\pi s_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad 3.19$$

where:

D = diameter of shaft to be determined in metre,

K_b and K_t are the combined shock and fatigue factors for bending and torsional moments and are taken as 2.5 and 2.0 respectively as given by Khurmi and Gupta (2007).

M_b and M_t are the maximum bending and torsional moments in newton metre (Nm) respectively, and

S_s is the allowable stress in the shaft material in newton per square millimetre (N mm^{-2}).

Taking permissible tensile stress S_s as 40 N mm^{-2}

$$D^3 = \frac{16}{\pi \times 40}\sqrt{(2.5 \times 100.04 \times 1000)^2 + (2.0 \times 25 \times 1000)^2}$$

D^3 = 32 473.85 mm^3

D = 32 mm.

Therefore, diameter of main shaft was taken as 35 mm.

3.9.13 Determination of diameter of reciprocating mechanism

From Section 3.9.9, the tension in the belt linking cylinder to shake shaft are gotten as

T_{R1} = 437.29 N and T_{R2} = 38.48 N for tight and slack sides of the belt respectively.

Thus, Torque on Pulley T = (T_{R1} – T_{R2}) x Radius of pulley

= (437.29 – 38.48) x 205/2

= 40, 878.03 N mm

Designing the shaft using twisting moment only, and using the equation as give by Khurmi and Gupta (2007):

$$T = \frac{\pi}{16} \tau\, d^3 \qquad 3.20$$

where τ = allowable torsional shear stress in the shaft = 40 N mm^{-2} and,

d = diameter of solid shaft

$$40,878.03 = \frac{\pi}{16}\, x40\, x d^3$$

d^3 = 5204.75 mm^3

d = 17.33 mm

Designing the shaft based on tortional rigidity, and using the equation as given by Khurmi and Gupta (2007):

$$J = \frac{Tx\ L}{G\ x\ \theta} \qquad 3.21$$

where θ = tortional defection or angle of twist in radians,

T = Twisting moment or torque on the shaft,

J = Polar moment of inertia of the cross-sectional area about the axis of rotation,

$$J = \frac{\pi}{32}\ x\ d^4 \qquad 3.22$$

G = Modulus of rigidity of shaft materials

Khurmi and Gupta (2007) gave the ratio of L/θ as 3° per metre length of shaft and G as 84 000 N mm^{-2}.

Thus, $\frac{\pi}{32}\ x\ d^4 = \frac{40{,}878.03\ x1000\ x\ 60}{\pi\ x\ 84{,}000}$

d^4 = 94, 669.95 mm^4

d = 17.54 mm

Hence either way, the diameter of the reciprocating shaft is 17.5 mm but 20.0 mm shaft was used in the thresher.

3.9.14 Determination of diameter of fan shaft

Torque T_F in fan shaft = (T_{F1} – T_{F2}) x Radius of fan pulley

where T_{F1} = tension of tight side of belt = 169.91 N

T_{F2} = tension of slack side of belt = 86.58 N and

Radius of pulley = 105/2 = 52.5 mm

Therefore, T_F = 4374.83 N mm

The vertical forces on the fan shaft are as shown in figure 3.5 and the maximum vertical moment = 2382.16 N mm.

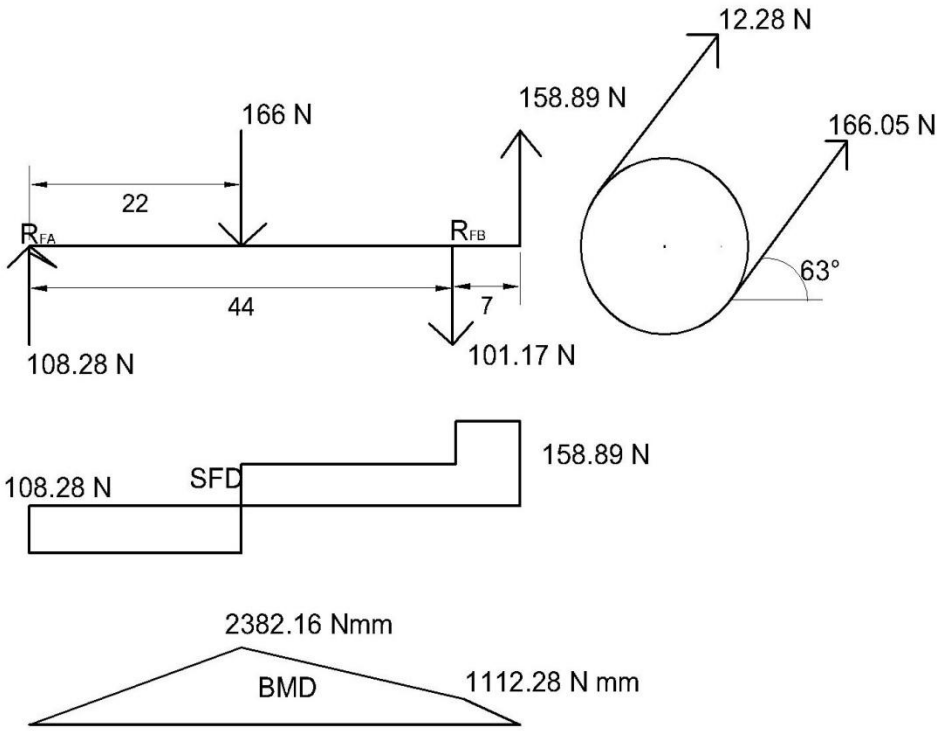


Figure 3.4 Schematic diagram of vertical forces on the fan shaft, its SFD and BMD

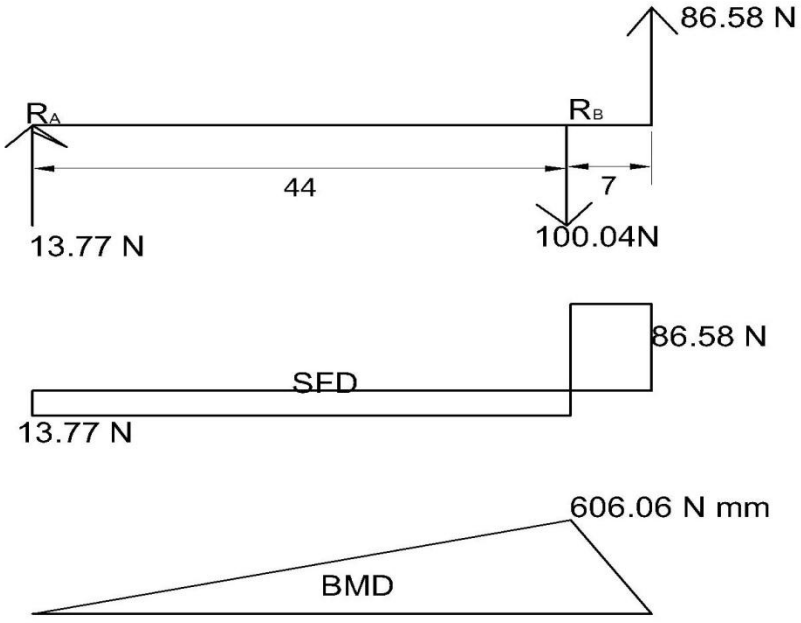


Figure 3.5 Schematic diagram of horizontal forces on fan shaft, its SFD and BMD

Similarly, the horizontal forces on the fan shaft are as shown in Figure 3.5 and the maximum horizontal moment = 606.06 N mm.

Thus, the total moment T_e at 22 mm from A = $\sqrt{(2382.16^2 + 302.94^2)}$

T_e = 2401.34 Nmm

but $T_e = \frac{\pi}{16} x \tau x d^3$ and τ = 40 N mm^{-2}

Therefore d =6.74 mm

Thus 10 mm shaft was used for the fan

3.10 Cost of Production of the Thresher

Table 3.2 shows the cost of production of the developed axial-flow thresher. It shows the cost of purchase of the components of the thresher per unit quantity and the amount spent on each component. The sum of ₦55 750:00 was used to produce the thresher at the prevalent market price of October 2014. If the costs of labour and other exigencies was taken as 20% of the cost price and the purchased of prime mover to power the thresher are needed, then the cost of the thresher would amount to ₦ 102 900:00 only.

3.11 Working Principle and Description of the Thresher

The pinnacles of the pearl millet to be threshed are fed into the thresher through the chute in Appendix 5. The fed ear-heads are threshed in the threshing chamber by robbing, beating and squeezing actions between the cylinder and the concave. The stationary concave and rotating cylinder make up the threshing chamber. The cylinder rotates on the

Table 3.2 Cost of production of the developed thresher

S/No	Material Description	Quantity	Unit Cost (₦)	Amount (₦)
1	Mild steel sheet 3 mm thick	1	6,500.00	6,500.00
2	Mild steel sheet 1.5 mm thick	1	6,000.00	6,000.00
3	50 × 50 × 5 mm angle iron	2	4,700.00	9,400.00
4	40 × 40 × 3 mm angle iron	$1\frac{1}{2}$	4,000.00	6,000.00
5	40 mm diameter shaft (960 mm)	1	4,800.00	4,800.00
6	40 mm diameter shaft (800 mm)	1	3,000.00	3,000.00
7	10 × 10 square rod	$1\frac{1}{2}$	1,400.00	2,100.00
8	25 mm rasp bar	$\frac{1}{2}$	1,500.00	750.00
9	Electrode G12	1 packet	1,300.00	1,300.00
10	230 mm diameter pulley	1	2,500.00	2,500.00
11	210 mm diameter pulley	1	2,500.00	2,500.00
12	110 mm diameter pulley	1	1,500.00	1,500.00
13	25 × 5 flat bar	1	1,200.00	1,200.00
14	Pillow Bearing	6	1,200.00	7,200.00
15	M10 bolt & nut	50	10.00	500.00
16	Wire gauze	$\frac{1}{2}$ yard	1,000.00	500.00
	SUB-TOTAL			55,750.00
17	Miscellaneous & Labour cost 20 % of sub-total			11,150.00
18	Prime mover	5 hp	36,000.00	36,000.00
TOTAL				**102,900.00**

frame by means of ball bearing supporting the cylinder on the frame. The threshed grains and chaff and other impurities fall through the perforated cylinder by gravity on mesh gauze acting as sieve. While on the mesh gauze, air from the fan housed in blower casing blows off the chaff and other lighter materials than the grains from the thresher to the opposite side of the chute inlet and the grain outlet. The reciprocating movement of the sieve aided by the camshaft attached to the shaker pulley enhances the thorough cleaning of the grains. The kernels are collected from the grain outlet as shown Appendix 5. The isometric view of the machine is shown in Appendix 5. It also shows the materials and the quantities of the material used for making each component of the machine. While Appendix 6 shows the plan, front and side views of the machine in first angle projection.

3.12 Performance Evaluation Parameters of the Millet Thresher

In order to evaluate the performance of the millet thresher, some selected evaluation parameters were considered. The threshing efficiency was used to determine how effectively the thresher was in carrying out its primary function of threshing the millet. The cleaning efficiency was used for the evaluation of the ability of the thresher to clean the crop effectively. The throughput capacity was used to evaluate for how fast the developed axial-flow thresher can perform its given task of threshing and cleaning the millet (*pennisetum glacum*). Also the amount of mechanical grains damage and the scatter loss by the thresher were considered in order to extensively and intensively assess the developed machine.

3.12.1 Threshing efficiency (T_E)

Threshing efficiency (T_E) is defined as the percentage ratio of the threshed grain to the total quantity of sample grain after a threshing process. It is given by Ndirika (1994) and Gbabo *et al.*, (2013) as:

$$T_E = 100 - \frac{Q_U}{Q_T} \times 100 \qquad 3.23$$

where:

T_E= threshing efficiency in percentage,

Q_U =unthreshed quantity of grains in a sample in kg, and

Q_T = the total quantity of grains (kg) threshed and unthreshed in the sample.

3.12.2 Cleaning efficiency (C_E)

Cleaning efficiency (C_E) is the ratio by weight of the grains collect at grain outlet to the total weight of the chaff and grains collect at the same outlet expresses as a percentage. It was expressed by Ndirika (1994) and Gbabo *et al.*, (2013) as:

$$C_E = \frac{(W_t - W_c)}{W_t} \times 100 \qquad 3.24$$

where:

C_E = Cleaning efficiency in percent

W_t = total weight at the outlet in kilogramme and

W_C= chaff weight at the outlet in kilogramme.

