DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER

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SEPTEMBER, 2017

DECLARATION

I hereby declare that this thesis titled "Development and Optimization of the Threshing Performance of a Multicrop Thresher" is written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree. All sources of information which were cited and did not originate from me were specifically acknowledged by means of references.

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N.H. MUNA Date

(PhD/ENG/6571/2010-2011)

CERTIFICATION

This is to certify, having read through, that this thesis "Development and Optimization of the Threshing Performance of a Multicrop Thresher" by the author Muna, Nyambi Humphred; meets the regulations governing the award of degree of Doctor of Philosophy (Agricultural Engineering) of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific/technical knowledge and literary presentation.

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DEDICATION

I dedicate this work to God Almighty for granting me His Grace, Mercy, Strength and Wisdom to complete this PhD degree programme, and to all my friends and members of my family who supported me morally and financially.

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ABSTRACT

The existing IAR multicrop thresher was evaluated and found to have low feed rate and output with millet and soybean crops. The machine was modified and reconstructed to increase its threshing performance. Its components were increased in size and a shredder was added below the feed hopper to cut stems of crops that entangle the threshing cylinder and stop its motion. The beaters were tilted and arranged spirally on the threshing cylinder to facilitate the flow of threshed grains, chaff and unthreshed materials. Performance tuning was done and the machine's performance was evaluated. With millet as the test crop the machine gave feed rate, threshing efficiency, cleaning efficiency, scatter loss, grain damage and output capacity of 14 kg/min, 99.98 %, 99.71 %, 12.18 %, 0.62 %, and 520.6 kg/hr as against 3 kg/min, 92 %, 80 %, 2.4 %, 3.5 %, and 81 kg/hr respectively for the existing IAR multicrop thresher. With soybean the machine gave 12 kg/min, 100 %, 97.26 %, 7.25 %, 6 %, and 205 kg/hr as against 1.7 kg/min, 80 %, 70 %, 2 %, 1.94 %, and 23 kg/hr respectively for the existing IAR soybean thresher. Therefore, feed rate was increased from 3 to 14 kg/min and from 1.7 to 12 kg/min; output was increased from 81 to 520 kg/hr and from 23 to 205 kg/hr for millet and soybean respectively. Threshing and cleaning efficiencies for both crops were also increased. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis using Duncan multiple range test shows that there was significant difference between the means at 1 % level of significance. A good linear relationship was achieved between the measured and predicted data with r^2 equals 0.73. Hence the threshing efficiency model was accurate as the calculated t-value (0.101) was less than the tabular value (1.96) at 1 % level of significance. Optimum feed rate, threshing efficiency, cleaning efficiency, scatter grain loss, grain damage, output capacity of 12 kg/min, 99.7 %, 97.4 %, 11.2 %, 0.02 %, 420 kg/hr and of 10 kg/min, 100 %, 92.5 %, 4.7 %, 0.3 %, 163 kg/hr were attained for millet and soybean at a cylinder speed of 18.7 m/s and crop moisture content of 11.9 % and 12.2 % respectively.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

A multicrop thresher is a machine capable of threshing many different types of grain crops such as Soybean and Millet. The threshing process is mechanical and the thresher can be powered by several types of prime movers such as an electric motor, diesel or petrol engines as well as a tractor power take off (PTO) shaft. Mechanical threshing was first invented in 1786 by a Scottish mechanical engineer Andrew Meikle for use in agriculture. It involved the detachment of grain kernels from the heads, cobs or pods depending on the crop type. It takes away the drudgery involved in the slow and laborious process of manual threshing and cleaning. It cuts down cost of production on farm and increase agricultural production worldwide. Since the invention of this machine, several engineers all over the world have progressively introduced improved varieties, all tending to simplify labour, and to augment the quantity and quality of the work performed on farms.

1.1.1 Varieties of soybean

Soybean, *Glysine max (L) Merr* is a leguminous plant that grows in tropical, subtropical and temperate climates. The stems, leaves and pods are covered with fine tawny or grey pubescence. The pods contain one to four seeds which are round or elliptical in shape. It grows

erect with cultivars ranging from 450-1200 mm and is bushy and leafy with a growth period of 75-150 days. The pods are small, straight or slightly curved. Soybean has many varieties world-wide. The varieties found in the United States of America includes: Amsoy, Corsoy and Harosoy. The varieties found in Nigeria developed by the National Coordinated Research Project on Soybean (NCRPS) include: Samsoy1, Samsoy2, TGX 536-020, TGX 344, TGX 814-270, TGX 855-610. All these are similar in botanical characteristics and are adapTable in most northern states of Nigeria such as Kaduna, Kano, Niger, Plateau, and Taraba (NCRPS, 1986).

1.1.2 Nutritional and economic values of soybean

Soybean is one of the world's most important food crops having superior amino acid profile compared to other sources of plant protein. It provides about 64 % of world's oil seed meal supply and is a major source of oil, accounting for about 29 % of total world's production. (Smith and Huyser, 1987). It is an important source of high quality but inexpensive protein and oil with dominant supply of the world's edible vegeTable oil and feed supplements for livestock. It is referred to as "meat of the world" (Tandon and Panwar, 1989). It contains about 40-41 % protein and 20.5-21.5 % oil and is second to groundnut in terms oil content amongst food legumes. Soybean production represents an important source of foreign currency especially in counties like Brazil and Argentina. World-wide soybean production amounts to about 130 million tones per year, utilizing about 60 million hectares of land. The largest producers being the USA, Brazil, China, Argentina, and India (Smith and Huyser, 1987). Other products of soybean include: Soybean Milk, Soy-Source, Soy Flour, Soybean Curd and Soybean Sprouts. Soybean also contain important nutrients including calcium, magnesium and many B-complex vitamins. Investigation has shown that from 100 g of soybean milk you can get 2.8-3.4 g of protein, 1.5 g of lipids, 12-24 mg iron. It is comparable to cow milk for amino acid and vitamin B (Marina, 1991).

1.1.3 Varieties of millet

Millets are a group of small - seeded species of cereal crops or grains belonging to the family Gramineae and widely grown around the world for food and fodder. It has slender stems which are divided into distinct nodes. The leaves of the plant are linear or lance-like, possess small teeth and can grow up to 1 m (3.3 ft) in length. The inflorescence of the plant is a spike-like panicle, made up of many smaller spikelets where the grain is produced. Pearl millet can reach 0.5 to 4 m (1.6 –13.1 ft) in height depending on the cultivar and is an annual plant, harvested after one growing season. Pearl millet may also be referred to as bulrush millet, cat-tail millet or yellow bristle grass and originates from the Sahel zone of Africa. Millet has many varieties world-wide. The various millet species can be divided into two broad categories: Pearl millet (*Pennisetum glaucum, P. typhoides, P. tyhpideum, P. americanum*) and Small millet (*Eleusine coracana, Eragrostistef, Panicum sumatrense, Digitariaexilis*). Amongst the cultivated pearl millet in Nigeria, only two varieties are extensively grown; 'Gero', *Penisetum Typoids*, and 'Maiwa', *Penisetum Maiwa*. These two varieties are similar in every aspect, except in the grain size. The grains of 'Gero' (Ex- Borno) are long while those of 'Maiwa' are more spherical. Gero constitutes the largest production of all the millet grown in Nigeria with a yield potential of 2,000 -3,000 kg/ha while the improved SOSAT variety has a yield potential of 2,500-3,500 kg/ha (LCRI, 1997). Nigeria produced 13 % of the world millet in 1990 (FAO, 1991). In the year 2010, the area under millet cultivation was 3.75 million hectare (FAOSTAT, 2012). The most widely cultivated species in order of worldwide production are pearl millet (*Pennisetum glaucum*), Foxtail millet (*Setaria italica*), Proso millet (*Panicum miliaceum*) and Finger millet (*Eleusine coracana*). The most important characteristic of millet is their unique ability to tolerate and survive under adverse condition of continuous or intermittent drought as compared to most other cereals like maize and sorghum (LCRI, 1997).

1.1.4 Nutritional and economic values of millet

Millets are principally food sources in arid and semi-arid regions of the world. Ikwelle *et al.* (1993) ranked pearl millet as the most important cereal in the southern Sudan and the Northern Guinea. Nkama (1998) outlined the uses and traditional food preparations of pearl millet in Nigeria. The grain serve as food for the majority of people of Africa who utilize it in the form of porridge produced from flour called 'tuwo', refreshing drink 'kunu', dessert 'dan wake' and palp 'ogi', millet beer in Cameroon , millet flour called ' Bajari' in western India. The flour is also used for making flat bread or cooked to form couscous. The plant stems can be used for roof thatch and building construction. In countries other than Africa and India it is most widely grown as fodder. Furthermore, the seed is a valuable food resource on account of its protein and lipids contents: 12% protein, 3% crude fiber, 4% fat (Ojediran, 2008). There is a growing interest in the crop because of its utilization in in starch production in industries. Therefore, consequent on the large scale production and commercial exploitation of the crop is the need to study its physical and mechanical attributes, which are important in the design of equipment for handling, cleaning, storing and processing (Sanchez *et al.*, 2008).

1.2 Statement of Problem

i. Tandon and Panwar (1989) reported percentage losses and grain damage in mechanical threshers to be as high as 40 %. Hyetson (2003) reported that the threshing cylinder of these machines have difficulties in rotating when bulky crops such as soybean and millet are fed. That the crop stems entangled on the threshing cylinder of the machine thereby either reducing its speed or completely stopping the rotation. This results to low threshing capacity, low threshing and cleaning efficiencies. As a result, most Nigerian farmers accomplish soybean and millet threshing manually by putting the crops in a sack and beating them with sticks to thresh. Cleaning is also done manually by winnowing. These traditional threshing and cleaning processes are costly, slow, energy consuming and results to much drudgery.

ii. The output capacity, threshing and cleaning efficiencies of the existing IAR multicrop thresher when threshing millet were determined to be low. A preliminary performance test conducted, indicated that the existing IAR multicrop thresher had a maximum feed rate of 3 kg/min with millet when operated at a speed of 20 m/s. At this speed, the threshing efficiency, cleaning efficiency, scatter loss, grain damage and output capacity obtained with SOSAT C88 Millet variety were 92 %, 80 %, 2.4 %, 3.5 %, and 81 kg/hr respectively. Also, the shaker was not working effectively as most of the chaff accumulates on the bottom sieve, causing it to clog frequently during threshing.

iii. The output capacity, threshing and cleaning efficiencies of the existing IAR prototype soybean thresher were low. IAR (2006) evaluated the thresher for performance and reported that the threshing efficiency, cleaning efficiency, scatter loss, grain damage and output capacity obtained with Samsoy-2 soybean variety were 80 %, 70 %, 2 %, 1.94 %, and 23 kg/hr, respectively, while the values obtained with TGX 1485-ID variety were 86 %, 64 %, 1.6 %, 2.2 %, and 21 kg/hr, respectively. It was concluded that the best combination of cylinder speed and feed rate that gave the highest threshing efficiency was 909 rpm cylinder speed and 1.7 kg/min feed rate with both varieties.

iv. The high cost incurred by farmers purchasing separate threshing machines per crop has made them to buy very few threshers or even abandon mechanical threshing completely. They prefer to thresh their crops manually using different techniques. Hence, it is necessary to produce a machine that can thresh more than one crop and make it available and affordable to farmers.

1.3 Aim and Objectives of the Study

The aim of the study was improving the threshing performance of IAR multicrop thresher for higher output capacity, threshing and cleaning efficiencies at lower scatter grain loss and grain damage.