3.12.3 Mechanical grain damage (M_D)

Mechanical grain damage was used to determine the quantity of visible physical damage or breakage done to grains that can be owed to the thresher. The mechanical grain damage as given by Ndirika (1994) and also Mohammed (2009) as:

$$M_D = \frac{Q_b}{Q_t} \times 100 \qquad 3.25$$

where:

M_D = Mechanical grain damage (in percent),

Q_b = the quantity of damage grains in kilogramme, and

Q_t = total weight of grains in the sample (kg).

3.12.4 Scatter loss (S_L)

During the threshing operation, some grains were lost as scatter loss from the pearl millet thresher and were not collected with others at the grains outlet. This was evaluated from an equation Ndirika (1994) and Gbabo *et al.*, (2013) give as:

$$S_L = \frac{Q_l}{Q_t} \times 100 \qquad 3.26$$

where:

S_L = Scatter loss expressed as a percentage,

Q_l =the quantity of grains scattered from machine in kilogramme, and

Q_t =total quantity of sample grains in Kilogramme.

3.12.5 Throughput capacity (T_C)

The machine throughput capacity was given by from Ndirika (1994) and Mohammed (2009). It is the amount of the actual cleaned grain that a machine is able to thresh per time.

$$T_C = \frac{Q_s}{T} \qquad 3.27$$

where:

T_C = Throughput capacity expressed in kilogramme per minute (kg min^{-1})

Q_S =quantity of grains collect at the grain outlet in kilogramme and

T = time taken to thresh in minutes.

The throughput was however converted to kg hr^{-1} in order to determine the quantity of grain that the thresher was able to process per hour.

3.13 Design of Experiment and Analysis of Data

Randomized complete block design (RCBD) was used in the experiment for the evaluation of the performance of the thresher. Three levels of moisture content (M_1, M_2 and M_3), four levels of feed rate (F_1, F_2, F_3 and F_4) and four levels of cylinder speed (S_1, S_2, S_3 and S_4) at a fixed cylinder-concave clearance of 5 mm considered. The layout of 3x4x4 experiment is shown in Appendix 1; each experiment was replicated three times. The levels of independent variables are shown in Table 3.3.

The effects of the variation of each of three independent factors and their interactions on the performance of the developed axial-flow pearl millet thresher were evaluated using

the analysis of variance (ANOVA). The ANOVA was used to verify if the effect of changing the variables is significant or not at two levels of significance (5% and 1%). Appendix 2 shows the format of the randomized complete block design used for the ANOVA. The performance parameters were evaluated in accordance with stated standard and procedure of ASAE (1998). Plates I and II show the thresher during its performance evaluation.

Table 3.3 Levels of independent variables used in the thresher's evaluation

	Variable	**levels of variation**
1	Crop moisture content, %	7.8, 9.7, 10.3
2	Feed rate, Kg hr^{-1}	60, 90, 120, 150
3	Cylinder speed, ms^{-1}	5.5, 7.3, 9.2, 11.0



Plate I: The thresher during its performance evaluation

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The results of the physical properties of millet grains and the performance evaluation of the developed thresher are discussed in this chapter.

4.1 Physical Properties of Pearl Millet

The result of the physical properties of the pearl millet (*Pennisetum glaucum*) is shown in Table 4.1. The table shows the results of three axial dimensions (length, breadth and thickness), geometric mean diameter, sphericity, surface area and volume of the crop at the various moisture contents. The length of the crop ranged from 2.31 to 5.19 mm depending on moisture content of the crop. The mean of the length increased from 3.42 to 4.02 mm as the moisture content of the crop increased. This implies that as the moisture content of the crop increased, the water content in the cells of the grain cause its length to increase. Ojediran *et al.,* (2010) got a similar trend for the length of the same variety (ex-borno) and reported a range of 3.16 to 3.80 mm. The difference in the values obtained is treaceable to the source of the variety used. While Ojediran *et al.,* (2010) used sample obtained from Lake Chad Research Institute (LCRI), the sample used in this study was source from local farmer in Shanono area of Kano state. Baryeh (2002) got a value range of 3.48 to 4.28 mm for the length of another variety of pearl millet (*pennisecum gambiense*). The values obtained by Baryeh (2002) are within those gotten in this evaluation.

Table 4.1 shows that the breadth of the crop ranged from 1.40 for the minimum value at 10.3 % moisture content to 2.97 mm at 11.6 % moisture content with the mean values at

Table 4.1 Physical properties of pearl millet grains

	Moisture (%)	Sample size	Mean Value	Min Values	Max Values	Std Dev	CV (%)
Length (mm)	7.8	50	3.41	2.31	4.94	0.42	12.20
	9.7	50	3.81	2.86	4.97	0.42	11.13
	10.3	50	3.83	2.30	5.18	0.59	15.35
	11.6	50	4.02	3.03	5.19	0.54	13.63
Breadth (mm)	7.8	50	2.05	1.64	2.54	0.24	11.59
	9.7	50	2.18	1.72	2.81	0.28	12.78
	10.3	50	2.27	1.40	2.94	0.35	15.57
	11.6	50	2.28	1.65	2.97	0.35	15.33
Thickness (mm)	7.8	50	1.95	1.57	2.42	0.21	10.84
	9.7	50	2.02	1.57	2.68	0.22	10.99
	10.3	50	2.10	1.15	2.75	0.35	16.75
	11.6	50	2.05	1.54	2.80	0.31	14.96
Diameter (mm)	7.8	50	2.38	1.83	2.80	0.21	9.00
	9.7	50	2.56	2.13	3.18	0.31	9.10
	10.3	50	2.62	1.67	3.20	0.32	12.02
	11.6	50	2.65	2.02	3.50	0.31	11.86
Sphericity (%)	7.8	50	70.32	50.82	84.18	0.06	8.94
	9.7	50	67.49	55.92	86.73	0.06	9.70
	10.3	50	69.32	47.04	86.76	0.09	13.26
	11.6	50	66.49	48.36	86.05	0.07	10.53
Area (mm^2)	7.8	50	18.06	10.57	24.72	3.21	8.94
	9.7	50	20.70	14.33	31.77	3.82	18.49
	10.3	50	21.91	8.72	32.09	5.00	22.84
	11.6	50	22.38	12.93	38.49	5.37	24.03
Volume (mm^{-3})	7.8	50	7.29	3.23	11.56	1.92	12.20
	9.7	50	8.87	5.10	16.84	2.53	14.33
	10.3	50	9.82	2.42	17.09	3.24	32.95
	11.6	50	10.16	4.37	22.45	3.73	36.75
P_b (kg m^{-3})	9.7	5	0.73	0.71	0.74	8.99	1.23
P_t (kg m^{-3})	9.7	5	1.14	1.13	1.16	0.01	1.0
P_o (%)	9.7	5	36.18	35.64	36.70	1.32	1.32
θ (°)	9.7	5	24.57	22.47	26.03	1.34	5.47
Glass		5	0.34	0.33	0.36	0.01	3.81
Metal	9.7	5	0.35	0.34	0.37	0.01	3.11
Aluminum		5	0.36	0.35	0.37	0.01	2.31
wood		5	0.40	0.39	0.43	0.02	3.75

the various moisture contents indicated against each. The mean values of the breadth of the crop increased with moisture content. This implies that the more the amount of water in the grain the larger its breadth. Ojediran *et al.,* (2010) and Baryeh (2002) also reported increase in breadth of the grains with increase in moisture content. Thus the result of the finding of this research agrees with those of the named researchers. Ojediran *et al.,* (2010) got a range of values of 2.30 to 2.66 mm which is within the values obtained in this work. The thickness of the millet grain at the various moisture contents are as given on table 4.1. The thickness of the crop ranged from 1.15 to 2.80 mm. The mean of the thickness of the crop increased with increase in moisture content. The mean thickness varied from 1.95 at 7.8 % moisture content to 2.10 mm at 10.3 %. Baryeh (2002) reported a thickness range of 2.23 to 3.00 mm. This difference in values is due to difference in the varieties evaluated. However, Ojediran *et al.,* (2010) got a range of 1.54 to 1.64 for the same variety used for this evaluation. Both Baryeh (2002) and Ojediran *et al.,* (2010) reported that the thickness of millet increases with rise in moisture content.

From Table 4.1, the sphericity of pearl millet was found to range from 0.66 to 0.71. Baryeh (2002) got sphericity range of 0.78 to 0.80 and Ojediran *et al.,* (2010) obtained a range of 0.66 to 0.70. Hence the result of the sphericity gotten in this study is within those obtained by both Baryeh (2002) and Ojediran *et al.,* (2010). The result implies that the sphericity of millet increases with increase in moisture content. The grain surface area increased with rise in the moisture content of the crop as shown in table 4.1. The mean of the grain surface area increased from 18.06 to 22.38 mm^2 with the respective standard deviation indicated at each moisture contents. Baryeh (2002) reported increased surface area with increase in crop moisture content and a value range of 23.53 to 33.51 mm^2. The

higher range of surface area reported by Baryeh (2002) is cause by the difference in the varieties used in the two evaluations. Jain and Bal (1997) also found that the grain surface area of a different pearl millet (*pennisetum typhoides*) variety to be 16.38 at 7.4 % grain moisture content (Baryeh, 2002). The volume of the pearl millet (*Pennisetum glaucum*) evaluated was found to increase from 7.30 mm^3 at 7.8 % crop moisture content to 10.16 mm^3 at 11.5 % moisture content. Baryeh (2002) got a volume range of 8 mm^3 at 5 % crop moisture to 15 mm^3 at 22.5 % crop moisture content. Apart from the difference in the varieties, the crop moisture content evaluated also contributed to the difference in the values obtained in the two cases. Jain and Bal (1997) found the volume of pearl millet evaluated to be 5.79 mm^3 at 7.4 % grain moisture content.

4.1.1 Result of one thousand unit mass and densities of millet grains

The 1000 grain mass (M_{1000}) of the millet grain was determined at 9.7 % crop moisture content and found to have an average value of 10.10 gramme. Jain and Bal (1997) found that the 1000 grain mass of *pennisetum typhoides* at 7.4 % grain moisture content was 9.19 gramme. Ojediran *et al.,* (2010) found 1000 grain mass of the same variety evaluated in this work to be 7.3, 9.08, 9.99 and 10.06 gramme at 10, 13, 15 and 20 % crop moisture content respectively. Thus the result found here is within the range gotten by Ojediran *et al.,* (2010). However, comparing the result obtained with that of Ojediran *et al.,* (2010) at 10 % crop moisture, the locally sourced variety has greater mass than that sourced from Lake Chad Research Institute (LCRI) used by Ojediran *et al.,*(2010). The mean bulk density of the Exborno variety of pearl millet was found to be 731.36 kg m^{-3}. This result falls within the range of 646.4 to 811.4 kg m^{-3} obtained by Ojediran *et al.,* (2010). Baryeh (2002) found that the bulk density of p*ennisetum gambience* another

variety pearl millet to peak at about 10 % crop moisture content and have the value of 730 kg m^{-3}. Thus the result of this work for bulk density conforms to those of Baryeh (2002) and Ojediran *et al.,* (2010).

The solid density of pearl millet at 9.7 % moisture content was found to be 1146 kg m^{-3}. This result is slightly above the value of 958.1 kg m^{-3} reported by Ojediran *et al.,* (2010) for the same variety millet at 10 % crop moisture content. The difference between the one thousand unit mass (M_{1000}) of the variety is responsible for difference in the bulk density at relatively similar moisture content. Porosity of the pearl millet grains evaluated was found to be 36.18 % at 9.7 % crop moisture content. Baryeh (2002) found the porosity of another variety of pearl millet to be 48.5 % at 10 % crop moisture content. Ojediran *et al.,* (2010) got a porosity of 15.17 % at 10 % crop moisture content. Jain and Bal (1997) found the porosity to be 48.8 % at 7.4 % grain moisture content for a variety. Porosity depends on true and bulk densities, thus the difference in its values is due to the difference in the values of true and bulk densities.

The average value of angle of repose is shown on table 4.1 and gotten as 24.57° at 9.7 % crop moisture content. Ojediran *et al.,* (2010) reported an angle of repose of 32.69 ° at 10 % crop moisture content, while Baryeh (2002) got angle of repose of 40 ° at the same crop moisture content for another pearl millet variety. The difference in angle of repose is due to difference in surface roughness of the grains based on variety and/or source of the samples.

The coefficient of friction of the crop with glass, mild steel, aluminium and wood at 9.7 % crop moisture content are gotten as 0.342, 0.352, 0.362 and 0.404 respectively. The

result is arranged in increasing order of the coefficient of friction of the material. Thus the coefficient of friction of the crop changes with the surface material on which the grains were placed. But Ojediran *et al.,* (2010) reported values of 0.391, 0.418 and 0.418 for glass, aluminium and steel respectively. The trend is due to the increasing order of roughness of the surfaces.

4.2 Effect of Feed Rate at Different Moisture Contents on Threshing Efficiency

Figure 4.1 shows the threshing efficiency as affected by feed rate at the various moisture contents. The threshing efficiency at 7.8 % moisture content gave the highest value at all the feed rates evaluated. The threshing efficiency at 7.8 % moisture content increased from 94.7 % at 60 kg hr^{-1} feed rate to 95.6 % at 150 kg hr^{-1}. At 9.7 % moisture content, the threshing efficiency ranged from 89.5 at 90 kg hr^{-1} feed rate to 94.7 % at 120 kg hr^{-1} feed rate. The threshing efficiency at 10.3 % crop moisture content is 91 % at all feed rates. The equation at each of the moisture content and the coefficient of determination are given. The general trend is that the threshing efficiency increased with decrease in moisture content. This is because the dryer the crop, the lower the amount of energy needed to detach the kernels from the stock. This trend was similar to the one obtained by Gbabo *et al.,* (2013). The rate of increase in efficiency per increases in feed rate at the various moisture content were 1.6, 2.9 and 0.5 % at the corresponding moisture content of 7.8, 9.7 and 10.3 % moisture contents respectively.

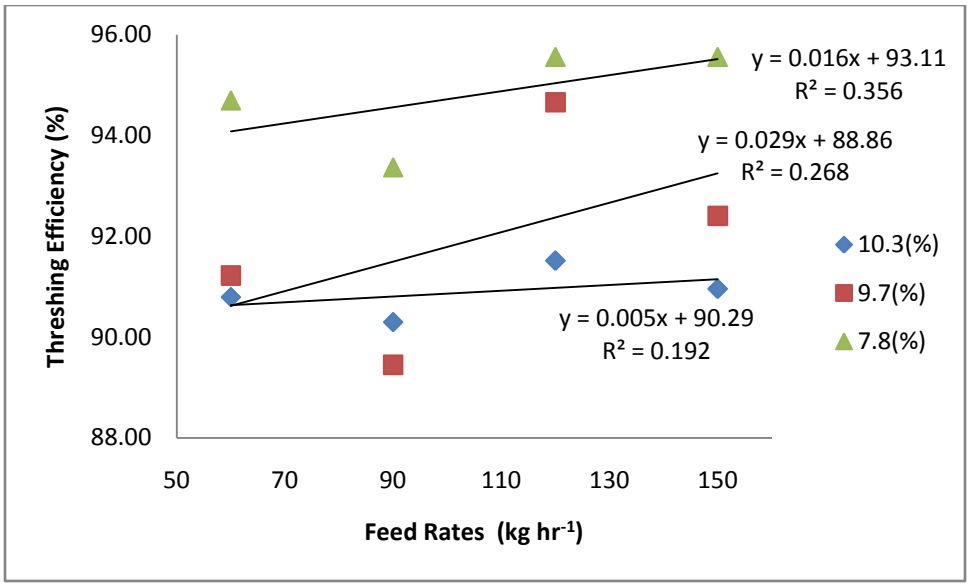


Figure 4.1 Threshing Efficiency as affected by Feed Rate at various moisture contents

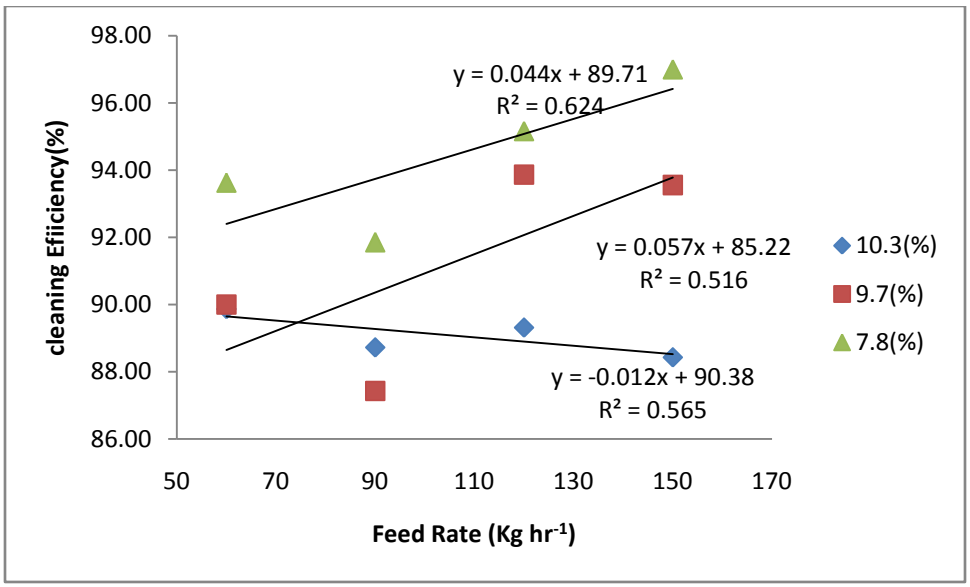


Figure 4.2 Cleaning Efficiency as affected by Feed Rate at the moisture contents evaluated

4.3 Effect of Feed Rate at Different Moisture Contents on Cleaning Efficiency

Figure 4.2 shows the cleaning efficiency as affected by the feed rate at the various moisture contents. At 7.8 % crop moisture content, the cleaning efficiency increased from 93.6 % at 60 kg hr^{-1} feed rate to 97 % at 150 kg hr^{-1}. Also at 9.7 % crop moisture content, the cleaning efficiency increased from 90 % at 60 kg hr^{-1} to 93.6 % at 150 kg hr^{-1}. Thus at 7.8 % and 9.7 % there was increased cleaning efficiency with increase in feed rate. But at 10.3 % the cleaning efficiency decreased with feed rate. The cleaning efficiency decreased at 10.3 % moisture content because more energy was needed to separate the chaff from the grains at higher moisture content than at lower moisture contents. Gbabo *et al.,* (2013) obtained that cleaning efficiency decreased with moisture content of millet. Abolaji (1980) also obtained that cleaning efficiency increased with decrease in moisture content of millet. Thus the result of the research agrees with those of Gbabo *et al.,* (2013) and Abolaji (1980).

4.4 Effect of Feed Rate at Different Moisture contents on Scatter loss

Figure 4.3 shows scatter loss as affected by feed rate at the various moisture content of the crop. The highest amount of scatter loss which range from 30 to 37 % occurred at 10.3 % crop moisture content. While the least percentage scatter loss was at 9.7 % crop moisture and it varied from 26 % to 17 % as the feed rate decreased. At all the moisture contents, the scatter losses were high, above 17 %. This high value of scatter loss was not due only to the air from the fan. But it is also due to largeness of the dimension of the grains at high moisture content. The large size of the grains at high moisture content

make some of the grains too large to pass through the openings gauze of the sieve, thereby making such large grains to run off on the sieve until they fall off as scatter loss. Baryeh (2002) and Ojediran *et al.,* (2010) reported that the dimensions of grains increased with the increase in their moisture content. Thus the result of the inability of the large grains to fall through the sieve holes at high moisture content resulted in an increase in the scatter loss at high moisture content of crop. Hence the inference is that the high scatter loss at high moisture content resulted from both the inability of the grains to fall through the sieve holes (from as a result of the large grain size) and from the air blowing off the grain from the thresher. At each of the crop moisture content, the highest feed rate of 150 kg hr^{-1} gave the lowest value of scatter loss percent. For instance the moisture content at 9.7 % crop moisture decreased from 24 % at 60 kg hr^{-1} feed rate to 17 % at 150 kg hr^{-1} feed rate at the same moisture content. Gbabo *et al.,* (2013) also evaluated millet thresher and got a scatter loss in the range of 36.8 to 51.68 %.

4.5 Effect of Feed Rate at Various Moisture Contents on Mechanical Grain Damage

Figure 4.4 shows the relationship between the mechanical grain damage at the feed rate. The highest evaluated moisture content of 10.3 % gave the least grain damage at all feed rates, while the moisture content of 9.7 % gave the highest values of grain damage at all feed rates. The mechanical grain damage increased with feed rate at all the moisture contents. The grain damage at 10.3 % moisture content increased from 2.38 to 2.64 % and from 2.67 to 2.80 % at the crop moisture content of 9.7 %. The increase in mechanical grain damage with increase in feed rate was caused by the presence of more materials in the threshing chamber with increase in feed rate. This makes the robbing

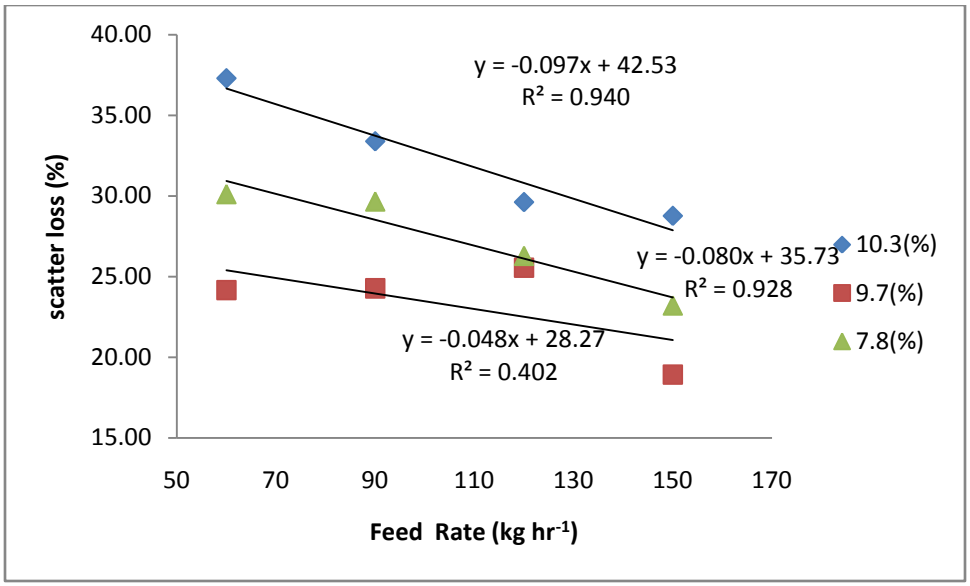


Figure 4.3 Scatter losses as affected by Feed Rates at various moisture contents

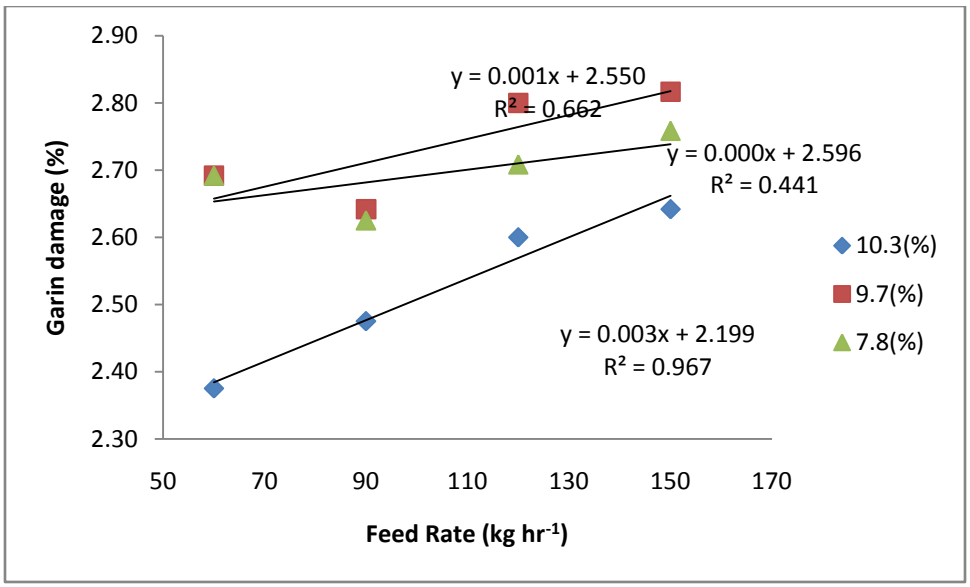


Figure 4.4 Grain Damage as affected by Feed Rate at various moisture contents

action of the cylinder on the grains to increase thereby increasing the amount of grain damage.