The specific objectives are:

i. to conduct design analysis for an improved IAR multi-crop thresher

ii. to construct the components of the prototype thresher and assembly of the machine

iii. to evaluate the performance of the thresher using Samsoy-2 soybean and SOSAT C88 millet varieties as the test crops

iv. to develop a model that predict and optimize the threshing performance of the machine

1.4 Justification of the Study

i. Modifying the existing IAR multicrop thresher to improve its threshing performance will solve the problem of farmers threshing bulky crops such as soybean and millet manually. The mechanical threshing/cleaning process will also be faster and easier than the traditional methods which are time wasting, energy consuming and result to much drudgery.

ii. Reconstructing this machine will increase its working efficiency for soybean and millet. Hence increasing their production as the quantity of materials fed, threshed and cleaned per minute will increase for both crops. It will also cut down the cost incurred by farmers purchasing separate threshing machine per crop.

iii. Performance evaluation of this machine with soybean and millet as the test crops will help determine its output capacity, threshing efficiency, cleaning efficiency, scattered grain loss, grain damaged and their relationships with cylinder speed, feed rate and crop moisture content.

iv. The mathematical model developed for predicting threshing efficiency of this machine will help researchers for improving and optimizing the performance of other spike tooth threshers, hence providing useful techniques for understanding the operations of these machines in different crop situations and different threshing conditions.

v. Optimizing the threshing performance of this machine will help in obtaining optimum combination of cylinder speed, feed rate and crop moisture content required for determining optimum threshing efficiency, cleaning efficiency, scatter loss, grain damage and output capacity of Samsoy-2 soybean and SOSAT C88 millet varieties.

CHAPTER TWO

2.13 LITERATURE REVIEW

2.14 Research and Development Efforts on Threshing

Several research and development efforts have been made over the years on soybean and millet threshers, some of which are stated below:

2.14.1 Research and development efforts on soybean threshing

Singh (1968) designed a spike tooth, vertical flow soybean thresher and observed that feed rate, concave clearance and type of concave have direct effect on the losses of grains with chaff. At a cylinder speed of 900 rpm, concave clearance of 1.03 cm, moisture content of 9.5 %, feed rate of 1.15 kg/min, a minimum seed damage of 3.6 % was obtained with the thresher.

Hyetson (2003) also worked on an existing IAR spike tooth, axial flow soybean thresher. Some missing components of the thresher were identified and replaced and the performance of the thresher was evaluated using some parameters. After the evaluation, the best performance with TGX 1485-ID variety was obtained at a cylinder speed of 900 rpm and feed rate of 20 kg/hr. This combination has 98 % threshing efficiency, 2.99 % mechanical grain damage, 75 % cleaning efficiency, 2.99 % scatter loss and 22 kg/hr output capacity. Also the result shows that threshing efficiency increases with increase in cylinder speed for both varieties. The mechanical

grain damage also increases with feed rate and cylinder speed for both varieties but samsoy-2 has greater grain damage than the TGX1485-ID variety. The cleaning efficiency decreases with an increase in feed rate in both varieties but with an increase in speed, samsoy-2 appears to have higher cleaning efficiency than the TGX 1485-ID variety. The scatter loss increases with speed and feed rate in both varieties but TGX1485-ID has the highest loss than Samsoy-2. The output capacity also increases with increase in cylinder speed and feed rate for both varieties with samsoy-2 having higher output capacity than the TGX1485-ID.

Oforka (2004) evaluated the IAR spike tooth, axial flow soybean thresher and obtained the best performance combination at a cylinder speed of 850 rpm, feed rate of 30 kg/hr with samsoy-2 variety at 10 % moisture content of the grain. Also from the results the values of the parameters obtained were 96 % threshing efficiency, 2.86 % mechanical grain damage, 97 % cleaning efficiency, 2.86 % scatter loss and 33 kg/hr output capacity.

IAR (2006) evaluated their existing prototype spike tooth, axial flow soybean thresher for performance and reported that the threshing efficiency, cleaning efficiency, scatter loss and output capacity obtained with Samsoy-2 variety were 80 %, 70 %, 2 %, 1.94 %, and 23 kg/hr respectively, while the values obtained with TGX 1485-ID variety were 86 %, 64 %, 1.6 %, 2.2 %, and 21 kg/hr respectively. The study also concluded that the best combination of cylinder speed and feed rate that gave the highest threshing efficiency was 900 rpm cylinder speed and 20 kg/hr feed rate with both varieties.

Anusorn *et al*. (2006) developed and evaluated a spike tooth, axial flow soybean thresher. Machine/crop parameters affecting the performance of the soybean thresher were evaluated. The threshing mechanism consists of a threshing cylinder with spike tooth rotating inside a two section concave. The diameter and length of the cylinder were 420 mm and 930 mm respectively. The concave was made up of mild steel rod arranged longitudinally with spacing of 25 mm, the clearance between the concave and the threshing cylinder was fixed at 40 mm. The

most common soybean variety KKU-35 grown in Thailand was used for the test. The performance evaluation shows that at grain moisture content of 14.34 % (w.b.), feed rate of 720 kg/hr and a cylinder speed of 700 rpm with an average power of 1.85 kW, the output capacity, threshing efficiency, grain damage and grain loss were found to be 214 kg/hr, 99.49 %, 2.6 % and 0.80 % respectively.

2.14.2 Research and development efforts on millet threshing

Several research and development efforts have been made on millet threshers, some of which are stated below:

Harrington (1970) designed an axial flow multicrop thresher using spike toothed cylinder and a fixed concave clearance of 2.5 cm for threshing Japanese paddy and American wheat. A 3 % grain loss was recorded for both paddy and wheat.

Wagami (1979) designed and fabricated a spike tooth, axial flow millet thresher. The thresher was evaluated by Abolaji (1980) and the author reported a low output capacity of 25 kg/hr.

Joshi (1981) reported that with a spike tooth, axial flow wheat thresher, threshing at 700 rpm and 63.5 mm peg spacing, the threshing efficiency, grain damage, cleaning efficiency and separation losses were 99.63 %, 0.47 %, 96.47 % and 2.4 % respectively.

Singhal and Thierstein (1987) developed a spike tooth, axial flow thresher with a multi-crop potential. Using pearl millet at 12 % moisture content, the author obtained a threshing efficiency of 86 %, scatter loss of 5 % and output capacity of 400 kg/hr.

Ndirika (1994) developed and evaluated the performance of a spike tooth, axial flow millet thresher and obtained the machine best output with threshing efficiency of 96.5 %,

cleaning efficiency of 98.3 %, mechanical grain damage of 3.5 %, scatter loss of 2.3 %, and output capacity of 75 kg/hr.

Kamble *et al.* (2003) developed and evaluated a spike tooth, axial flow pearl millet thresher and obtained the machine's best output with a threshing efficiency of 98.6 %, grain damage of 2.75 %, and total grain loss of 2.1 %. The author also obtained 87 % germination of the threshed seeds.

2.15 Kernel Physical and Mechanical Properties

Kebede and Mishra (1990) stated that before fabricating a thresher, it is necessary to obtain certain design parameters based on the engineering properties of grains. These include moisture content, bulk density, size, angle of internal friction and angle of repose. The angle of repose or angle with a horizontal surface formed when a free flowing grain come to rest, can be used to estimate the slope of the oscillating sieve. The angle of repose for soybean is in the range 12-18° (Huji, 2001) and that of millet is in the range 29-40° (Ojediran, 2008). These variations depends on the mechanical properties and other factors such as size and shape of kernels, moisture content, foreign materials content, presence of molds and also the filling and emptying method.

2.15.1 Mechanical and physical properties of soybean

Huji (2001) conducted a research on the physical and mechanical properties of two soybean varieties and the findings are shown in Table 2. Refik *et al.*, 2006 determine some physical properties of soybean at different moisture content. The authors stated that the physical properties of soybean increases with moisture content as shown in Table 2.1

Table 2: Some physical and mechanical properties of two soybean varieties

	Samsoy-2			TGX 1485-ID		
Parameters	**Nº of Sample**	**Mean Value**	**Standard Deviation**	**Nº of Sample**	**Mean Value**	**Standard Deviation**
Length (mm)	60	6.39	0.47	60	6.47	0.64
Width (mm)	60	5.28	0.44	60	5.43	0.57
Thickness (mm)	60	4.69	0.51	60	4.65	0.65
Weight (g)	30	0.17	0.05	30	0.17	0.04
Surface Area (cm^2)	30	3.24	0.68	30	3.73	0.35
Volume (mm^3)	30	0.21	0.03	30	0.24	0.04
Density (kg/m^3)	30	0.83	0.43	30	0.21	0.05
Sphericity	30	1.44	0.33	30	1.65	0.41
Roundness	30	0.63	0.07	30	0.74	0.14
Angle of Repose	20	17.50	3.97	20	12.85	3.05
Grain to Formice	20	5.10	0.86	20	7.43	2.41
Hardness (kg)	20	28.06	6.57	20	19.37	4.77
Compressive Strength	20	98.65	13.62	20	101.30	17.30

Source: (Huji, 2001).

Table 2.1: 1000 seed mass and axial dimensional properties of soybeans (STD in Parentheses)

Moisture content % db	1000 seed Mass g	Length (L) mm	Width (W) mm	Thickness (T) mm	Arithmetic mean diameter $\frac{L+W+T}{3}$ mm	Geometric mean diameter $(L\times W\times T)^{1/3}$ mm
6.7	121.76 (4.03)	7.41 (0.40)	5.34 (0.43)	4.50 (0.39)	5.75	5.62
9.6	155.45 (7.37)	8.09 (0.60)	5.55 (0.43)	4.75 (0.52)	6.13	5.97
12.1	193.98 (7.66)	9.29 (1.00)	6.49 (0.53)	5.21 (0.47)	7.01	6.80
15.3	223.65 (7.66)	9.57 (0.31)	6.75 (0.43)	5.17 (0.29)	7.16	6.94

L/W, Length/Width; L/T, Length/Thickness; L/D_g, Length/Geometric mean diameter

Source: (Refik *et al.*, 2006).

2.15.2 Mechanical, physical and aerodynamic properties of millet

Ojediran *et al.* (2006) determine the aerodynamic properties of pearl millet and reported that terminal velocity increased from 3.73 to 5.13 with an increase in moisture content from 10 % to 20 %. Ojediran (2008) conducted a research on the physical and mechanical properties of millet using two varieties and reported his findings as shown in Table 2.1.

Table 2.2: Some physical properties of Ex-Borno and SOSAT C88 millet seeds

Variety	Ex-Borno					SOSAT C88				
Moisture Content (% w.b)	10	13	15	20	R^2	10	13	15	20	R^2
Length, a (mm)	3.16 *(.253)*	3.57 *(.113)*	3.33 *(.157)*	3.80 *(.134)*	1	3.87 *(.364)*	3.80 *(.110)*	3.79 *(.076)*	4.46 *(.063)*	1
Width, b(mm)	2.30 *(.090)*	2.65 *(.082)*	2.45 *(.126)*	2.66 *(.109)*	1	2.93 *(.379)*	2.77 *(.085)*	2.62 *(.412)*	3.39 *(.053)*	1
Thickness, c (mm)	1.54 *(.069)*	1.64 *(.179)*	1.49 *(.086)*	1.6 *(.049)*	1	2.05 *(.348)*	1.78 *(.176)*	2.19 *(.438)*	2.51 *(.082)*	1
Sphericity	.7007 *(.0006)*	.692 *(.0006)*	.6849 *(.0003)*	.6675 *(.0004)*	1	.7285 *(.0008)*	.6930 *(.0008)*	.7289 *(.0008)*	.7445 *(.0002)*	1
1000 seed mass, (g) (M_{1000})	7.3 *(.492)*	9.08 *(.017)*	9.99 *(.012)*	10.06 *(.026)*	1	9.47 *(.611)*	11.42 *(.012)*	11.09 *(.024)*	11.95 *(.026)*	1
Bulk density(kg/m^3)	811.4 *(.064)*	684.8 *(11.973)*	679.2 *(12.749)*	646.4 *(5.987)*	1	817.64 *(.305)*	728.8 *(8.908)*	726.0 *(7.155)*	725.6 *(9.329)*	1
Solid density (kg/m^3)	958.1 *(36.255)*	953.26 *(35.331)*	956.13 *(49.041)*	960.59 *(32.458)*	1	995.24 *(42.560)*	982.48 *(18.269)*	985.21 *(30.473)*	988.61 *(12.082)*	1
Porosity (%)	15.17 *(.033)*	27.26 *(.037)*	26.18 *(.035)*	32.64 *(.023)*	1	17.28 *(.036)*	20.37 *(.013)*	26.3 *(.027)*	26.60 *(.002)*	1
Angle of repose (^{0})	32.67 *(1.247)*	37.67 *(.047)*	34.67 *(.471)*	40.00 *(0)*	1	29.33 *(5.185)*	34.67 *(.471)*	34.67 *(.471)*	40.00 *(0)*	1

(Numbers in parenthesis are standard deviations)

Source: (Ojediran, 2008).