4.6 Effect of Feed Rate at Various Moisture Contents on Throughput Capacity

Figure 4.5 shows the throughput at the various feed rates at the moisture contents of crop. The throughput increased with increase in the feed rate for all the moisture contents. The throughput capacity at 10.3 % moisture content gave the lowest values at all the feed rates. This is attributed to the high amount of scatter loss which occurred at 10.3 % moisture content. Figure 4.3 shows that 10.3 % crop moisture content had the highest amount of scatter loss for all feed rates. The high amount of scatter loss lowers the throughput obtained at the moisture content. The moisture content at 9.7 %, which had the least proportion of scatter loss in figure 4.3, gives the highest value of throughput at all moisture contents. This implies that the lower the scatter loss, the higher the throughput. The general trend at the various moisture contents is that the throughput increased with increase in feed rate. The equations of the trend and coefficients of determination (R^2) at each moisture contents are shown on figure 4.5. The values of the R^2 of 0.989, 0.979 and 0.976 for 7.8, 9.7 and 10.3 % moisture contents respectively

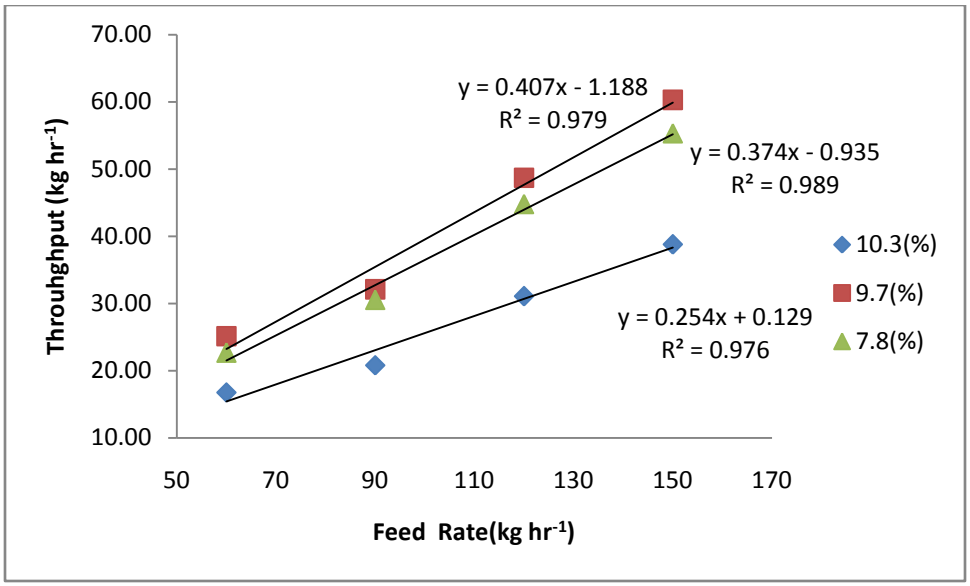


Figure 4.5 Throughput as affected by Feed Rate at diverse moisture contents

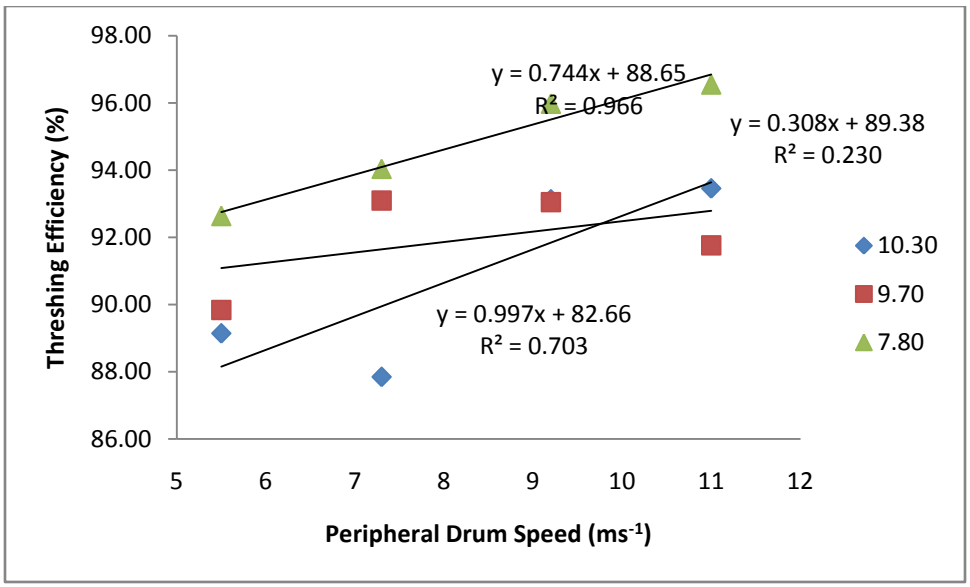


Figure 4.6 Threshing Efficiency as affected by Drum Speed at different moisture contents

show that there is a strong correlation between feed rate and throughput of the thresher. The least throughput of 17 kg hr^{-1} was gotten are 10.3 % moisture and 60 kg hr^{-1} feed rate. And the highest throughput of 60 kg hr^{-1} was obtained at the feed rate of 150 kg hr^{-1}.

4.7 Effect of Drum Speed at Various Moisture Contents on Threshing Efficiency

Figure 4.6 shows the effect of peripheral cylinder-drum speed on the threshing efficiency at the various moisture contents. At all peripheral speeds of the drum, 7.8 % moisture content of the crop gives the highest threshing efficiency. The lowest threshing efficiency of 88 % was obtained at cylinder speed of 7.3 ms^{-1} and 10.3 % crop moisture content. The highest efficiency was obtained as 96.5 % at 11 ms^{-1} peripheral speed of the drum. Essentially, the threshing efficiency at each moisture content increased with the peripheral speed of the drum. From the figure, the graph of moisture content of 7.8 % (dry basis) of crop gave the most linear graph with a coefficient of determination of 0.966. Ndirika (1994) also plotted a similar graph and got a positively sloped straight line. Abolaji (1980) plotted a similar graph and obtained a gradually increased line which ranged from 87.6 to 93 % threshing efficiency. And Abarchi (2011) plotted and got a similar trend where the threshing efficiency of threshed millet increased with cylinder speed.

4.8 Effect of Drum Speed at Various Moisture Contents on Cleaning Efficiency

Figure 4.7 shows the effect of the peripheral speed of the drum on the cleaning efficiency at the moisture contents. At all the three moisture contents of the crop, the cleaning efficiency increased with increase in the drum speed. The cleaning efficiency of 95 % was obtained at the peripheral speed of 11.0 ms^{-1} and 7.8 % crop moisture content. While

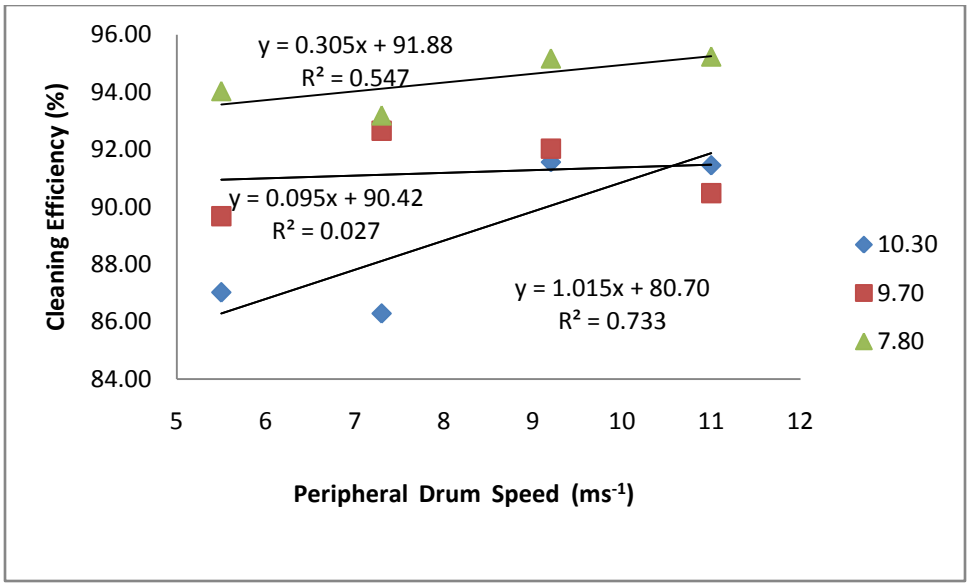


Figure 4.7 Cleaning Efficiency as affected by Drum Speed at different moisture contents

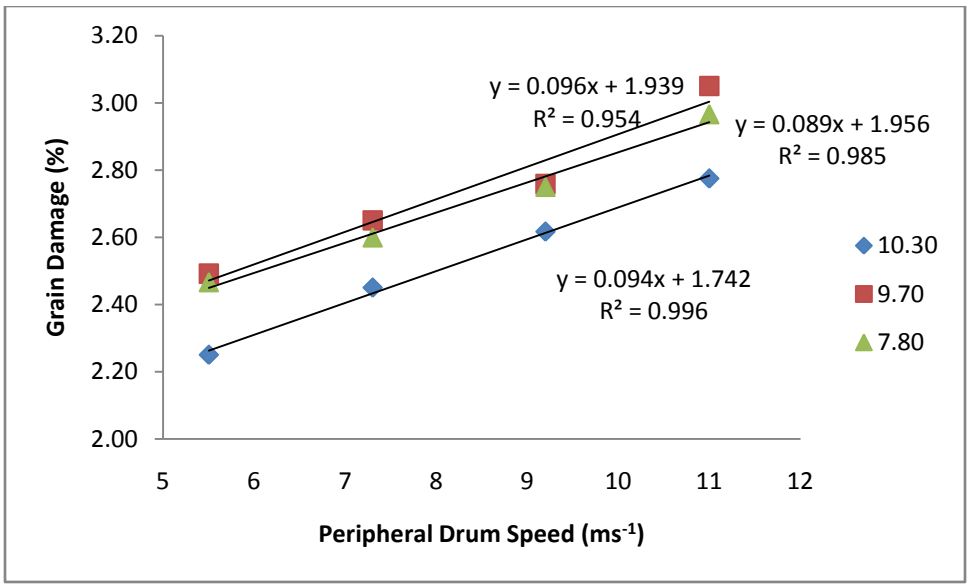


Figure 4.8 Grain Damage as affected by Drum Speed at various moisture contents

the least cleaning efficiency of 86 % was obtained at the speed of 7.3 ms^{-1} and 10.3 % moisture content. It implies that the highest value of cleaning was obtained at the least crop moisture and the highest speed of the drum. Ndirika (1994) plotted a similar graph where cleaning efficiency of millet increased with cylinder speed. Abarchi (2011) got a straight line graph when he plotted cleaning efficiency against speed of revolution of millet thresher and Abolaji (1980) result for a similar plot was not different from that gotten in this work.

4.9 Effect of Drum Speed at Various Moisture Contents on Mechanical Grains Damage

Figure 4.8 shows the effect of drum speed at various moisture contents on mechanical grains damage by the thresher. The three moisture contents of the crop evaluated gave separate layers on the plot, with the highest moisture content of 10.3% lying as the lowest line. The general trend on the figure is that the grain damage increased as the peripheral speed (ms^{-1}) of the thresher increased. The grain damage was lowest at the highest moisture content of the crop because the grains were more malleable at higher moisture content than at the lower moisture contents (Kamble *et al.*, 2003). However, the grains damage curves for the two lower moisture contents (7.8 and 9.7 %) are very close on the plot. The coefficient of determination (R^2) at each of the moisture content is at least 0.956 indicating that the mechanical grain damage and cylinder speed are correlated. The three moisture contents gave straight positively sloped curves. Thus, it can be drawn that there is a strong relationship between the running speed of the thresher and the amount of mechanical grains damage that can be owed to the thresher. Similar trend was obtained by Abolaji (1980) where the curve raised from 1.7 % at 750 rpm of the drum to 2.9% grain damage at 1250 rpm speed of drum. Abarchi (2011) also had the same trend on his

plot of mechanical grain damage against speed of cylinder. The ranged of mechanical damage for Abarchi (2011) was from 0.75 to 5 %.

4.10 Effect of Drum Speed at Various Moisture Contents on Scatter loss

Figure 4.9 is the plot of the percentage scatter loss against the peripheral speed of the cylinder drum at various moisture contents. It shows an increase in the scatter loss from the thresher with increase in drum peripheral speed at each of the moisture contents. The scatter loss incurred at 10.3% moisture content was the greatest at all speeds of the thresher, it ranged from 27.7 to 38.4 %. The line for 9.7 % crop moisture content lie as the lowest line. The scatter loss at that moisture content ranged from 17.8 to 27.8 %. The high scatter loss at the highest moisture content evaluated was due to the largeness of the grains dimensions at this moisture content; which caused the inability of the large grains not to fall through the sieve holes and also due to air discharge from the blower carrying off the grains with the chaff during cleaning. On comparing the two lower moisture content of the crop, it was observed that the lower the moisture content, the easier it was for the air discharge from the fan to carry off the grains from the thresher. Kamble *et al.*, (2003) expressed in a tabular form that scatter loss increases with increase in the feed rate. Gbabo *et al.*, (2011) reported that scatter losses are lowest at the lowest moisture content but decreased with speed. Thus, Gbabo *et al.*, (2011) reported that scatter losses were at the lowest at the least moisture content of the crop but decreased with increase in drum speed. Hence, Gbabo *et al.*, (2012) report on the relation

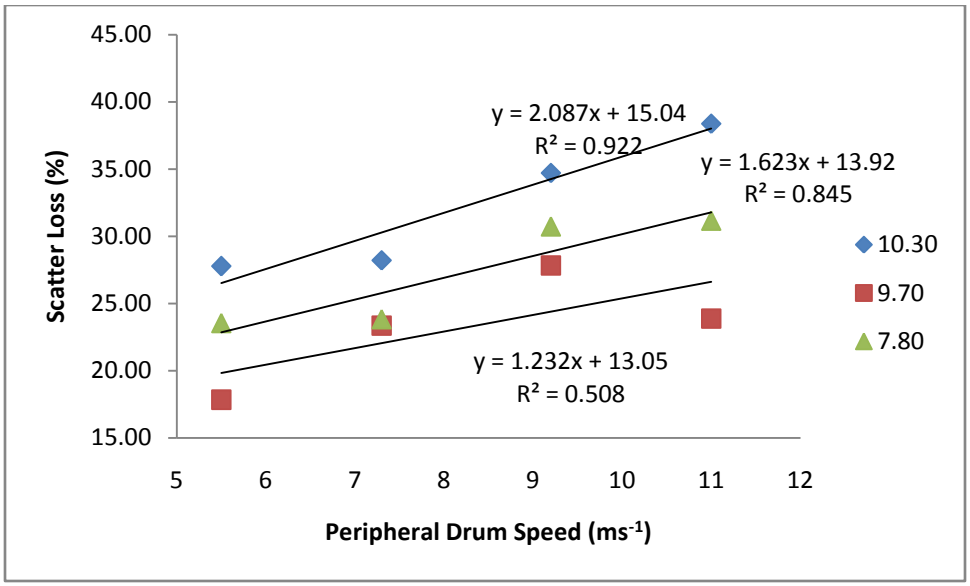


Figure 4.9 Scatter Loss as affected by Drum Speed at various moisture contents

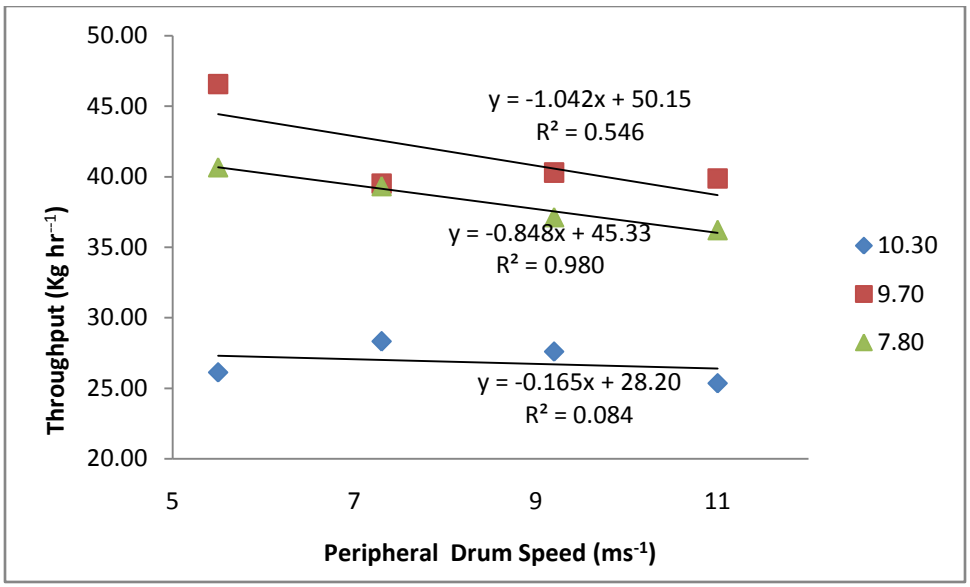


Figure 4.10 Throughput Capacity against Drum Speed at 3 levels of moisture content

between drum speed of the threshing and amount of scatter loss is in sharp contrast with that of this work.

4.11 Effect of Drum Speed on Throughput Capacity

Figure 4.10 shows the effect of the drum speed at the moisture contents on the throughput (in kilogramme per hour) of the thresher. The coefficient of determination (R^2) at the lowest crop moisture content gave the best value of 0.98, which indicates that the throughput is most dependent on the drum speed at the lowest moisture of crop. At 10.3 % crop moisture content, the throughput was lowest with the values of 27 kg hr^{-1}. While at 9.7% crop moisture content, the throughput had the greatest value and it ranged from 41 to 47 kg hr^{-1}. At all the three moisture contents the throughput decreased with increase in drum speed. However, Gbado *et al.*, (2011) reported that throughput capacity would increase with an increase in the operating speed of a thresher. But Figures 4.9 and 4.10, the moisture content with the highest amount of scatter loss gave the least amount of throughput. Thus the throughput at 10.3 % moisture content was lowest because it had the highest amount of scatter loss. And the throughput at 9.7 % moisture content was greatest because it had the least scatter loss. The throughput at all moisture content decreased because the amount of scatter losses increased with speed. The greatest value of throughput of 46.7 kg hr^{-1} was obtained at 9.7 % moisture content and 5.5 ms^{-1} cylinder speed.

4.12 Effect of Threshing Efficiency on the cleaning Efficiency

Figure 4.11 shows the plot of threshing efficiency against cleaning Efficiency. The plot shows that there is a linear relationship between the two efficiencies. The coefficient of

determination (R^2) of 0.8941 was gotten for the relationship. Thus given the cleaning efficiency, the threshing efficiency can be determined from the equation on the plot. The figure also shows the gradient between the efficiencies is 0.67 and the equation between the efficiencies is given on the plot. The intercept on the threshing efficiency axis is 31.13 % and the threshing efficiency increased with the cleaning efficiency. The relationship shows that similar trend of result are obtained for both efficiencies as the experimental factors are being varied.

4. 13 Relationship between Scatter loss and Throughput

Figure 4.12 is the graph of the percentage scatter loss of grain versus the throughput (kg hr^{-1}). The plot reveals that the scatter loss of the grains decreased with the throughput capacity of the thresher. The coefficient of determination (R^2) of 0.6385 was gotten for the relationship. The equation of the relationship between scatter loss and throughput is given on the graph and it indicates that a negative relationship exist between scatter loss and throughput. The curve indicates that the throughput capacity is inversely proportional to the scatter loss all through the performance evaluation of the machine.

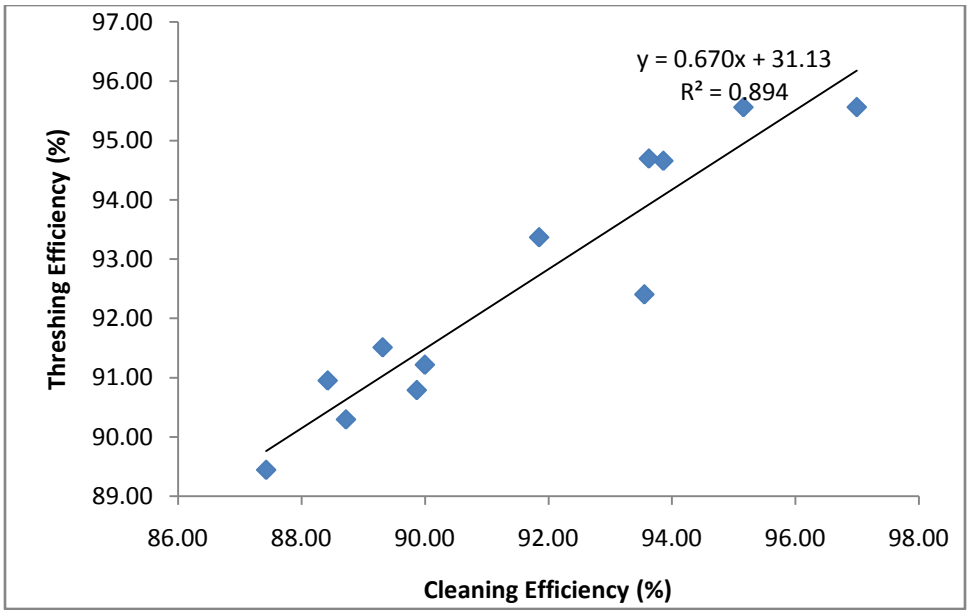


Figure 4.11 Correlation of Threshing Efficiency with Cleaning Efficiency

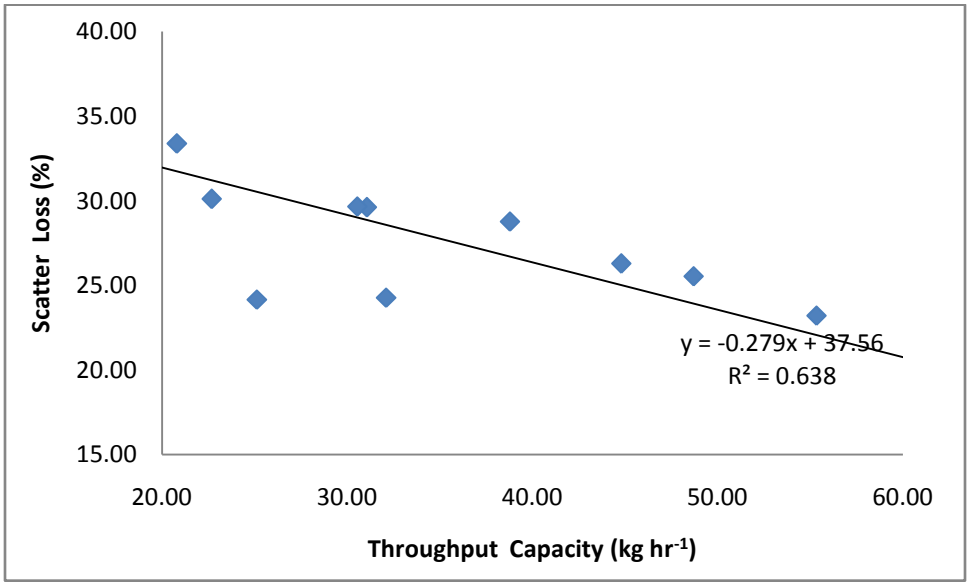


Figure 4.12 Correlation of Scatter Loss with Throughput Capacity

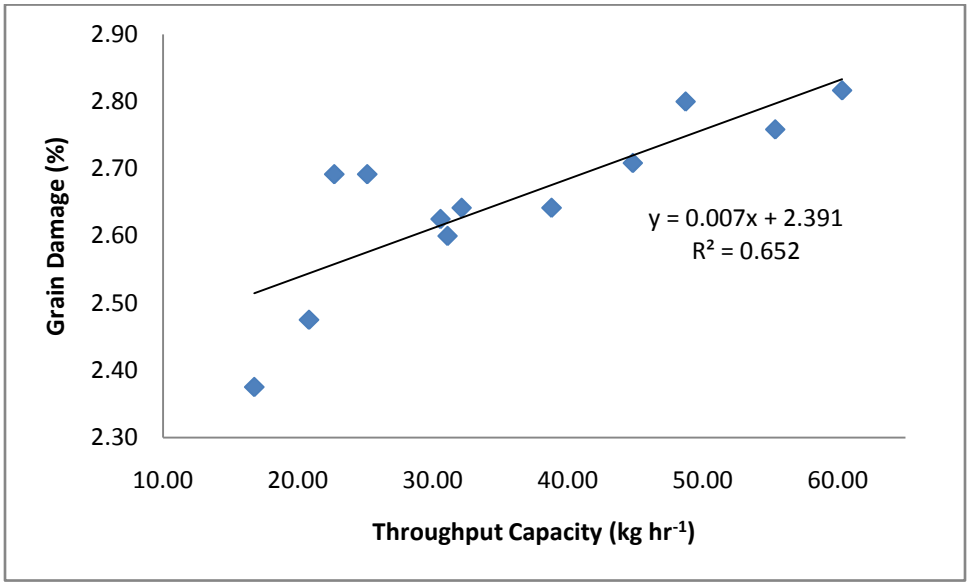


Figure 4.13 Correlation Grain Damage with Throughput Capacity

4.14 Regression of Throughput on Grain Damage

Figure 4.13 shows the relationship between throughput capacity (kg hr^{-1}) and grain damage percent. The graph shows that grain damage increased with throughput capacity with coefficient of determination of 0.65. The equation of the relationship indicating the gradient of 0.007 is given on the plot. While the plot shows that the grain damage ranged from 2.38 to 2.82, the throughput was from 16.7 to 60 kg hr^{-1}.