2.16 **Threshing Parameters**

Sharma and Devnani (1978) developed a specially designed variable speed thresher used for determining threshing parameters like feed rate, grain output, threshing efficiency, energy consumption, and grain damage for soybean and cowpea at the sun dried moisture content of 6.1 % and 6.5 % respectively. The authors found that energy consumption in threshing was found to be directly proportional and highly correlated with feed rate and cylinder tip speed, irrespective, of the concave clearance. At the same rate of material flow the cylinder tip speed the energy consumption for cowpea was higher than for soybean. Also the cleaning and separating units for cowpea consumed 0.625 kW hr/g while that of soybean consumed 0.5 kW hr/g.

This higher energy consumption at some speed and feed rate was associated with the more bushy nature of the crop. It was also noted that the peripheral speed of the cylinder and concave clearance were the most important factors that causes grain damage. For the same cylinder speed and concave clearance, the visible grain damage was grater for soybean whereas the internal grain damage was greater for cowpea. It was also noticed that, although at higher speeds the visible grain damage was below 5 %, the internal damage to grain was very high as determined by germination test.

2.17 **Factors Affecting Grain Threshing**

Threshing of soybean, millet and other similar grain crops can be done with a squeezing action, a rubbing action or a combination of the two, and is a function of crop and machine variables. The crop variables are related to the type, variety, maturity, and moisture content. The machine variables include the feed rate, type of cylinder and concave, cylinder tip speed and concave clearance (Sharma and Devnani 1978).

2.17.1 Cylinder tip speed

Semple *et al*. (1989) stated that damage from rasp bar cylinder increased with peripheral speed, especially at speed above 15.2 m/s. The author also reported that the trend is one of increased crack with increasing or decreasing moisture content. At high kernel moisture content, the soft kernels are easily crushed from impact loading. At low kernel moisture content, the kernel becomes hard and brittle, in this condition it becomes easily fractured under impact loading of the threshing cylinder. Sandra *et al*. (1981), investigated crack formation in maize kernel due to impact loading. The author found no significant difference in both internal and external damage at cylinder speed of l0 m/s. However, at 18m/s, the author obtained highest internal and external damage. Waeiti and Buchele (1969), reported that mechanical damage to seeds which occur during threshing and other farm operations can seriously affect seed viability, germination ability, growth, vigor, insect and fungal attack and the quality of the final product. Therefore, it is important that threshing be done with care, otherwise this operation can cause damage (crack) of grain or protective husk, thus reducing the products quality and fostering subsequent losses from the action of insects and moulds.

2.18 Factors Affecting Grain Cleaning

Grains cleaning occur while particles are changing their orientation rapidly in a random manner within the threshing space. The physical parameters affecting the cleaning process are grouped into:

(i) Machine factors which include : frequency of sieve oscillation, amplitude of oscillation, sieve slope, length of sieve, width of sieve, sieve hole diameter, threshing pressure, air density, angle of air flow and terminal velocity of the grain.

(ii) Crop factor which include: crop varieties, maturity stage, grain moisture content, straw moisture content, bulk density of grain, bulk density of straw, stalk length, grain diameter and angle of repose.

2.18.1 Terminal velocity

Air separation, also called winnowing has been an age long seed cleaning method used by man, where a mixture of grain and chaff was thrown into the air. The heavy grain fell almost straight back onto the reed tray, while the light chaff was moved laterally by the wind beyond the rim of the tray and fell to the ground. The main disadvantages of natural winnowing are due to unpredicTable direction, velocity and continuity of natural wind (Aguirre and Carry, 1999). Since the wind was not a dependable source of moving air, winnowing was later mechanized, (Vaughn and De Louche, 1968). Wang *et al*. (1994), stated that when a grain mass enters a processing plant for cleaning, contaminants are removed on the principles of differences of physical characteristics of components in the mixture. These characteristics are; shape, density, surface texture, terminal velocity, color, electric conductivity. The pertinent of these properties is the terminal velocity, which is the speed a seed will attain in free fall before air resistance will keep it from falling faster (Vaughn and De Louche, 1968). The author stated that this phenomenon could be defined in another way as equivalent to that velocity of air required to suspend the seed in a confined rising column of air. Clark (1984) stated that terminal velocity (U_g) is given as;

$$u_g{}^2 = 3dg\left(\frac{\rho_s - \rho_f}{\rho_f}\right) \quad (2.1)$$

Where,

u_g = terminal velocity (ms^{-1})

d = geometric mean of kernel physical dimensions in the three axial directions (m)

ρ_s = particle density (kgm^{-3})

ρ_f = fluid density (kgm^{-3})

g = gravitational acceleration (ms^{-2})

According to Bolz (1953), the geometric mean of kernel physical dimensions in the three axial directions can be determined as follows;

d = (mean length x mean width x mean thickness)$^{1/3}$ (2.2)

2.18.2 Orientation of particle

Henderson and Newman (1972) stated that when the oscillating frequency of a pan is greater than the natural rocking frequency of a prolate spheroid the particle will orientate itself with its major axis parallel to the plane of oscillation, and when the oscillating frequency of the pan is less than the natural rocking frequency, the particle will orientate itself with its major axis perpendicular to the plane of oscillation**.** Harrison and Blecha (1983) observed that the natural rocking frequency of grains is considerably larger than the oscillating frequency of commercial grain cleaners, suggesting that the major axis of kernels will be perpendicular to the plane of oscillation. The author stated that an equation relating the rocking frequency, f (Hz), with the major and minor axis is given as:

$$f = \left(1/2\pi\right)\left[5g\left(\frac{a^2}{b^2} - 1\right)\right]^{\frac{1}{2}} \Big/ \left[b\left(\frac{a^2}{b^2} + 6\right)\right]^{\frac{1}{2}} \quad (2.3)$$

Where,

f = the rocking frequency (Hz)

a = the length of the major axis (mm)

b = the length of the minor axis (mm)

g = the acceleration due to gravity (mms^2)

Refik *et al*. (2006) determine the aerodynamic properties of soybean at different moisture content. The author stated that the terminal velocity of soybean increases with moisture content as shown in Table 2.3

Table 2.3: Aerodynamic properties of soybean at different moisture content

Moisture content % d.b	**Terminal velocity (m/s)**	**SD**
6.7	7.13	0.31
9.6	7.49	0.62
12.1	8.88	0.50
15.3	9.24	0.56

Source: (Refik *et al.*, 2006).

2.19 Types of Shaft Loadings

A load applied to a mechanical member will induce mechanical forces within the member called stresses when those forces are expressed on a unit basis. The stresses acting on the material causes deformation of the material in various manners. The deformation of the material is called strain when those deformations too are placed on a unit basis. The applied load may be axial (tensile or compressive), or shear. The various types of loadings are stated below:

2.19.1 Transverse loading

Transverse loading is where forces are applied perpendicular to the longitudinal axis of a member. Transverse loading causes a member to bend and deflect from the original position, with internal tensile and compressive strains accompanying the change in curvature of the member. Transverse loading also includes shear forces that cause shear deformation of the material and increase the transverse deflection of the member.

2.19.2 Torsional loading

Torsional loading is where twisting action caused by a pair of externally applied equal and oppositely directed force couples acting on parallel planes or by a single external couple applied to a member that has one end fixed against rotation.

2.19.3 Axial loading

Axial loading is where the applied forces are collinear with the longitudinal axis of the member. The forces cause the member to either stretch or shorten.

(www.wikipedia.org/wiki/strength of materials/types of shaft loading/)

2.20 Important Design Factors (Criteria)

In every design process there are many important design criteria taken into consideration. Some of these factors are stated as follows.

2.20.1 Factor of safety (FoS)

Factor of safety (FoS) also known as safety factor (SF) is a design criteria that an engineered component or structure must achieve. It is a term describing the structural capacity of a system beyond the expected loads or actual loads. Essentially, it is how much stronger that system is than it usually needs to be for an intended load. Factor of safety is usually defined as the ratio of absolute strength (structural capacity) to actual applied load. This is a measure of reliability of a particular design. Components whose failure could result in substantial financial loss, serious injury, or death may use a safety factor of four or higher. Non critical components generally might have a factor of safety of two.

2.20.2 Design factor

The design factor is defined for an application (generally provided in advance and often set by regulatory code or policy) and is not an actual calculation. The safety factor is a ratio of maximum strength to intended load for the actual item that was designed. Design factors for specific applications are often mandated by law, policy or industry standards.

2.20.3 Reserve factor

A measure of strength frequently used in Europe is the reserve factor (RF). With the applied loads expressed in the same units, the reserve factor is defined as:

RF = Proof Strength / Proof Load

RF = Ultimate Strength / Ultimate Load

Design stresses that have been determined from the ultimate or yield point values of the materials give safe and reliable results only for the case of static loading. Many machine parts fail when subjected to non steady and continuously varying loads even though the developed stresses are below the yield point. Such failures are called fatigue failure. The failure is by a fracture that appears to be brittle with little or no visible evidence of yielding. However when the stress is kept below "fatigue stress" or "endurance limit stress", the part will endure indefinitely. When a part is subjected to a cyclic stress, also known as stress range (Sr), it has been observed that the failure of the part occurs after a number of stress reversal (N) even if the magnitude of the stress range is below the material's yield strength. Generally, the higher the stress range, the fewer the number of reversals needed for failure. For loading that is cyclical, repetitive, or fluctuating, it is important to consider the possibility of metal fatigue when choosing factor of safety. A cyclic load well below a material's yield strength can cause failure if it is repeated through enough cycles (www.wikipedia.org/wiki/strength of materials/terms used in design/).

2.21 **Performance Tuning**

Performance tuning is the improvement of a system performance. It is typical with computer systems. Steps of performance tuning involve measuring; evaluating, improving and validating until the goal are reached as listed below.

i. assess the problems by evaluating the performance of the machine before modification.

ii. analyze the result.

iii. identify the parts of the machine that were critical for improving the performance. These were the bottleneck.

iv. modify these parts of the machine to remove the bottleneck.

v. evaluate the performance of the machine again after the modifications were completed.

vi. if the modification makes the performance better, adopt it. If the modification makes the performance worse, put it back the way it was.

(www.wikipedia.org/wiki/performance_tuning).

Certain rules should be kept in mind when optimizing performance:

i. performance tuning must be part of every project.

ii. do not optimize early in the development cycle.

iii. performance is only as good as the weakest link.

iv. always think about capacity vs. volume.

v. optimize important things first.

vi. never optimize without realistic goals.

(www.docs.adobe.com/docs/en/cq/5-6-1/deploying/performance.html)

2.22 **Threshing and Separation Model Development**

Threshing and separation process can be divided into the following sections:

(a) Detachment of the grains from the ears by which the grains becomes free separable grains in the threshing space.

(b) Segregation of free grains kernels through the straw mat to the concave/grate surface.

(c) Passing of free grains kernels through the opening of concave or grates.

(Huynh *et al*., 1982, Miu, 1994, 1995)

(Wacker, 1985; Gasparetto *et al*., 1989; Miu, 2002) has developed the universal mathematical model for grain threshing and separation. The distribution frequency of un-threshed grain percentage into the threshing space is a continuous variable. At the end of the threshing space (e.g x=L for axial unit), the un-threshed grain becomes threshing loss, V_t (%).

$$V_t = S_n(L) = e^{-\lambda L} \qquad (2.4)$$

Where,

V_t = Threshing loss (%)

S_n = Percentage of un-threshed grain

L = Length of the threshing space (m)

λ = Space increments between respective successive event changes (m^{-1})

Enaburekan (1994) developed mathematical and optimization models for the threshing process in a stationary grain thresher using wheat and sorghum. He developed amongst others the following threshing efficiency model:

$$E_t = 1 - e^{-3K_T\rho(1-\alpha)VWDL/2QC} \quad (2.5)$$

Where,

E_t = threshing efficiency (%)

K_T = threshing constant

ρ = crop bulk density (kgm^{-3})

α = crop moisture content (%, dry basis)

V = velocity of threshing cylinder (m/s)

W = width of thresher (m)

D = effective cylinder diameter (m)

L = concave length (m)

Q =crop mass feed rate (kg/s)

C= concave clearance (m)

Miu, (1995) developed a universal mathematical model of grain threshing and separation and was applied to tangential feeding (Miu *et al.,* 2008). The probability that grains will reach the separation surface is the same over the separation length as the probability of free grain passage through the openings of separation surface (Huynh *et al*., 1982; Mailander, 1984; Miu,

1994, 1995; Miu *et al*., 2008; Kutzback and Quick, 1999). The probabilistic laws that respectively describe the above mentioned events were identified as follows:

(a) $$F_x(x) = e^{-\lambda x} \quad (2.6)$$

(b) $$F_f(x) = \frac{\lambda}{\lambda - \beta}\left(e^{-\beta x} - e^{-\lambda x}\right) \quad (2.7)$$

(c) $$F_S(x) = \frac{1}{\lambda - \beta}\left[\lambda\left(1 - e^{-\beta x}\right) - \beta\left(1 - e^{-\lambda x}\right)\right] \quad (2.8)$$

Where,

$F_x(x)$ = un-threshed fraction over the threshing length, x.