4.15 Analysis of Variance for Threshing Efficiency of Developed Thresher

Table 4.2 shows the result of the analysis of variance (ANOVA) for the threshing efficiency of the machine. From the table, there is no significant difference between any two of the interaction of the independent factors, neither is there significant difference in the interaction of the three experimental variables. This implies that none of the main effects is been influenced by the interactions of the independent variables. And hence, the results of the main effects or independent factors are reliable and free from the interactions of the factors in the experiments (Walpole *et al.*, 2007). From the ANOVA result, while all the combination of interaction are not significant, two of the main effects namely, crop moisture content and cylinder speed, are highly significant. As such, these two independent variables individually affect the threshing efficiency of the developed thresher but the interactions of these variables would not have effect on the efficiency. The ANOVA result shows that the F-calculated value for crop moisture content is 9.04 which is highly significant. This means that the threshing efficiency from the thresher depended on the moisture content of the crop. The cylinder speed F-calculated for the threshing efficiency has the value of 4.95. This is highly significant, which implies that the threshing efficiency changes with the cylinder speed. The feed rate F-calculated gave

a value of 2.42, which show that the feed rate is not significant to the threshing efficiency. However, the probability that the levels of the feed rate differ is 7.07 %. Thus the Duncan multiple range test was able to rank the four levels of the feed rates for the threshing efficiency. Kamble *et al.*, (2003) evaluated another pearl millet thresher while varying crop moisture content, cylinder speed, cancave clearance and feed rate. Kamble *et al.*, (2003) found that all the four main effects, the interactions of every two factors, every three factors and the interaction of all four factors are all highly significant for threshing efficiency of the thresher. Kamble *et al.*, (2003) also found that all the main effects were significant at 1 % level-a result capable of being influenced by the results of the interactions of the main variables (Walpole *et al.*, 2007).

Table 4.2 ANOVA of threshing Efficiency

Source of Variation	Degree of Freedom	Sum of squares	Mean Square	Computed F	Pr > F
Replication	2	760.42	380.21	17.30	< .0001
Moisture content, M	2	397.27	198.64	9.04**	0.0003
Feed rate, F	3	159.71	53.24	2.42 ns	0.0707
Speed, S	3	326.03	108.67	4.95**	0.0031
M x F	6	61.40	10.23	0.47 ns	0.8321
M x S	6	164.11	27.35	1.24 ns	0.2907
F x S	9	115.16	12.95	0.58 ns	0.8086
M x F x S	18	132.25	7.34	0.33 ns	0.9947
Errors	94	2065.37	21.97		
Total	143	4181.71			

ns = not significant, ** = significant at 1% level

Table 4.3 Duncan ranking of independent variables for threshing efficiency

Moisture (%)	Means	Feed Rate ($kghr^{-1}$)	Means	Speed (rpm)	Means
10.3	90.89b	60	92.24ab	300	90.54b
9.7	91.93b	90	91.04b	400	92.67b
7.8	94.82a	120	93.91a	500	94.08a
		150	93.00ab	600	93.92a
Means	2 3	2	3	2	3
Critical values	1.9 2.0	2.194	2.309	2.194	2.309

In any column, means followed by a common letter are not significantly different at 5 % level

4.16 Duncan's Multiple Range Test for Main Effects on Threshing Efficiency

The ANOVA for the threshing efficiency above shows that two of the main factors are highly significant at 1 % level, and that there is high chance that feed rates may also be different. These main factors are ranked using the Duncan's multiple range test which is present in table 4.3. The result of the ranking of the moisture content for threshing efficiency shows that the lowest moisture content has the highest efficiency of 94.8 %. And that the threshing efficiencies of values 90.9 % and 91.9 % achieved at the other two moisture content of 10.3 % and 9.7 % are statistically at par. This indicates that threshing the crop at 10.3 and 9.7 % moisture content would give the same threshing efficiency. The ranking for the feed rate reveals that the feed rate of 120 kg hr^{-1} would give the highest threshing efficiency of 93.9 % while the least threshing efficiency of 91 % is at 90 kg hr^{-1}. However, the Duncan's ranking shows that there is significant difference between the highest and the lowest threshing efficiency values, while the other two in-between efficiencies are not different from the extremes. From this Duncan ranking, it can be inferred that feeding the thresher at the rate of 90 kg hr^{-1} is not advisable because it yielded the lowest value of threshing efficiency. For the threshing efficiency as related to the cylinder speed, the four levels of speed evaluated produced only two statistical classes of threshing efficiencies, with the values of 90.5 and 92.7 % threshing efficiency in the lower class and 94 and 93.9 % in the upper class. The better class of threshing efficiency can be achieved at either of the two highest speeds of 500 and 600 rpm. While the poorer class of threshing efficiency can be achieved at either of the two lowest speeds of 300 and 400 rpm.

4.17 Analysis of Variance for Cleaning Efficiency of Developed Thresher

The analysis of variance (ANOVA) result for the cleaning efficiency of the developed pearl millet thresher is presented on the table 4.4. This result shows that the interactions between all three variables and between any two of the varied factors are not significant. Thus, the results of the tests on the main effects are more meaningful and reliable (Walpole *et al.*, 2007). It implies that the results of the main effects (or factors) are not masked nor unduly influenced by the interactions of the factors. Hence, the result of main effects-moisture, feed rate and speed-can be said to be their true reflection and are not influenced on by the results of interactions. From table 4.4, the replication of the experiment is highly significant. This may be attributed not to the developed thresher but to the crop. Since the crop is a biological substance, it does not have the entire homogeneity as man-made substances. Also, the germination and yield are not expected to be the same from the individual ear heads as the soil nutrient and other agronomic factor may be responsible for this variation. Hence the significant difference at 1 % level for replication is understandable. The results from table 4.4 also show that the moisture content of threshed crop, with the F-value of 8.16, is significant at 1 % level. Thus, the cleaning efficiency of crop was highly affected by the moisture content at which the crop is being threshed by the thresher. Also from the table, the feed rate of the thresher with F-value of 2.46 was not significant. But special attention must be paid to the probability that the F value calculated would be greater than F tabulated which is 0.068. Thus the feed rate can only be said not to be significant at about 6.8 % level. This implies that the chance that the mean values of the cleaning efficiencies at the different feed rates would be different is present. Thus the result of the Duncan's multiple range

Table 4.4 ANOVA of Cleaning Efficiency

Source of Variation	Degree of Freedom	Sum of squares	Mean Square	Computed F	Pr > F
Replication	2	880.43	440.22	10.32	< .0001
Moisture content, M	2	695.87	347.93	8.16**	0.0005
Feed rate, F	3	314.48	104.83	2.46 ns	0.0677
Speed, S	3	182.59	60.86	1.43 ns	0.2397
M x F	6	218.44	36.41	0.85 ns	0.5320
M x S	6	207.30	34.54	0.81 ns	0.5646
F x S	9	543.23	60.36	1.42 ns	0.1926
M x F x S	18	340.21	18.90	0.44 ns	0.9739
Errors	94	4008.37	42.64		
Total	143	7390.92			

ns = not significant, ** = significant at 1 % level

Table 4.5 Duncan ranking of independent variables for cleaning efficiency

Moisture (%)	Means	Feed Rate (kg hr^{-1})	Means	Speed (rpm)	Means
10.3	89.08b	60	91.16ab	300	90.25a
9.7	91.21b	90	89.33b	400	90.71a
7.8	94.43a	120	92.78a	500	92.95a
		150	93.02a	600	92.39a
Means	2 3	2	3	2	3
Critical values	1.9 2.0	3.056	3.216	3.056	3.216

In any column, means followed by a common letter are not significantly different at 5 % level

test for the feed rate of the thresher shows (in table 4.5) that a significant difference exist in the levels of the feed rate used in the thresher. From the same table 4.4 also, the F value of the speed was gotten as 1.43. The value is not significant, which implies that the speed at which the thresher was run did not have any effect on the cleaning efficiency obtained as the output. Hence, whatsoever the level of revolution per minutes at which the thresher was set, the same amount of cleanliness of the threshed crop would be achieved. F value column of table 4.4 shows that only replication and crop moisture content are significant to the cleaning efficiency of the thresher. That means that at whatever speed and feed rate the thresher was run, the cleaning efficiency of the thresher was not altered. Thus all the speed and the feed rate gave statistically equally good cleaning efficiencies.

4.18 Duncan's Multiple Range Test for Main Effects on Cleaning Efficiency

The result of the Duncan's multiple range test for the main effects on cleaning efficiency is shown in table 4.5. From the table, the cylinder speed of 300, 400, 500 and 600 rpm have the mean cleaning efficiencies of 90.3, 90.7, 93.0 and 92.4 % respectively. But the ranking shows that there is no significant difference among the speed levels. This agrees with the result of the ANOVA of the cleaning efficiency reported on table 4.4. The moisture content results also agree with the ANOVA stated. The lowest crop moisture content of 7.8 % happened to give the highest value of cleaning efficiency of 94.43 %. There is no significant difference between cleaning efficiencies of 89.08 % and 91.21 % for the moisture contents of 10.3 and 9.7 % (dry basis) respectively. Thus, threshing at the lowest crop moisture content on the thresher would give the best cleaning efficiency.

Hence, it can be concluded that the lowest moisture content evaluated (that is 7.8 %) at any of the feed rates except 90 kg hr^{-1} would give equally good cleaning efficiency.

The Duncan multiple range test result for the feed rates at which the thresher was evaluated shows that the feed rate of 90 kg hr^{-1} with the mean cleaning efficiency of 89.33 % is significantly different from those of 120 and 150 kg hr^{-1} feed rates which have statistically similar cleaning efficiencies. The mean cleaning efficiencies at 120 and 150 kg hr^{-1} feed rates are 92.8 and 93 % respectively. But, the cleaning efficiency at 60 kg hr^{-1} of 91.2 % has statistically equal cleaning efficiency with that of 90 kg hr^{-1}.

4.19 Analysis of Variance for Mechanical Grains Damage of the Developed Thresher

The result of the analysis of Variance (ANOVA) for the mechanical grains damage of the developed thresher is shown in table 4.6. The F value of the interaction of the three independent variables is 0.64 and the interaction of moisture and feed rate gave the F value of 1.33. The interaction of moisture and speed and that of feed rate and speed gave the F values of 0.53 and 0.51 respectively. This result shows that the interactions of any two of the variables and the interaction of all the three variables have no significant difference on the grains damage. Thus, the results of the main effects on the grains damage were not influenced by the interaction of any two or all the three variables (Walpole *et al.,* 2007). The results of the three main effects are also shown on the table 4.6. The F values of crop moisture, feed rate and cylinder sped are 27.9, 11.1 and 79.6 respectively. This implies that each of the main effects is highly significant to the percentage of grains damage from the thresher. Thus, crop moisture content, feed rate of loading the thresher and the cylinder speed all have significant impacts on the thresher's

Table 4.6 ANOVA of grains damage

Source of Variation	Degree of Freedom	Sum of squares	Mean Square	Computed F	Pr > F
Replication	2	0.2263	0.1131	4.97	0.0089
Moisture content, M	2	1.2704	0.6352	27.90**	<.0001
Feed rate, F	3	0.7586	0.2529	11.11**	<.0001
Speed, S	3	5.4414	1.8138	79.66**	<.0001
M x F	6	0.1818	0.0303	1.33 ns	0.2513
M x S	6	0.0724	0.0121	0.53 ns	0.7845
F x S	9	0.1042	0.0116	0.51 ns	0.8652
M x F x S	18	0.2621	0.0146	0.64 ns	0.8595
Errors	94	2.1404	0.0223		
Total	143	10.4575			

ns = not significant and ** = significant at 1% level

Table 4.7 Duncan ranking of independent variables for grain damage

Moisture (%)	**Means**	**Feed Rate (kg hr^{-1})**	**Means**	**Speed (rpm)**	**Means**
10.3	2.72b	60	2.59b	300	2.40d
9.7	2.73b	90	2.58b	400	2.57c
7.8	2.52a	120	2.70a	500	2.72b
		150	2.73a	600	2.93a
Means	2 3	2	3	2	3
Critical values	.06 .068	0.0706	0.07432	0.0706	0.07432

In any column, means followed by a common letter are not significantly different at 5 % level

performance in terms of mechanical grains damage. Kamble *et al.*, (2003) in their work on pearl millet thresher obtained that all the interactions of four variables (crop moisture content, concave clearance, feed rate and cylinder speed) evaluated by them at any level of combination are highly significant to the magnitude of grains damage percent from their evaluated pearl millet thresher. Kamble *et al.*, (2003) also found that the four main effects are each of significance at 1 % level to grain damage from their thresher.