$F_f(x)$ = free grain fraction

$F_s(x)$ = cumulative separated grain, fraction

λ and β are probability density function, in decimals, as defined on the threshing space length (x). They represent space increments between respective successive event changes.

λ = specific threshing / segregation rate (m^{-1}).

β = specific separation (m^{-1})

Ndirika (1997) developed mathematical and optimization models for the threshing process in a stationary grain thresher using millet and sorghum. The author developed amongst other things the following threshing model:

$$T_e = 1 - e^{\frac{-1.5K_t\rho_d D V_b L_c}{(1-\beta)F_r}} \quad (2.9)$$

Where,

T_e = threshing efficiency parameter (%)

K_t = threshing constant

ρ = bulk density (kg/m^3)

V_b = cylinder velocity (m/s)

L_c= concave length (m)

F_r = feed rate (kg/s)

D = cylinder diameter (m)

β = moisture content (%, dry basis)

2.23 Dimensional Analysis

Dimensional analysis offers a method for reducing complex physical problems to the simplest form prior to obtaining a quantitative answer. To understand its principles, we must return to some of the very fundamental concepts in science (Sonin, 2001).

2.23.1 Methods of dimensional analysis

The following two methods are important to develop the Effect of physical quantities:

i. Rayleigh's method.

This method of dimensional analysis was originally proposed by Lord Rayleigh in 1899. In this method, functional relationship of variables is expressed in the form of an exponential equation which must be dimensionally homogeneous. It has been observed that Rayleigh's method of dimensional analysis becomes bulky when more variable are involved. In order to overcome this, Buckingham's method may be used.

ii. Buckingham's pi-theorem

When a complete Effect of dimensional physical quantities is expressed in dimensionless form, the number of independent quantities that appear in it is reduced from the original n to n-k, where k is the maximum number of the original n that are dimensionally independent.

Thus:

If $\pi_o = F(A_1, A_2, ..., A_n)$ (2.10)

Then

$$\pi_o = f(\pi_1, \pi_2, \ldots, \pi_{r<n}) \quad (2.11)$$

Where,

π_o = dependent variable.

$A_1, A_2, \ldots, A_n$= independent variables.

$\pi_1, \pi_2, \ldots, \pi_{r<n}$= non dimensional groups of A_i's.

F, f = functional relationships of A_n's and π_r's respectively.

Every correct physical equation; that is every equation that expresses a physically significant Effect of numerical values of physical quantities must be dimensionally homogeneous. Dimensionally homogeneity imposes the following constraints on any mathematical representation of a relationship:

i. Both sides of the equation must have the same dimension.

ii. Where a sum of quantities appears in *f*, all the terms in the sum must have the same dimension.

iii. All arguments of any exponential, logarithmic, trigonometric or other special functions that appear in *f* must be dimensionless.

For example; if a physical equation is represented by

$$A = Be^{-C} - \frac{(D_1 + D_2)}{E} + F \quad (2.12)$$

C must be dimensionless, D_1 and D_2 must have the same dimension, and *A*, *B*, *D/E* and *F* must have the same dimension. An important consequence of dimensional homogeneity is that the form of a physical equation is independent of the size of the base units.

2.23.2 Methods of determining pi terms

i. Inspection method

ii. Step-by-step Method

iii. Exponent Method

2.24 Performance Optimization

To optimize is to make as effective, perfect, or useful as possible. In mathematics it is to determine the maximum or minimum values of a specified function that is subject to a set of constraints. In engineering design it is to find the best compromise among several often conflicting requirements (www.thefreedictionary.com/optimize).

Process optimization is the discipline of adjusting a process so as to optimize some specified set of parameters without violating some constraint. The most common goals are minimizing cost, maximizing output, and/or efficiency. When optimizing a process, the goal is to maximize one or more of the process specifications, while keeping all others within their constraints (www.wikipedia.org/wiki/process_optimization).

2.24.1 MATLAB optimization process

MATLAB optimization is done with MATLAB software. A MATLAB optimization tool "optimtool" is used to select the solver, the optimization options and to run the problem. The optimization tool provides a convenience interface to all optimization routings including those of Genetic Algorithm and Direct search toolbox functions and the results exported to an M-file or to the MATLAB workspace as a structure. The optimization tool also made it easier to:

i. Define and modify the problem quickly

ii. Use the correct syntax for optimization functions

iii. Import and export from the MATLAB workspace

iv. Generate code containing configurations for the solver used and options

v. Change parameters of the optimization during the execution of certain genetic Algorithm and direct search Toolbox Functions

The steps involved in the MATLAB optimization process include:

i. Problem formulation

ii. Defining the problem in the MATLAB toolbox syntax

iii. Running the optimization

iv. Interpreting the Result

(Cleve *et al*., 2008).

2.25 **Description of the Existing IAR Multicrop Thresher**

The IAR multicrop thresher is a vertical flow thresher consisting of the following components: a feed hopper, threshing unit, suction unit, shaker unit, sieve plate, shaker tray, structural frame and power transmission unit. The feed hopper which is trapezoidal in cross section is constructed from gauge 18 mild steel metal sheet with a dimension of 375 mm x 50 mm x 332 mm. The threshing unit consists of a cylinder, beaters and perforated concave Plate. Clearance between the free end of the beaters and concave was 20 mm for soybean threshing and 10 mm for millet threshing. Beaters made of rasp bars are attached on the cylindrical-shaped threshing cylinder. A concave sieve plate made of square iron rods is located below the threshing cylinder to separate the threshed grains from the chaff. As the threshed materials flows down the funnel by gravity onto the shaker, chaff are further removed by a suction fan located at one end of the shaker. The shaker sieve plate constructed with gauge 16 mild steel metal sheet is positioned inside the shaker to separate the chaff that falls along with the grains. The clean grain is then collected in the bottom tray and conveyed through the grain outlet. The structural frame consists of four vertical angle iron 1000 mm high positioned at the four corners of the machine. Two angle iron 800 mm long are welded along its length to support the bottom cover of the machine while two square pipes 470 mm long are welded along its width to support the bearings of the threshing cylinder. The power transmission unit consists of pulleys, V-belts and a 5 Hp petrol engine mounted on a structural frame. The thresher is stationary with its entire weight resting on the ground. A preliminary performance test conducted, indicated that the existing IAR multicrop thresher had a maximum feed rate of 3 kg/min with millet when operated at a speed of 20 m/s. At this speed, the Threshing efficiency, Cleaning efficiency,

Scatter loss, Grain damage and Output capacity obtained with SOSAT C88 Millet variety were 92 %, 80 %, 2.4 %, 3.5 %, and 81 kg/hr respectively. Plates 2a and 2b are rear and front views of the existing IAR multicrop thresher used for threshing millet and sorghum.



Plate 2a: Rear view of the existing IAR multicrop thresher used for threshing millet and sorghum.



Plate 2b: Front view of the existing IAR multicrop thresher used for threshing millet and sorghum.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.24 Design Considerations

The following factors were considered in the design of the multicrop thresher:

i. The choice of materials used for construction of the machine was based on durability, strength, cost and availability in the local market.

ii. The size of the feed hopper was increased to accommodate bulky crops.

iii. The threshing drum diameter was varied along its length to increase volume.

iv. The peripheral threshing cylinder speeds were in the range 10 to 20 m/s.

v. Millet and soybean grain characteristics were considered in determining concave clearance and sieves hole diameter of the concave and shaker sieves.

vi. The terminal velocities of free falling grains were considered in determining the number of blades on the blower for perfect cleaning.

vii. The frequency of the shaker was maintained at 2.4 Hz and the shaker tray was maintained at a slope angle of 23 ^{o} to the horizontal for easy grain flow.

viii. All power transmission was made to take place at one end of the shaft

ix. The moisture content wet bases considered were in the range 10 % to 16 %.

x. The strength of soybean and millet stem was considered in selecting the thickness of the shredder, top sieve and beaters.

xi. The total volume of crop fed per minute was considered in selecting the volume of the hopper and threshing chamber.

xii. The operator's safety was considered by locating the operator's stand away from all rotating machine parts and crop particles propelled by the machine.

xiii. Towing of the machine was considered by incorporating a tow bar and rear wheels.

3.25 Selection of Construction Materials

The following materials were selected and used: Gauge16 (3 mm) and 18 (2 mm) mild steel sheets, medium carbon steel rods (C1040), angle iron bar (250 mm x 250 mm x 3 mm), square pipe (250 mm x 250 mm x 3 mm), pulleys (of different diameters), V-belts (of different lengths), Flat belt, bolts and nuts, bearings (of different diameters), spraying machine, leaf green paint and two 14 inches tires.

3.26 Design Equations (Design Theories)

The following equations were employed in the design of the machine.

3.26.1 Determination of blower casing diameter

Mohammed (2009) and Hem (1981) stated that the airflow (Q_A) through a blower is given as;

$$Q_A = V \times D \times W \quad (3.1)$$

Where,

V= velocity of air required for cleaning, (ms^{-1}).

D = depth of air stream (m).

W= width over which air is required (m).

The authors stated that the efficiency of a centrifugal blower is 30 %. Therefore, theoretical air discharge (Q_T) is given as:

$$Q_T = \frac{Q_A}{0.3} \tag{3.2}$$

Also, the outer casing of a blower should follow a spiral of the arithmetic form given by the equation below:

$$\gamma = \gamma_o(1 + \kappa\theta) \tag{3.3}$$

Where,

γ = radius of casing at 6° shift from initial radius of casing (mm).

γ_o = initial radius of casing (mm).

k = constant (0.0020 to 0.0023).

θ = angular displacement in degrees.

3.26.2 **Determination of shaker frequency of oscillation**

Harrison and Blecha (1983) stated that an equation relating the rocking frequency f (Hz), with the major and minor axis is given as:

$$f = \left(1/2\pi\right)\left[5g\left(\frac{a^2}{b^2} - 1\right)\right]^{\frac{1}{2}} \Big/ \left[b\left(\frac{a^2}{b^2} + 6\right)\right]^{\frac{1}{2}} \tag{3.4}$$

Where,

f = the rocking frequency (Hz)

a = the length of the major axis (mm)

b = the length of the minor axis (mm)

g = the acceleration due to gravity (mms^2)

3.26.3 **Determination of threshing cylinder diameter**

Hem (1981) recommended the peripheral cylinder speed *V* for maize threshing to fall in the range 750 to 1220 m/min, while Mohammed (2009) recommended the number of revolutions of the threshing cylinder *N* for maize threshing to fall in the range 450 to 986 rpm. The threshing cylinder diameter was determined by Hem (1981) and Mohammed (2009) as follows:

$$V = \pi DN \tag{3.5}$$

Where,

D = diameter of circle inscribed by beater tip (m)

N = number of revolution of the threshing cylinder (rev/min)

V = peripheral cylinder speed (m/min)

Hence $D = \frac{V}{\pi N}$

Also, *D* = d + 2 p

Where,

D = diameter of circle inscribed by beater tip (m)

d = diameter of threshing cylinder (m)

p = height of peg (m)

Therefore, d = D - 2p

and $d = \frac{V}{\pi N} - 2p$

3.26.4 **Determination of concave sieve radius**

Nalado (2006) and Mohammed (2009) stated the expression for determining the concave sieve radius as follows:

$$r_c = r_d + h_p + c_c \tag{3.6}$$

Where,

r_c = radius of concave sieve (mm)

r_d = radius of threshing cylinder (mm)

h_p = height of peg (mm)

c_c = concave clearance (mm)

3.26.5 Determination of sieve hole diameter

(ASAE, 1984) stated the expression for determining the diameter of sieve hole as follows:

$$D_e = \left[6V_g/\pi\right]^{\frac{1}{3}} \quad (3.7)$$

Where,

D_e = equivalent diameter (sieve hole) (mm)

V_g = grain volume (mm^3)

3.26.6 Determination of power required for sieve oscillation

Hem (1981) stated that the power required for oscillation is the summation of the power required for movement in the vertical and horizontal directions.

Power required for vertical and horizontal movement were given as:

$$kW_1 = \frac{w_s \times N \times 2 \times y}{4500} \quad (3.8)$$

$$kW_2 = \frac{w_s \times N \times \mu \times 2 \times x}{4500} \quad (3.9)$$

Where,

kW_1 = the power required for vertical movement

kW_2 = the power required for horizontal movement

w_s = weight of reciprocating unit along with the material on it (kg)

N = eccentric speed (rpm)

y = the vertical displacement of the reciprocating system in meter per stroke

x = the horizontal displacement of reciprocating system in meter per stroke

μ = the kinetic coefficient of friction at hinge points

Total power required for sieve oscillation was therefore given by:

$$P = kW_1 + kW_2$$

3.26.7 Determination of weight of the blower blades

Hannah and Steven (1984) stated the expression used for determining the weight of blower blades (W_b) as follows:

$$W_b = \delta g v \tag{3.10}$$

Where,

W_b = weight of blower blade (N)

δ = density of blower galvanized steel blade (kg/m^3)

g = acceleration due to gravity (m/s^2)

v = volume of the blower blades (length x width x thickness) (m^3)

3.26.8 Determination of fan speed required for cleaning

Joshi (1981) stated the expression for determining air discharge through the blower as follows:

$$V = \frac{2\pi r N}{60} \tag{3.11}$$

Where,

N = fan speed (rpm)

V = air velocity required for cleaning (m/s)

r = distance between the center of the shaft to the apex of the fan blade (m)

3.26.9 Determination of air discharge by blower

Joshi (1981) stated that the air flow rate was given as:

$$Q = AV \tag{3.12}$$

Where,

Q = air flow rate (m^3/s)

A = area of inlet duct of the blower (m^2)

V = terminal velocity of the threshed grain (air velocity required for cleaning) (m/s)

But $A = LW$

Where,

A = area of inlet duct of the blower (m^2)

L = length of inlet duct of the blower (m)

W = width of inlet duct of the blower (m)

3.26.10 Determination of number of blades

Joshi (1981) stated that the number of blades required by a blower was obtained as:

$$N_b = \frac{Q}{V} \tag{3.13}$$

Where,

N_b = number of blades required

V= volume of air displaced per blade (m^3)

Q= required air flow rate for cleaning (m^3/s)

3.26.11 Determination of pulleys diameter

Hannah and Stephen (1984) stated the expression used for determining pulleys diameter (D) as follows:

$$N_1 D_1 = N_2 D_2 \tag{3.14}$$

Where,

N_1 = speed of drive (petrol engine) pulley (rpm)

D_1 = diameter of drive Pulley (m)

N_2= speed of driven pulley (rpm)

D_2 = diameter of driven pulley (m)

3.26.12 Determination of belt length

Khurmi and Gupta (2007) stated the expression used for determining length of each belt of a machine (L) as follows:

$$L = \frac{\pi}{2}(D+d) + 2c + \frac{(D-d)^2}{4c} \quad (3.15)$$

Where,

L = effective length of belt (cm)

c = center distance from drive to driven pulley (cm)

d = outside diameter of drive pulley (cm)

D = diameter of driven pulley (cm)

3.26.13 Determination of belt speed

Hannah and Stephen (1984) stated the expression used for determining speed of each belt of a machine (V) as follows:

$$V = \frac{\pi DN}{60} \quad (3.16)$$

Where,

N = drive speed (rpm)

D = diameter of drive pulley (m)

V = belt speed (m/s)

3.26.14 Determination of belt tension ratio

Hannah and Stephen (1984) stated the expression used for determining the tension on each belt of a machine (T) as follows:

$$\frac{T_t}{T_s} = e^{\mu\theta \operatorname{cosec}(\beta)} \quad (3.17)$$

Where,

T_t = tension on the tight side of belts (N)

T_s = tension on the slack side of belts (N)

θ = angle of lap (^{o})

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

μ = coefficient of friction between the belt (rubber) and the pulley (steel)

Also $T_t - T_s = \frac{m_t}{r}$ (3.18)

Where,

m_t = torsional moment (Nm)

r = radius of driven pulley (m)

3.26.15 Determination of torsional moment

Hannah and Stephen (1984) established the expression used for determining torsional moment of a machine (m_t) as follows:

$$m_t = \frac{P}{w}, \text{ and } w = \frac{2\pi N}{60}$$

Hence $m_t = \frac{Px60}{2\pi N}$ (3.19)

Where,

m_t = torsional moment (Nm)

P = rated engine power (kW)

w = angular velocity (rads/sec)

N = rated engine speed (rpm)

3.26.16 Determination of angle of lap (contact) of belt

Mohammed (2009) determines the angle of lap (θ) of a V- belt as follows:

$$\theta_1 = 180 - 2\sin^{-1}\left(\frac{R-r}{C}\right) \quad (3.20)$$

$$\theta_2 = 180 + 2\sin^{-1}\left(\frac{R-r}{C}\right) \quad (3.21)$$

Where,

R = radius of larger pulley (mm)

r= radius of smaller pulley (mm)

C = center distance between driven and driving pulleys (mm)

θ_1 =angle of lap for smaller pulley (^{o})

θ_2 =angle of lap for larger pulley (^{o})

3.26.17 **Determination of power required by the engine**

The power required by the engine for threshing and cleaning soybean/millet was determined by the relationship:

$$P_E = P_T + P_C \quad (3.22)$$

Where,

P_E = engine power (kW)

P_T = power required for threshing (kW)

P_C = power required for cleaning (kW)

But,

$P_E = T_E W_E$

$P_T = T_T W_T$

$P_C = T_C W_C$

Where,

T_E = engine torque (Nm)

W_E = angular velocity of engine (rads/sec)

T_T = torque required for threshing (Nm)

W_T = angular velocity required for threshing (rads/sec)

T_C = torque required for cleaning (Nm)

W_C = angular velocity required for cleaning (rads/sec)

3.26.18 Determination of power required by the blower

The power required by the blower was determined according to William *et al.* (2015) thus:

$$P = P_d Q \tag{3.23}$$

$$P_d = \frac{1}{2}\rho V^2$$

Where:

P = power required by the blower (W)

P_d = dynamic pressure (N/m^2)

Q = volume flow rate (m^3/s)

ρ = density of air (kg/m^3)

V = velocity of air (m/s)

3.26.19 Determination of weight of a material

Hannah and Stephen (1984) stated the expression used for determining the weight of a material as follows:

$$W = \delta g v \tag{3.24}$$

Where,

W = weight of material (N)

δ = density of galvanized steel (kg/m^3)

g = acceleration due to gravity (m/s^2)

v = volume of the material (length x width x thickness) (m^3)

3.26.20 Determination of shaft diameter

To determine the diameter of a shaft ASME code (1948) stated that the maximum allowable shear stress is obtained as the lower value of 18 % ultimate tensile stress (S_t) and 30 % yield stress (S_y). And for shaft with keyway the maximum allowable shear stress is reduced by 25 % to take care of the stress concentration.

Hall and Holowenko (1982) stated the expression for determining the diameter of a shaft that is subjected to only bending and torsion as follows:

$$d^3 = \frac{16}{\pi S_a}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (3.25)$$

Where,

d = shaft diameter (m)

S_a = allowable shear stress (N/m^2)

M_b = bending moment (Nm)

M_t = torsional moment (Nm)

K_b = combined shock and fatigue factor applied to bending moment (1.5)

K_t = combined shock and fatigue factor applied to torsional moment (1.0)

3.27 Design Calculations

The following calculations were conducted in the design of the machine. Details of the calculations are shown on Appendix A.

3.27.1 Determination of blower casing diameter

The diameter of blower casing was determined using the expression in equation (3.3).

$\gamma = \gamma_o(1 + \kappa\theta)$

γ_o = radius of blade + clearance = 176 mm + 14 mm = 190 mm

k = 0.0023

θ = 15° (assume a displacement of 15° from initial position)

γ = 190 (1+ 0.0023×15) = 196.555 mm

A radius of 197 mm was determined thus, the diameter of the blower casing was chosen to be 394 mm.

3.27.2 **Determination of threshing cylinder diameter**

The threshing cylinder diameter was carefully selected. The threshing cylinder was designed to have two different diameters along its length. A section on the cylinder was chosen to have a diameter of 210 mm. This forms the larger diameter section of the threshing cylinder which lay directly below the feed hopper so that crops such as soybean with cultivars ranging from 450 mm to 1200

mm will not entangle easily on the cylinder. Another section on the cylinder was chosen to have a diameter of 160 mm. This forms the smaller diameter section of the threshing cylinder with a larger threshing volume to accommodate much threshing material at a time. Both diameters were carefully selected to solve the problem of bulky crops such as soybean and millet entangling the cylinder causing it to slow down or stop as was observed on the existing IAR multicrop thresher.

3.27.3 **Determination of sieves hole diameter**

The diameter of sieve hole was determined using the expression in equation (3.7).

$$D_e = \left[6V_g / \pi\right]^{\frac{1}{3}}$$

The grain volume of SOSAT C88 millet seed at 20 % moisture content V_g = 37.9496 mm^3

For easy discharge of grains the chosen diameter was made 20 % larger than the calculated equivalent diameter of the millet seed.

Thus, the chosen diameter D = 0.2D_e +D_e

The sieve hole diameter for millet threshing was determined to be 5 mm.

The grain volume of TGX 1485-ID soybean seed at 15 % moisture content V_g =163.36 mm^3

For easy discharge of grains the chosen diameter was made 25 % larger than the calculated equivalent diameter of the soybean seed.

Thus, the chosen diameter D = 0.25D_e +D_e

The sieve hole diameter for soybean threshing was determined to be 8.5 mm.

3.27.4 **Determination of the concave sieve radius**

The radius of the concave sieves was determined using the expression in equation (3.6).

$$r_c = r_d + h_p + c_c$$

r_d = 80, h_p = 130, c_c = 20 for soybean and c_c = 10 for millet

Thus, r_c = 80 + 130 + 20 = 230 mm

The soybean concave sieve radius was determined to be 230 mm

Thus, r_c = 80 + 130 + 10 = 220 mm

The millet concave sieve radius was determined to be 220 mm

3.27.5 **Determination of fan speed required for cleaning**

The fan speed required for cleaning was determined using the expression in equation (3.11).

$$V = \frac{2\pi rN}{60}$$

The terminal velocity of millet (V)= 5.13 m/s, r = 0.176 m

Hence, $5.13 = \frac{2 \times \pi \times 0.176 \times N}{60}$

$$N = \frac{5.13 \times 60}{2 \times \pi \times 0.176} = 278.1 \text{ rpm}$$

The fan speed required for cleaning millet was determined to be 278.1 rpm

The terminal velocity of soybean (V) = 9.24 m/s, r = 0.176 m

Hence, $9.24 = \frac{2 \times \pi \times 0.176 \times N}{60}$

$N = \frac{9.24 \times 60}{2 \times \pi \times 0.176}$ = 501.1 rpm

The fan speed required for cleaning soybean was determined to be 501.1 rpm

3.27.6 **Determination of air discharge by the blower**

The air discharge by the blower was determined using the expression in equation (3.12).

Air flow rate (Q) = AV

But the area of inlet duct of the blower $(A) = LW$

L = 0.510 m, W = 0.126m

A = 0.510 x 0.126 = 0.06426 m^2

Considering the terminal velocity of the heavier grain V = 9.24 m/s

Therefore, Air flow rate Q = 0.06426 x 9.24 = 0.5938 (m^3/s)

Since the efficiency of a blower is 30 %, (Hem, 1981) the actual air flow rate was given as:

Q_a = 0.3 x 0.5938 = 0.1781 (m^3/s)

Therefore, the actual air flow rate of the blower was determined to be 0.1781 (m^3/s)

3.27.7 **Determination of the number of blades required**

The number of blades required was determined using the expression in equation (3.13).