4.20 Duncan's Multiple Range Test for Main Variables on Mechanical Grains Damage from Developed Thresher

The result of the Duncan's multiple range test for mechanical grains damage is shown on table 4.7. The result of the test agrees with the result of the ANOVA for grains damage which stated that there was high significant difference between the levels of the main effects at which the developed thresher was evaluated. The result shows that the least grains damage of 2.52 % was at the lowest crop moisture content of 7.8 %. However, the multiple range test reveals that there is no difference in the amount of grain damage at the two other crop moisture contents of 9.7 and 10.3 % both of which have the value of 2.7 %. For the feed rate, the grain damages when feeding the thresher at 60 and 90 kg hr^{-1} are not statistically different. In the same vein, the grains damage percentage from feeding the thresher at 120 and 150 kg hr^{-1} are also statistically equal. For the grain damage, it is obvious that is better to feed the developed thresher at either 60 or 90 kg per hour than to feed it at 120 or 150 kg per hour as the former set of feed rate would have less grain damage than the later set.

On the ranking of the speed of operation of the thresher in terms of grain damage, all the four speeds evaluated are statistically different one from the other. The lowest speed of

300 rpm caused lowest grain damage of 2.4 % and the speed of 600 rpm caused the highest grain damage of 2.93 %. The trend is that the higher the cylinder speed, the higher the amount of grains damage which would be caused on the threshed grains.

4.21 Analysis of Variance (AVONA) for Scatter Loss of the Developed Thresher

The analysis of variance (ANOVA) result for scatter loss from the performance evaluation of the developed pearl millet thresher is presented in table 4.8. The result of the F-value of the interactions of all three variables is 0.69 and those of the interaction of any two variables are shown on the table. It shows that there is no significant difference at 1 % level on the interactions of any two variables nor is there significant difference in the interaction of all the three main variables of moisture content of crop, feed rate of loading the thresher and its cylinder speed. The result of no significant difference in the interactions of the factors makes the result of the main effects reliable as there is no possibility of being influenced in the results of the main effects from the interaction of the variables (Walpole *et al.*, 2007).

The F values of the main effects of moisture content of crop, feed rate of the thresher and speed of the operation of the thresher are 9.80, 3.19 and 6.16 respectively. This indicates that only the feed rate is significant at 1 % level of confidence, while moisture content of the crop and speed of operation of the thresher are highly significant to the scatter loss from the machine. When evaluating their own pearl millet thresher, Kamble *et al.,* (2003) found that the only non significant main effect was the concave clearance while cylinder speed, moisture content and feed rate are significant. The interaction of concave clearance and crop moisture was not significant. Thus the result of this work is in perfect agreement with the result of Kamble *et al.,* (2003).

Table 4.8 ANOVA of scatter loss

Source of Variation	Degree of Freedom	Sum of squares	Mean Square	Computed F	Pr > F
Replication	2	743.69	371.84	3.71	0.0283
Moisture content, M	2	1967.69	983.84	9.80**	0.0001
Feed rate, F	3	961.86	320.62	3.19*	0.0271
Speed, S	3	1853.24	617.74	6.16**	0.0007
M x F	6	272.13	45.35	0.45 ns	0.8419
M x S	6	346.54	57.75	0.58 ns	0.7489
F x S	9	1374.95	152.77	1.52 ns	0.1513
M x F x S	18	1240.54	68.91	0.69 ns	0.8161
Errors	94	9433.30	100.35		
Total	143	18193.93			

ns = not significant, * = significant at 5 % level and ** = significant at 1 % level

Table 4.9 Duncan ranking of independent variables for scatter loss

Moisture		Feed Rate		Speed	
(%)	Means	($kghr^{-1}$)	Means	(rpm)	Means
10.3	32.27a	60	30.52a	300	23.05b
9.7	27.32b	90	29.10a	400	25.13b
7.8	23.22c	120	27.15ab	500	31.09a
		150	23.63b	600	31.14a
Means	2 3	2	3	2	3
Critical values	9.4 9.84	4.69	4.93	10.80	11.36

In any column, means followed by a common letter are not significantly different at 5 % level

4.22 Duncan's Multiple Range Test for Main Variables on Scatter Loss from Developed Thresher

Table 4.9 shows the result of the Duncan's multiple range test for the three main effects of crop moisture content, feed rate of the thresher and its operation speed for scatter loss of the evaluation experiment. The crop has the scatter loss range of 23.22 % to 32.27 % in increasing order of moisture content. It was observed that the different moistures content have difference amount of scatter loss (in percent) with the scatter loss increasing with increase in the moisture content of the threshed millet. Thus the best moisture content at which there would be least scatter loss from the thresher is 7.8 %. As for the effect of the feed rate of the thresher on its scatter loss, feeding the thresher at 120 kg per hour is not statistically different from feeding it at 90 kg per hour or at 60 kg per hour. And feeding the thresher at 120 and 150 kg hr^{-1} feed rates gave statistically equal percent scatter loss from the machine. The result of the average percentage scatter loss from the thresher shows that the scatter loss from it decreased with the increase in the feed rate of the thresher. The analysis of the cylinder speeds (rpm) effects on the scatter loss shows that there are two different outcomes-labelled 'a' and 'b' in the last column of table 4.9. The values of the mean scatter losses at 300 and 400 rpm gave statistically equal percent though their values were 23 and 25 % respectively. And those of the 500 and 600 rpm with 31 % scatter are also at par statistically too. In a nut shell, operating the thresher at 300 and 400 rpm produced the same outcome in term of the scatter loss from the thresher, and running the thresher at 500 and 600 rpm also produced similar outcome on the scatter loss percent from the thresher. However, it is better to run the developed thresher at 300

or 400 rpm than at 500 or 600 rpm in order to minimize the scatter loss percentage from the thresher.

4.23 Analysis of Variance (AVONA) for Throughput of the Developed Thresher

The result of the Analysis of Variance (ANOVA) for the throughput of the developed thresher is present on table 4.10. As in the previous cases for the ANOVA of other evaluated parameter such as threshing efficiency and cleaning efficiency, the throughput ANOVA shows that there is no significant difference in the interactions of any two variables nor is there significant difference in the interaction of all three factors- crop moisture content, cylinder speed and feed rate of loading the thresher. This lack of significant difference in the results of the interactions from the ANOVA lends credence to the results of the main effects (Walpole *et al.,* 2007). The F–values of the interactions are as shown on the table. Thus, there is no significant difference in all the interactions, and so the results of the main effects can be interpreted without any doubt of the effects been influenced by the interactions between the factors. The F values of moisture content, feed rate and cylinder speed are 35.6, 80.59 and 1.35 respectively. This shows that the crop moisture content levels and the feed rate levels have high significant differences. But the cylinder speed has no significant difference. Hence, the throughput (in kg hr^{-1}) got from the developed thresher is significantly affected by the crop moisture content and the feed rate at which the thresher is operated. Whereas, the cylinder speed does not in any way influence the throughput from the thresher. This is to say, whether the cylinder speed was 300, 400, 500 or 600 rpm, the throughput capacity of the thresher (in kg hr^{-1}) remained the same.

Table 4.10 ANOVA of throughput capacity

Source of Variation	Degree of Freedom	Sum of squares	Mean Square	Computed F	Pr > F
Replication	2	384.00	192.00	2.42	0.0944
Moisture content, M	2	5660.92	2830.46	35.67 **	<.0001
Feed rate, F	3	19181.80	6393.93	80.59 **	<.0001
Speed, S	3	321.64	107.21	1.35 ns	0.2626
M x F	6	689.74	114.96	1.45 ns	0.2044
M x S	6	346.45	57.74	0.73 ns	0.6282
F x S	9	977.73	108.64	1.37 ns	0.2132
M x F x S	18	765.70	42.54	0.54 ns	0.9335
Errors	94	7458.10	79.34		
Total	143	35786.08			

ns = not significant and ** = significant at 1% level

Table 4.11 Duncan ranking of independent variables for throughput capacity

Moisture (%)	Means	Feed Rate ($kghr^{-1}$)	Means	Speed (rpm)	Means
10.3	26.85b	60	21.52d	300	37.79a
9.7	41.56a	90	27.82c	400	35.72a
7.8	38.03a	120	41.52b	500	34.59a
		150	51.06a	600	33.81a
Means	2 3	2	3	2	3
Critical values	3.6 3.80	4.169	4.387	4.169	4.387

In any column, means followed by a common letter are not significantly different at 5 % level

4.24 Duncan's Multiple Range Test for Main Variables on Throughput of Developed Thresher

The table 4.11 shows the Duncan's multiple range tests for crop moisture content, cylinder speed and feed rate on the throughput of the evaluated thresher. Although the mean of the throughput of the speeds ranged from 33.8 to 37.7 kg hr^{-1}, the results reveal that the cylinder speed does not have effect on the throughput of the thresher within the level of speed evaluated. This is because the throughput at all the speeds evaluated was statistically classed as the same. The crop moisture content as seen by the ANOVA is significantly different for the throughput. From the table 4.10, the throughput for the crop moisture content of 7.8 and 9.7 % are statistically equal, while the throughput of the highest moisture content evaluated (10.3 %, dry basis) is different from that of the other two moisture contents. The moisture of 10.3 % has the lowest value of throughput of 26.85 kg per hour, while the mean throughput at 9.7 and 7.8 % crop moisture content are 41.56 and 38.03 kg hr^{-1} respectively. On the same table, the four feed rates evaluated on the thresher are significantly different one from the other in them of their throughput capacities. Thus, the feed rate of 150 kg per hour gave the highest throughput of 50 kg hr^{-1} from the thresher and the feed rate of 60 kg hr^{-1} gave the lowest throughput of 21.5 kg hr^{-1}. The other two evaluated feed rates of 90 and 120 kg hr^{-1} fall in between the two extremes with the throughput of the former greater than that of the later. From the law of conservation of matter, which stated that matter cannot be created nor destroyed, it means that this result is logically expected, as output is always proportional to input. Besides, it is a common saying that 'cabbage in, cabbage out.' thus the more the rate of feeding into the thresher, the more was its throughput.

4.25 Comparison of other Millet Threshers with the Developed Axial-Flow Thresher

Table 4.12 shows the performance indices of seven developed millet thresher that span from 1979 to 2014. The sources indicate the developers and the year in which each of the threshers were made. The feed rate of each of the threshers is as tabulated against it. Kamble *et al.,* (2003) has the highest feed rate. It is followed by the developed axial flow millet thresher of this work which has the feed rate of 60 to 150 kg hr^{-1}. On the threshing efficiency, the developed thresher for this work has a range of 89.1 to 96.5 % which is either better than or equally as good as those of earlier sources. The cleaning efficiency of 86 to 95 % is in numerical value greater than those of the other listed millet threshers. And the cleaning efficiency of the developed thresher increased on the best among others by 3%.

The scatter loss from the developed millet thresher is large, yet this is not peculiar as those of Gbabo *et al.*, (2013), Abolaji (1980) and Wagami (1979) gor scatter losses that are numerical large to the magnitude of above 11% each. The grain damage 2.45 to 3.05 for this developed thresher was within the results of the earlier developed millet threshers such as that of Kamble *et al.,* (2003). The throughput output capacity of the developed thresher for this work with the value of 60.3 kg hr^{-1} was at least 25 % greater than those of the other millet thresher.