Volume of air displaced = Area of blade x Distance covered by blade per second

$V = (l \times w) \times (\pi \times D)$

l = 430 mm = 0.43 m, w = 130 mm = 0.13 m, D = 260 mm = 0.26 m

Therefore, $V = (0.43 \times 0.13) \times (\pi \times 0.26)$= 0.04566 ($m^3$/s)

The number of blades (N_b) required = Actual air flow rate / Volume of air displaced per blade (V)

$N_b = \frac{Q_a}{V}$

$$N_b = \frac{Q_a}{V} = \frac{0.1781}{0.04566} = 3.9$$

$N_b = 3.9 \approx 4$

The number of blades required by the machine was determined to be four.

3.27.8 **Determination of weight of the blower**

The weight of the blower was determined using the expression in equation (3.10).

$$W_b = \delta g v$$

δ = 7850 (kg/m^3), g = 9.81 (m/s^2), v = (0.43 x 0.13 x 0.002) = 1.118 x 10^{-4} (m^3)

Hence, all four blower blades W_1= 34.4 N

The weight of blower shaft (W_2) = 18.9 N

The weight of blower pulley (W_3) = 13.1 N

Therefore, $W_b = W_1 + W_2 + W_3$ = 34.4 + 18.9 + 13.1 = 66.4 N

The weight of the blower was determined to be 66.4 N; thus the mass was 6.64 kg

3.27.9 **Determination of pulley diameters**

The pulley diameters were determined using the expression in equation (3.14).

$$N_1 D_1 = N_2 D_2$$

The diameter of the driven cylinder pulley (D_2) was determined as shown below:

N_1 = 1300 rpm, D_1 = 100 mm, N_2= 650 rpm

Thus, $D_2 = \frac{N_1 D_1}{N_2} = \frac{1300x100}{650}$ = 200 mm

The diameter of the driven cylinder pulley D_2 was chosen to be 200 mm.

The diameter of the shaker pulley (D_4) was determined as shown below:

N_3 = 650 rpm, D_3 = 90 mm, N_4 = 189 rpm

Thus, $D_4 = \frac{N_3 D_3}{N_4} = \frac{650 \times 90}{189}$ = 309.5 ≈ 310 mm

The diameter of the shaker pulley was determined to be 310 mm.

The diameter of the blower pulley (D_5) was determined as shown below:

N_4 = 650 rpm, D_4 = 200 mm, N_5 = 929 rpm

Thus, $D_5 = \frac{N_4 D_4}{N_5} = \frac{650 \times 200}{929}$ = 140 mm

The diameter of the blower pulley was determined to be 140 mm.

3.27.10 **Determination of belt lengths**

The length of each belt was determined using the expression in equation (3.15).

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

The cylinder belt length (L_1) was determined as shown below:

c =107 cm, d =10 cm, D =20 cm

Thus, $L_1 = \frac{\pi}{2}(20+10) + 2(107) + \frac{(20-10)^2}{4(107)}$ = 261.4 cm OR $\frac{261.4}{2.5}$ = 104.5 ≈ 105 inches

The cylinder belt length was determined to be A105.

The shaker belt length (L_2) was determined as shown below:

c = 42 cm, d = 9 cm, D = 31 cm

Thus, $L_2 = \frac{\pi}{2}(31+9) + 2(42) + \frac{(31-9)^2}{4(42)}$ = 149.7 cm OR $\frac{149.7}{2.5}$ = 59.9 ≈ 60 inches

The shaker belt length was determined to be A60.

The blower belt length (L_3) was determined as shown below:

c = 64 cm, d = 20 cm, D = 14 cm

Thus, $L_3 = \frac{\pi}{2}(14+20) + 2(64) + \frac{(14-20)^2}{4(64)}$ = 181.5 cm OR $\frac{181.5}{2.5}$ = 72.6 ≈ 73 inches

The blower belt length was determined to be A73

3.27.11 **Determination of belt speeds**

The speed of each belt was determined using the expression in equation (3.16).

$$V = \frac{\pi DN}{60}$$

When the prime mover was set at 909 rpm, the cylinder belt speed was determined as shown below:

N = 909 (rpm), D = 100 mm = 0.1 (m)

Thus, $V_1 = \frac{\pi \times 0.1 \times 909}{60}$ = 4.76 m/s

The cylinder belt speed was determined to be 4.76 m/s.

When the prime mover was set at 909 rpm, the shaker belt speed was determined thus:

$N_1D_1 = N_2D_2$

N_1 = 909 rpm, D_1 = 100 mm, D_2 = 200 mm

N_2 was determined to be = 454.5 (rpm)

D_3 = 90 mm = 0.09 (m)

Thus, $V_2 = \frac{\pi \times 0.09 \times 454.5}{60}$ = 2.14 m/s

The shaker belt speed was determined to be 2.14 m/s.

When the prime mover was set at 909 rpm, the blower belt speed was determined as shown below:

N_2 = 454.5 (rpm)

D_2 = 200 mm = 0.2 (m)

Thus, $V_3 = \frac{\pi \times 0.2 \times 454.5}{60}$ = 4.76 m/s

The blower belt speed was determined to be 4.76 m/s

3.27.12 **Determination of angles of lap (contact) of belts**

The angle of lap (contact) of V-belt on a pulley was determined using the expression in equations (3.20) and (3.21).

$$\theta_1 = 180 - 2\sin^{-1}\left(\frac{R-r}{C}\right)$$

$$\theta_2 = 180 + 2\sin^{-1}\left(\frac{R-r}{C}\right)$$

The belt lap angles between prime mover and cylinder pulleys:

R = 100 mm, r = 50 mm and C = 1160 mm

The lap angle on the prime mover pulley was 175.1 ^{o} and that on the cylinder pulley was 184.9 ^{o}.

The belt lap angles between cylinder and shaker pulleys:

R = 155 mm, r = 45 mm and C = 420 mm

The belt lap angle on the cylinder pulley was 149.6 ^{o} and that on the shaker pulley was 210.4 ^{o}.

The belt lap angles between cylinder and blower pulleys:

R = 100 mm, r = 70 mm and C = 640 mm

The belt lap angle on the cylinder pulley was 185.4 ^{o} and that on the blower pulley was174.6 ^{o}.

3.27.13 Determination of power required to oscillate sieve

The power required to oscillate sieve was determined using the expression in equations (3.8) and (3.9).

$$kW_1 = \frac{w_s \times N \times 2 \times y}{4500}$$

$$kW_2 = \frac{w_s \times N \times \mu \times 2 \times x}{4500}$$

w_s = 15 kg, N = 900 rpm, x = 4 cm, y = 4 cm and μ=0.08

Power required for vertical movement (kW_1) was determined to be = 0.24 kW

Power required for horizontal movement (kW_2) was determined to be = 0.02 kW

Total power required $P = kW_1 + kW_2$

P = 0.24 + 0.02 = 0.26 kW

The power required to oscillate sieve was determined to be 0.26 kW

3.27.14 **Determination of power required by the blower**

The power required by the blower was determined using the expression in equation (3.23).

$$P = P_d Q$$

$$P_d = \frac{1}{2}\rho V^2$$

ρ =1.165 kg/m^3 at 30 ^{o}C, V = 9.24 m/s, Q = 0.5938 m^3/s

$$P_d = \frac{1}{2} \times 1.165(9.24)^2 = 49.73 \text{ N/m}^2$$

$$P = 49.73 \times 0.5938 = 29.53 \text{ W} = 0.03 \text{ kW}$$

The power required by the blower was determined to be 0.03 kW

3.27.15 **Determination of power required by the engine**

The power required by the engine for threshing soybean or millet was determined using the expression in equations (3.22)

$P_E = P_T + P_C$

But, $P_E = T_E W_E$, $P_T = T_T W_T$, $P_C = T_C W_C$

The power required for cleaning (P_C) equals the power required by the shaker and the power required by the blower.

The power required by the shaker was determined previously as 0.26 kW and that required by the blower was also dertermined to be 0.03 kW.

Hence, P_C = 0.26 + 0.03 = 0.29 kW

The power required to thresh crop equals the total torque on the shaft multiplied by the total angular velocity.

Thus, $P_T = T_T W_T$

The total torque on the shaft is equal to the effective torque on the beaters required for cutting plus that required for threshing.

Hence, T_T = 23.94 +7.56 = 31.5 Nm

The threshing speed of the IAR thresher for soybean and millet was determined during preliminary test to be (20 m/s). From Appendix O3 the diameter of the peripheral cylinder was 420 mm or 0.42m. Hence, the required speed of the threshing cylinder for the developed thresher was determined as follows:

$$V = \frac{\pi DN}{60}$$

$$20 = \frac{\pi \times 420 \times N}{60}$$

$$N = \frac{60 \times 20}{\pi \times 0.42} = 909 rpm$$

Hence, for the developed thresher 20 m/s equals to 909 rpm.

Thus,

$$W_T = \frac{2\pi N}{60} = \frac{2\pi 909}{60} = 95.19 \text{ rads / sec}$$

And $P_T = T_T W_T$

$$P_T = 31.5 \times 95.19 = 2998.49 \text{ W} = 3 \text{ kW}$$

Therefore the power required for threshing soybean or millet was 3 kW.

The engine power required for threshing soybean or millet was determined thus:

$P_E = P_T + P_C$

$P_E = 3 + 0.29$

$P_E = 3.29$ kW

The engine power required for threshing and cleaning soybean or millet was determined to be 3.29 kW.

3.27.16 **Determination of belt tensions ratio**

The tension on each belt (T) was determined using the expressions in equations (3.17), (3.18) and (3.19).

$$m_t = \frac{P}{w} \text{ , and } w = \frac{2\pi N}{60}$$

Hence, $m_t = \frac{P \times 60}{2\pi N}$

Also, $m_t = (T_t - T_s)\, r$

$$T_t - T_s = \frac{m_t}{r}$$

$$\frac{T_t}{T_s} = e^{\mu\theta \operatorname{cosec}(\beta)}$$

$\theta = 175.1^o$, $\beta = 20^o$ and $\mu = 0.5$

The belt tension driving the cylinder pulley on the slack side was 7.04×10^{-40} N and that driving the cylinder pulley on the tight side was 313.3 N

The initial tension on the cylinder belt (T_i) was 156.65 N

$\theta = 149.6^o$, $\beta = 20^o$ and $\mu = 0.5$

The belt tension driving the shaker pulley on the slack side was 9.2×10^{-35} N and that driving the shaker pulley on the tight side was 35.23 N

The initial tension on the shaker belt (T_i) was 17.62 N

$\theta = 185.4^o$, $\beta = 20^o$ and $\mu = 0.5$

The belt tension driving the blower pulley on the slack side was 1.25×10^{-44} N and that driving the blower pulley on the tight side was 9 N

The initial tension on the blower belt (T_i) was 4.5 N

3.27.17 **Determination of shaker frequency of oscillation**

The frequency of oscillation of the shaker tray was determined using the expression in equation (3.4).

$$f = \left(1/2\pi\right)\left[5g\left(\frac{a^2}{b^2}-1\right)\right]^{\frac{1}{2}} \Big/ \left[b\left(\frac{a^2}{b^2}+6\right)\right]^{\frac{1}{2}}$$

With a = 505 mm, b = 140 mm and g = 10000 mms^2

The frequency of oscillation of the shaker tray was determined to be 2.4 Hz. Therefore the shaker makes 2.4 circles per second.

3.27.18 Determination of torsional moment

The maximum torsional moment was determined using the expression in equation (3.19).

$m_t = \frac{P}{w}$, $w = \frac{2\pi N}{60}$ Hence, $m_t = \frac{P \times 60}{2\pi N}$

Determination of torsional moment required for threshing (M_1)

From above, the total torque on the shaft required for threshing was calculated to be 31.52 *Nm*.

Determination of torsional moment required by shaker shaft (M_2)

P = 0.26 *kW* and N = 454.5 *rpm*

M_2 = 5.46 *Nm*.

Determination of torsional moment required by the blower shaft (M_3)

P = 0.03 *kW* and N = 454.5 *rpm*

M_3 = 0.63 *Nm*.

The maximum torsional moment of the machine was given by:

$m_t = M_1 + M_2 + M_3$

m_t = 31.52 + 5.46 + 0.63

m_t = 37.61 *Nm*

The maximum torsional moment used for threshing and cleaning was 37.61 *Nm*

3.27.19 Determination of total load on the threshing cylinder shaft

The weight of a material was determined using the expression in equation (3.24).

$W = \delta g v$

Determination of threshing cylinder weight (W_1)

δ = 7850 (kg/m^3), g = 9.81 (m/s^2) and v = 2.271 x 10^{-3} (m^3)

W_1= 7850 x 9.81 x 2.271 x 10^{-3} = 174.9 N

Determination of beaters weight (W_2)

δ = 7850 (kg/m^3), g = 9.81 (m/s^2) and v = 9.31 x 10^{-4} (m^3)

W_2 = 7850 x 9.81 x 9.31 x 10^{-4} = 71.7 N

Determination of chaff thrower weight (W_3)

δ = 7850 (kg/m^3), g = 9.81 (m/s^2) and v = 2.1 x 10^{-4} (m^3)

W_3 = 7850 x 9.81 x 2.1 x 10^{-4}= 16.2 N

The total load on the threshing cylinder shaft was given by:

$W = W_1 + W_2 + W_3$

W = 174.9 + 71.7 + 16.2 = 262.8 N

The total load on the shaft due to the cylinder, beaters and chaff throwers was 262.8 N

Determination of load on the cylinder shaft due to belt tensions

The load on the cylinder shaft due to shaker belt tension was determined to be 35.23 N.

The load on the cylinder shaft due to blower belt tension was determined to be 9 N.

The load on the cylinder shaft due to prime mover belt tension was determined to be 313.3 N.

Since the prime mover and the blower share the same pulley on the threshing cylinder shaft their combined load exerted at that point was = 313.3 + 9 = 322.3 N

The loads acting on the shaft are represented on a free body diagram (FBD) in Fig. 3a.

R_1 and R_2 are normal reaction forces acting at the bearings.

R_1 was determined to be 106.94 N

R_2 was determined to be 504.39 N

3.27.20 **Determination of maximum shear force and bending moment**

Considering the forces acting downward as positive while those acting upward as negative, the shear forces at each point (A, B, C, D and E) of the shaft were determined.

The maximum shear force was determined to be 348.53 N

Considering the bending moment (BM_A and BM_E) at the end loads as zero and considering clockwise direction as negative and anti clockwise direction as positive, the bending moments at each point (A, B, C, D and E) of the shaft were determined.

The maximum bending moment was determined to be 75.03 Nm

The free body diagram (FBD), shear force diagram (SFD) and bending moment diagram (BMD) of the cylinder shaft loadings are shown on Fig. 3a, 3b and 3c respectively.

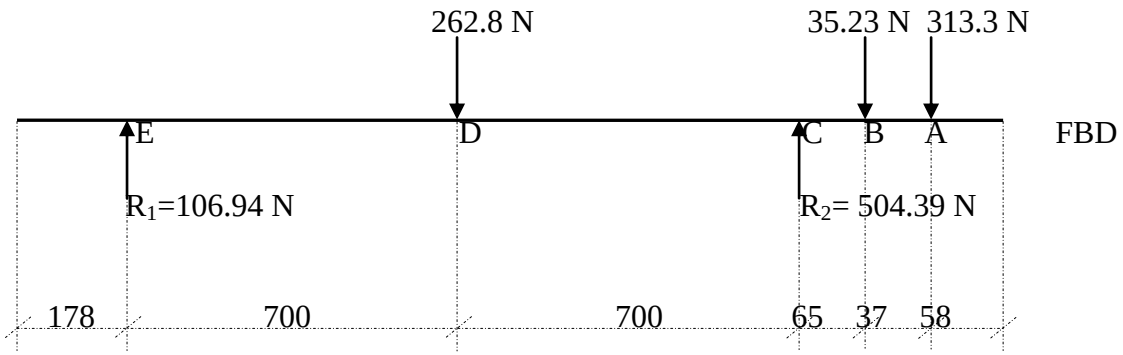


Fig. 3a: Free body diagram of the cylinder shaft (The dimensions are in millimeters).

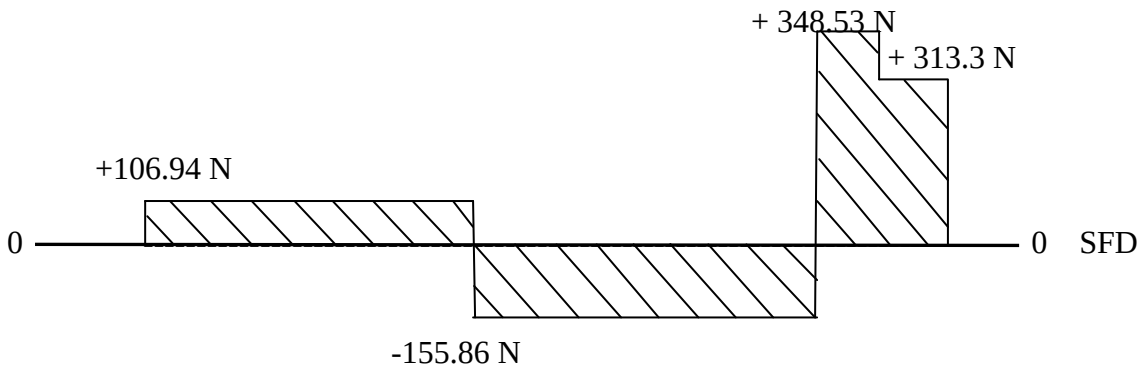


Fig. 3b: Shear force diagram of the cylinder shaft.

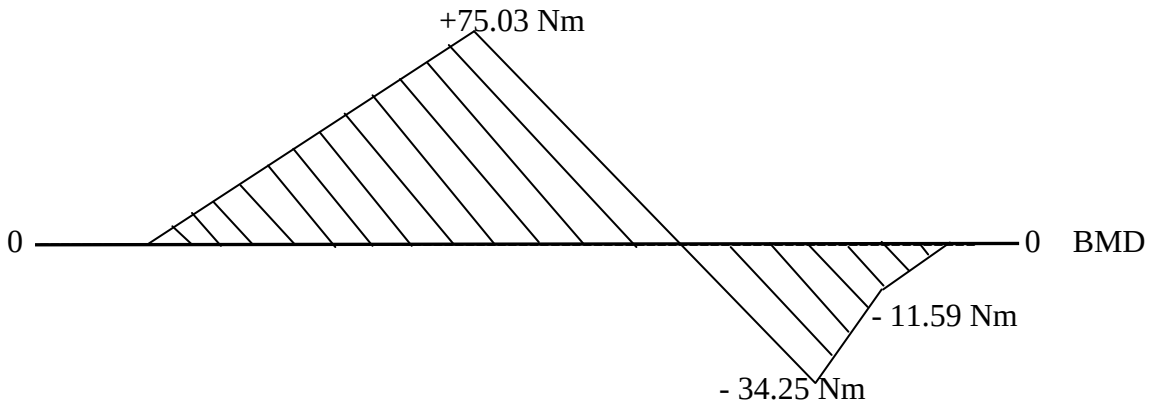


Fig. 3c: Bending moment diagrams of the cylinder shaft.

3.27.21 **Determination of the threshing cylinder shaft diameter**

The threshing cylinder shaft diameter was determined using the expression in equation (3.25).

$$d^3 = \frac{16}{\pi S_a}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$$

The maximum allowable shear stress was obtained as the lower value of 18 % ultimate tensile stress (S_t) and 30 % yield stress (S_y). Since the shaft has keyway the maximum allowable shear stress was reduced by 25 % to take care of the stress concentration.

With S_a = 90.3 MN/m^2, K_b = 1.5, K_t = 1.0, M_b = 75.03 Nm and M_t = 37.61 Nm

The threshing cylinder shaft diameter was determined to be 18.85 mm

A factor of safety of 1.32 was chosen to take care of deformation due to fatigue caused by cyclic loading. Thus, a 25 mm diameter shaft was chosen for the threshing cylinder.

3.28 Construction of the Machine

The following tools were used for construction: Center punch, hammer, vice, hake saw, chisel, square, drilling machine, drill bits, cutting machine, cutting disc, grinding machine,

grinding disc, bending machine, rolling machine, lathe machine, welding machine, electrodes, Vernier caliper (fischer scientific with resolution count of 0.01 cm), measuring tapes and spanners. The components of the machine were constructed at Agricultural Engineering Department workshop, Ahmadu Bello University, Zaria. The specifications determined by design calculations were used in the construction of the components. These components include: the structural frame, feed hopper, threshing cylinder, sieves, blower, shaker mechanism, power transmission unit, tow bar and rear wheels. The costs of materials used for developing the multicrop thresher as at December, 2016 are shown in Table 3. The multicrop thresher components are shown in Plates 3(a, b), 3.1(a, b), 3.2(a, b), 3.3 and Appendix O1 to O16. Their fabrication methods are given in Table 3.1.

Table 3: Cost of materials used for developing the multicrop thresher as at December, 2016

Description	**Quantity**	**Unit Cost (₦)**	**Total Cost (₦)**
(50 x 50) mm Angle iron	3	7500	22500
Gauge18 mild steel Sheet (3 mm)	1	15400	15400
Gauge16 mild steel Sheet (2 mm)	3	11500	34500
Flat bars (5 mm thick)	1	4500	4500
15 mm diameter rod	1	5200	5200
25 mm diameter shaft	1	3800	3800
20 mm diameter shaft	1	1900	1900
A 73 V-belt	1	750	750
A 60 V-belt	1	750	750
A 105 V-belt	1	800	800
P 250 Thrust bearing	2	2400	4800
P 200 Thrust bearing	4	2200	8800
20 mm Ball bearings	2	1300	2600
G 12 Electrodes	2pkts	1400	2800
M 19x3 bolts and nut	14pcs	80	1120
M 24x4 bolts and nuts	6pcs	50	300
M 17x3 bolts and nuts	12pcs	20	240
4 mm Drill bits	6	130	780
5 mm Drill bits	6	130	780
7.5 mm Drill bits	6	290	1740
8.5 mm Drill bits	6	340	2040
11 mm Drill bits	2	550	1100
90 mm diameter pulley	1	2100	2100
140 mm diameter pulley	1	2800	2800
200 mm diameter pulley	1	3900	3900
310 mm diameter pulley	1	8500	8500
14 inch tyre and wheels	2	12000	24000

Body filler	1tin	5500	5500
Gloss paint	1tin	5300	5300
Sub -Total			**169,300.00**
7 Hp Diesel Engine	1	83,000	83,000
		Grand Total	**₦ 252,300.00**

Table 3.1: The multicrop thresher components and their fabrication methods

S/N^{o}	Component	Materials	Tools	Method
1.	Frame (Appendix) O13, O14	Square pipe and Angle iron 50 x 50 x 5 mm,	Power saw, Drilling, Welding and Grinding machines, G 12 Electrodes, Tape, Square, Scriber, 8.5	Measure, mark and cut all materials. Drill holes for bolts and nut before welding in position. Grind all rough and sharp edges.

			and 11 mm drill bit.	
2.	Hopper (Appendix) O13, O14	Gauge16 mild steel sheet (2 mm)	Welding, Bending, Cutting and Grinding machines, Vise, Tape, Square, Scriber, G 12 Electrodes.	Measure, mark and cut all materials. Bend to the required angle before welding in position. Grind all rough and sharp edges.
3.	Threshing cylinder cover (Appendix) O13, O14	Gauge16 mild steel sheet (2 mm), M 19x3 bolts and nut	Welding, Bending, Cutting and Grinding machines, Hack saw, Vise, Tape, Square, Scriber, 2.5 mm electrode.	Measure, mark and cut all materials. Bend to the required angle before welding in position. Drill holes for bolts and nut then grind all rough / sharp edges.
4.	Threshing cylinder (Appendix) O3, O4	Gauge18 mild steel sheet (3 mm), 15 and 25 mm Medium carbon steel rods, P 250 Thrust bearing, M 24x4 bolts and nuts, 90 and 200 mm diameter pulleys, A105 V-belt.	Welding, Cutting, Grinding, Drilling and Rolling machines, Hack saw, Vise, Tape, Square, Scriber, G 12 Electrodes.	Measure, mark and cut all materials. Roll to the required circumference before welding in position. Weld all beaters vertically on the cylinder before tilting 45^{o}. Grind all rough / sharp edges. Install bearings and pulleys.
5.	Top Sieves (Appendix) O5, O6, O7, O8	Gauge18 mild steel sheet. (3 mm), 5 mm flat bars	Cutting, Drilling, Rolling, Bending and Grinding machines, Center punch, Hammer, Tape, Square, Scriber, 5 mm and 8.5 mm drill bits.	Measure, mark and cut all materials. Mark and punch drilling points. Drill all sieve holes before rolling to the required semi circle. Bend edges and weld flat bar. Grind all rough / sharp edges.
6.	Bottom sieves (Appendix) O9, O10, O11, O12	Gauge16 mild steel sheet. (2 mm)	Cutting, Drilling, Rolling, Bending and Grinding machines, Center punch, Hammer, Tape, Square, Scriber, 4 mm and 7.5 mm drill bits.	Measure, mark and cut all materials. Mark and punch drilling points. Drill all sieve holes then bend the edges. Grind all rough / sharp edges.