Table 4.12 Comparison of selected millet threshers

Source/ developer	Feed rate (kg hr^{-1})	Threshing Efficiency (%)	cleaning Efficiency (%)	Scatter Loss (%)	Grain Damage (%)	Throughput Capacity (kg hr^{-1})
Wagami (1979)	-	70 -80	70.0	18 - 32	-	25.0
Abolaji (1980)	30 - 61	87.7 – 93.0	88.5 – 92.3	11.4 - 27.4	1.34 – 2.93	15.0 – 23.4
Ndirika (1994)	20, 40	94.4 – 96.8	85.0 – 89.6	3.5 – 4.5	1.30 – 2.10	47.5
Kamble *et al.*, (2003)	300, 400, 500	78.1 – 96.8	†	2.10 -6.98	2.75 -8.25	†
Abarchi (2011)	28, 36	78.0 - 88.0	65.0 -85.0	0.8 -2.25	0.93 – 2.60	18.4 - 27.1
Gbabo *et al.*, (2013)	5	40.7 – 63.2	56.3 – 62.7	36.8 – 51.7	†	†
Developed Thresher	60 -150	89.1 – 96.5	86.3 – 95.2	17.84 – 37.26	2.45 – 3.05	16.8 – 60.3

† means the value was not given by source



Plate II: The student during the performance evaluation of the thresher

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMEDATION

5.1 Summary

The physical properties of pearl millet grains were determined. From the three principal dimensions of the grains, the geometric diameter, sphericity, surface area and volume of the grains were computed. Also the bulk and true densities, porosity, angle of repose of the grains were calculated. And the coefficients of friction of the grains on glass, wood, mild steel and aluminium were determined. Using the information gathered from the physical properties, an axial-flow pearl millet thresher was designed by applying fundamental engineering principles. The thresher was made from affordable and locally available materials so as to make its cost of production as low as possible without compromising on the reliability and longevity of the thresher nor the safety of it users. The cost of its production was also made low with the view to making the thresher affordable to small and medium scale farmers who cannot afford the luxury of owning expensive machinery on their farms. Other considerations in the design of the thresher are the ergonomics of users and availability of power source to prime the developed thresher. The millet thresher was evaluated in order to determine its performance in terms of threshing efficiency, cleaning efficiency, throughput capacity that can be obtained from the usage of the machine and the extent to which scatter loss and mechanical grain damage are caused to the threshed grains. The variables are the moisture content of the crop at three levels of 7.8, 9.7 and 10.3 % (dry weight basis), the cylinder peripheral speeds at 5.5, 7.3 9.2 and 11.0 ms^{-1}, and the feed rates of 60, 90, 120 and 150 kg hr^{-1}.

Analysis of Variance (ANOVA) and Duncan's multiple range test were used to assess the effects of the independent variables (crop moisture content, cylinder speed and the feed rate) on the performance indices of the developed thresher. The findings from the experiments show that each of threshing efficiency, cleaning efficiency, scatter loss from thresher, grains damage and throughput capacity was not significantly influence by the interactions of the independent variables but each index was directly influenced by the independent variables.

5.2 Conclusion

Fundamental physical properties of millet grains essential for the design of a thresher for the crop were determined. And an axial-flow millet thresher was designed and constructed from cost effective, readily available materials. On the evaluation of the developed thresher, the following findings were gotten:

i. The threshing of the crop was best done at the lowest moisture content of 7.3 % in order to get the best threshing and cleaning efficiencies from the thresher. The feed rate of 120 kg hr^{-1} and 150 kg hr^{-1}gave the highest values threshing efficiency and cleaning efficiency of 93.91 % and 93.02 % respectively. However, the feed rates of 120 and 150 kg hr^{-1} gave an equally good threshing and cleaning efficiencies with those of 120 and 150 kg hr^{-1} feed rates. Although the cylinder should be kept at minimum of 9.2 ms^{-1}peripheral speed in order to get the highest threshing efficiency, the cleaning efficiency was independent of the speed of the thresher as the cleaning efficiency at all evaluated cylinder speeds were statistically at par.

ii. The lowest moisture content of 7.8 % (dry basis) gave the least scatter loss of 23.2 % from the thresher. However, the higher the feed rate amount, the less the proportionate amount of scatter loss from the thresher. While the moisture content of 7.8 % gave a mechanical grains damage of 2.52 %, the grains damage increased as either of the cylinder speed and the feed rate increased.

iii. The throughput output capacity of the developed thresher for this work with the value of 60.3 kg hr^{-1} has at least 25 % greater value than those of the previously made millet threshers. The cleaning efficiency of the developed thresher improved on the best among others by 3%. The highest throughput capacity of 60 kg hr^{-1} was gotten by feeding the thresher at 150 kg hr^{-1}. The grain damage of the developed thresher was within the range of the older threshers.

5.3 Recommendation

Having developed, constructed and evaluated the axial-flow millet thresher, the following recommendation is hereby given:

i. The cleaning unit should be re-oriented in the thresher with the view to improving on the scatter loss from the thresher while at least maintaining or increasing on the cleaning efficiency already achieved on the thresher.

ii. The rasp bars in the cylinder should be changed to spike-tooth in the section of the cylinder opened to the hopper. This is to give room for the feeding of the thresher at greater rates than those used in the evaluation of the thresher.

iii. The thresher should be evaluated at higher moisture content of crop of say 12 to 21 %. This would enable the performance of the thresher within the higher moisture content than the ones used in this work to be investigated.

iv. Local pearl millet farmers should adopt the thresher in order to improve on the timeliness in threshing of the crop and so as to alleviate the drudgery associated with the manual threshing of the crop.

v. A bigger gauze sieve size should be adopted for the thresher in order to reduce scatter loss from the thresher especially when threshing at high moisture content of the crop.

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Appendix 1 Layout of a 3x4x4 experiment used in the evaluation of the developed thresher

RI

$F_4S_1M_3$	$F_2S_1M_2$	$F_3S_3M_3$	$F_1S_4M_2$	$F_4S_1M_1$	$F_1S_4M_3$	$F_3S_2M_2$	$F_3S_4M_2$	$F_3S_3M_1$	$F_3S_1M_3$	$F_1S_2M_1$	$F_2S_2M_2$
$F_1S_4M_1$	$F_4S_3M_3$	$F_4S_2M_1$	$F_3S_4M_1$	$F_4S_2M_2$	$F_2S_1M_3$	$F_1S_1M_3$	$F_1S_1M_1$	$F_2S_4M_2$	$F_1S_2M_2$	$F_4S_2M_3$	$F_4S_3M_2$
$F_2S_4M_3$	$F_3S_1M_1$	$F_2S_3M_2$	$F_3S_2M_1$	$F_1S_2M_3$	$F_4S_4M_1$	$F_4S_4M_3$	$F_3S_1M_2$	$F_1S_3M_3$	$F_4S_3M_1$	$F_3S_3M_2$	$F_1S_3M_1$
$F_2S_3M_1$	$F_1S_3M_2$	$F_1S_lM_2$	$F_2S_2M_3$	$F_3S_4M_3$	$F_4S_4M_2$	$F_2S_2M_1$	$F_2S_3M_3$	$F_4S_1M_2$	$F_2S_1M_1$	$F_2S_4M_1$	$F_3S_2M_3$

RII

$F_1S_2M_1$	$F_3S_2M_3$	$F_2S_4M_3$	$F_1S_1M_1$	$F_3S_2M_2$	$F_1S_3M_1$	$F_4S_3M_3$	$F_1S_2M_3$	$F_2S_4M_1$	$F_4S_1M_3$	$F_1S_4M_3$	$F_1S_lM_2$
$F_3S_3M_2$	$F_2S_1M_2$	$F_2S_2M_1$	$F_3S_1M_3$	$F_2S_2M_3$	$F_3S_3M_3$	$F_3S_4M_1$	$F_2S_2M_2$	$F_4S_3M_2$	$F_2S_1M_1$	$F_3S_3M_1$	$F_2S_3M_3$
$F_2S_1M_3$	$F_2S_3M_1$	$F_4S_2M_2$	$F_2S_3M_2$	$F_3S_1M_1$	$F_4S_1M_2$	$F_1S_3M_2$	$F_4S_4M_2$	$F_3S_2M_1$	$F_1S_4M_2$	$F_4S_4M_1$	$F_3S_4M_2$
$F_1S_4M_1$	$F_3S_4M_3$	$F_1S_1M_3$	$F_1S_2M_2$	$F_4S_3M_1$	$F_2S_4M_2$	$F_4S_1M_1$	$F_4S_4M_3$	$F_4S_2M_3$	$F_3S_1M_2$	$F_1S_3M_3$	$F_4S_2M_1$

RIII

$F_2S_1M_1$	$F_2S_2M_3$	$F_3S_4M_1$	$F_4S_2M_3$	$F_4S_4M_1$	$F_3S_2M_1$	$F_1S_4M_3$	$F_1S_2M_3$	$F_4S_1M_2$	$F_3S_3M_3$	$F_3S_2M_2$	$F_2S_3M_3$
$F_4S_3M_3$	$F_1S_4M_1$	$F_4S_3M_2$	$F_3S_1M_1$	$F_1S_3M_2$	$F_2S_4M_2$	$F_1S_3M_3$	$F_3S_3M_1$	$F_3S_2M_3$	$F_4S_2M_2$	$F_1S_2M_1$	$F_2S_1M_2$
$F_2S_4M_3$	$F_4S_2M_1$	$F_1S_1M_3$	$F_1S_2M_2$	$F_3S_1M_3$	$F_4S_3M_1$	$F_3S_1M_2$	$F_4S_1M_1$	$F_2S_4M_1$	$F_1S_1M_1$	$F_2S_3M_2$	$F_4S_3M_2$
$F_1S_lM_2$	$F_3S_3M_2$	$F_2S_3M_1$	$F_2S_1M_3$	$F_2S_2M_1$	$F_3S_4M_3$	$F_4S_4M_2$	$F_2S_2M_2$	$F_1S_4M_2$	$F_4S_4M_3$	$F_4S_1M_3$	$F_1S_3M_1$

Three moisture contents (M_1, M_2 and M_3), four feed rates (F_1, F_2, F_3 and F_4) and four cylinder speed levels (S_1, S_2, S_3 and S_4) arranged in a completely randomized block design with three replications. M = moisture content of crop, F = Feed rate, and S = cylinder peripheral speed

Appendix 2 ANOVA table for 3x4x4 factorial experiment in RCBD

Source of Variation	Degree of Freedom	Sum of squares	Mean Square	Computed F	Tabulated F	
					5%	1%
Replication	r-1= 2					
Moisture content, M	m-1=2					
Feed rate, F	f-1=3					
Speed, S	s-1=3					
M x F	(m-1)(f-1)=6					
M x S	(m-1)(s-1)=6					
F x S	(f-1)(s-1)=9					
M x F x S	(m-1)(f-1)(s-1)=18					
Errors	(r-1)(mfs-1)=94					
Total	Rmfs-1=143					

Note: r = number of replication, m, f and s are levels of three factors of moisture contents, feed rates and cylinder speeds respectively.

Appendix 3 Performance evaluation results of the thresher at diverse feed rates and moisture contents

Feed Rate (kg/h)	Crop Moisture content (%)	Threshing Efficiency (%)	Cleaning Efficiency (%)	Grains damage (%)	Scatter Loss (%)	Throughput (kg/h)
60		90.79	89.87	2.38	37.29	16.75
90		90.30	88.72	2.48	33.38	20.80
120	**10.3**	91.51	89.31	2.60	29.62	31.06
150		90.95	88.42	2.64	28.77	38.78
60		91.22	90.00	2.69	24.16	25.12
90		89.45	87.43	2.64	24.27	32.10
120	**9.7**	94.66	93.86	2.80	25.55	48.70
150		92.41	93.55	2.82	18.92	60.30
60		94.69	93.63	2.69	30.11	22.68
90		93.37	91.85	2.63	29.66	30.54
120	**7.8**	95.56	95.16	2.71	26.29	44.79
150		95.56	96.99	2.76	23.21	55.33

Appendix 4 Performance evaluation result of the thresher at diverse drum speeds and crop moisture contents

Cylinder speed (rpm)	Crop Moisture content (%)	Threshing Efficiency (%)	Cleaning Efficiency (%)	Grains damage (%)	Scatter Loss (%)	Throughput (kg/h)
300		89.14	87.02	2.25	27.76	26.13
400		87.84	86.29	2.45	28.21	28.31
500	**10.3**	93.13	91.56	2.62	34.71	27.60
600		93.45	91.45	2.78	38.37	25.35
300		89.84	89.68	2.49	17.84	46.56
400		93.09	92.65	2.65	23.35	39.51
500	**9.7**	93.04	92.03	2.76	27.82	40.29
600		91.76	90.48	3.05	23.88	39.87
300		92.63	94.04	2.47	23.55	40.67
400		94.04	93.19	2.60	23.83	39.33
500	**7.8**	95.97	95.17	2.75	30.73	37.13
600		96.54	95.24	2.97	31.16	36.21