Table 3.1: Continue

S/N^{o}	Component	Materials	Tools	Method
7.	Blower (Appendix) O14, O15	Gauge16 mild steel sheet (2 mm), 20 mm diameter medium carbon	Welding, Rolling, Bending and Grinding machines, Hack saw, Vise, Tape, Square,	Measure, mark and cut all materials. Roll casing to the required circumference and bend

		steel rod, P 200 Thrust bearing, M 17x3 bolts and nuts, A 73 V-belt.	Scriber, G 12 Electrodes	blades to the required angle before welding in position.
8.	Shaker (Appendix) O13, O14, O15	Gauge16 mild steel sheet (2 mm), 5 mm flat bars, 20 mm medium carbon steel rod, P 200 Thrust bearing, 20 mm diameter ball bearings, 310 mm diameter pulley, A 60 V-belt.	Welding, Bending and Grinding machines, Hack saw, Vise, Tape, Square, Scriber, G 12 Electrodes	Measure, mark and cut all materials. Mount shaker tray first before installing bearings, pulleys and shaker mechanism in position. Grind all rough / sharp edges
9.	Tow bar (Appendix) O13, O14, O15	Square pipe and Angle iron 50 x 50 x 5 mm, 20 mm diameter medium carbon steel rod, 14 inch tyre and wheel.	Power saw, Grinding, Welding and Drilling machines, G 12 Electrodes, Tape, Square, Scriber	Measure, mark and cut all materials. Weld in position and install tyres and stand. Grind all rough and sharp edges.
10.	Engine Seat (Appendix) O14, O15	Angle iron 50 x 50 x 5 mm, 7 Hp Diesel Engine.	Power saw, Grinding, Welding, and Drilling machines, G 12 Electrodes, Tape, Square, Scriber, 8.5 mm drill bit.	Measure, mark and cut all materials. Drill holes for bolt and nuts before welding in position. Grind all rough and sharp edges.
11.	Machine body (Appendix) O13, O14, O15	Body filler and Gloss paint	Filler applicator, Spraying machine	Clean all components from dust. Apply body filler to all rough edges and tiny holes before spraying.



Plate 3a: Illustrations of the threshing cylinder cover of the multicrop thresher with a feed hopper and a platform.



Plate 3b: Illustration of the multicrop thresher step-shaped threshing cylinder having tilted beaters and chaff throwers welded at fixed points on the cylinder

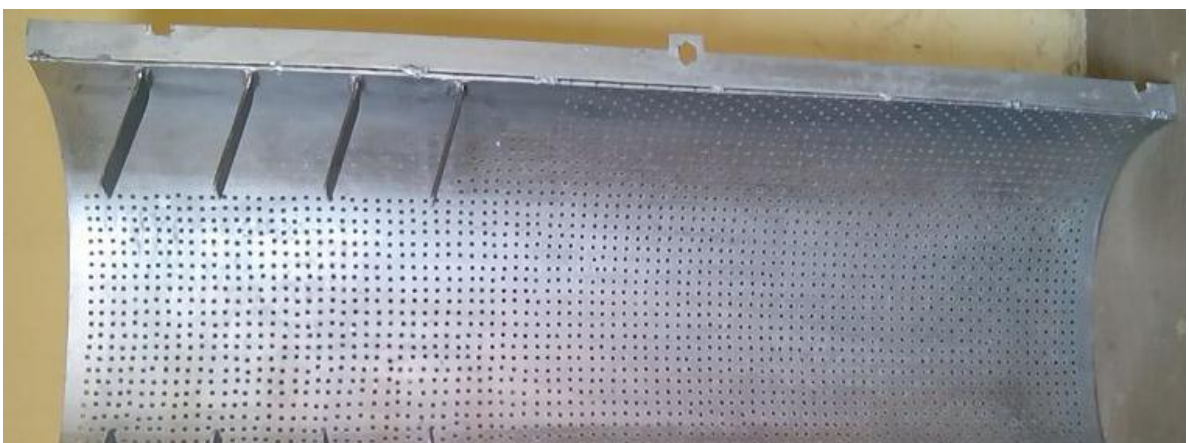


Plate 3.1a: Illustration of the multicrop thresher top sieve with 5 mm diameter sieve holes for millet threshing.



Plate 3.1b: Illustration of the multicrop thresher top sieve with 8.5 mm diameter sieve holes for soybean threshing



Plate 3.2a: Illustration of the multicrop thresher bottom sieve with 4 mm diameter sieve holes for millet threshing.

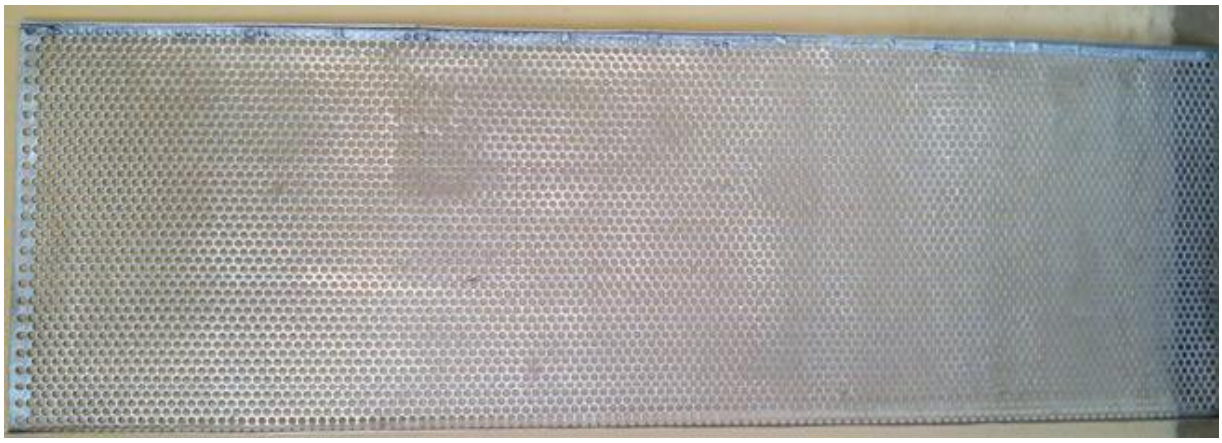


Plate 3.2b: Illustration of the multicrop thresher bottom sieve with 7.5 mm diameter sieve holes for soybean threshing



Plate 3.3: Illustration of the multicrop thresher shaker mechanism

3.29 Description of the Developed Multicrop Thresher

The developed multicrop thresher consists of the following components: A structural frame, top cover with feed hopper, step-shaped threshing cylinder with beaters and chaff thrower, perforated concave sieve plate with horizontal knife edge flat bars, centrifugal blower,

shaker mechanism, power transmission unit which consist of pulleys and the shaker tray with flat sieve plate. The feeder was constructed from gauge 18 mild steel metal sheets and consists of two sections; a platform and a hopper. The platform extends outward from the hopper with length 640 mm, width 610 mm and height 80 mm. A tow bar and two 14 inch tires were fixed at the base of the frame. The front view, end view and plan of the developed multicrop thresher are illustrated in Appendix O13, O14 and O15 respectively. The autographic projection is illustrated in Appendix O16. The isometric view of the front and rear sides of the machine are illustrated in Appendix O1 and O2 respectively.

3.30 Operations of the Developed Multicrop Thresher

The developed multicrop thresher was design such that the direction of flow for grains after threshing was vertical by a combination of impact by the beaters and gravitational force acting on it while the direction of flow for chaff and un-threshed material was lateral by a combination of impact by the beaters and suction generated by the chaff throwers positioned at the end of the threshing cylinder. The threshing unit is directly below the feed hopper and consists of the step-shaped threshing cylinder with beaters and chaff thrower. A perforated concave sieve plate with horizontal cutting knives was placed below the threshing cylinder for primary separation of grains from chaff. Clearance between the free end of the beaters and concave sieve plate was maintained at 20 mm for soybean threshing and 10 mm for millet threshing. The blower unit was located below the concave sieve plate and consists of a four blade centrifugal fan that blow's off the lighter chaff and dust from the grain as it flows down a funnel on to a sieve plate on the shaker tray. The shaker sieve plate at the bottom of the machine further separates grains and chaff of similar weight as the shaker oscillates. The clean grain was then collected at the bottom of the tray and conveyed through the grain outlet. All power transmission took place at one end of the machine and the unit consists of pulleys, V-belts and a 7Hp (5.22 kW) diesel engine which was mounted on the engine seat. The tow bar and two 14 inch tires

fixed at the base of the frame help to facilitate towing by a tractor. Plates 3.4 (a, b) and 3.5 (a, b) illustrates the front views and rear views of the machine respectively.

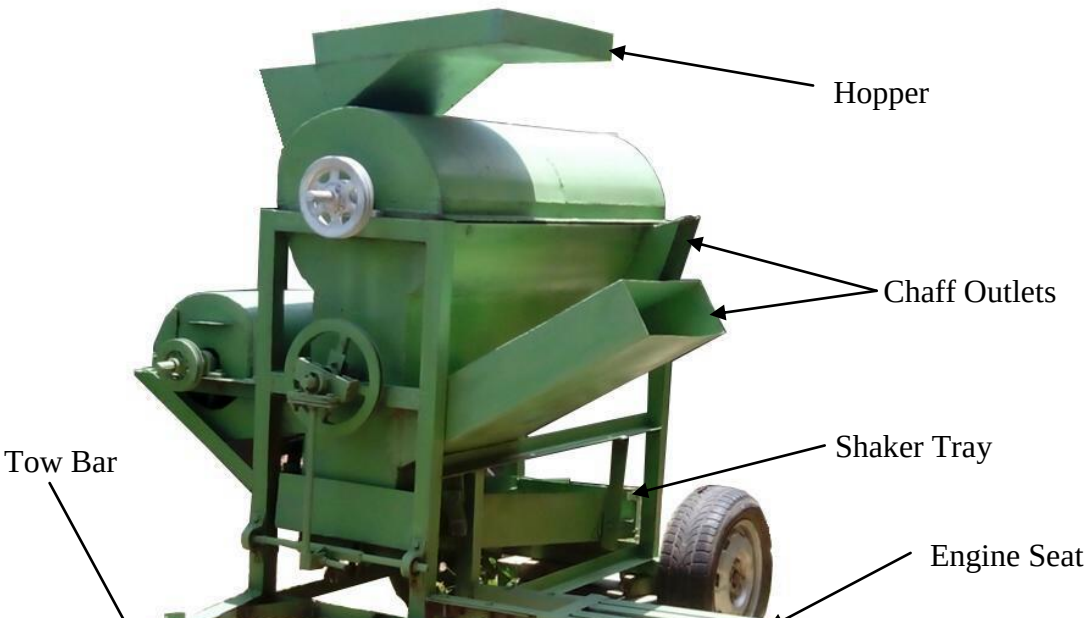


Plate 3.4a: Isometric view of the developed multicrop thresher from the front illustrating the Hopper, Chaff Outlets Tow Bar, Shaker tray and Engine seat



Plate 3.4b: Front view of the developed multicrop thresher illustrating the Hopper, Chaff Outlets Tow Bar, Shaker tray and Engine seat

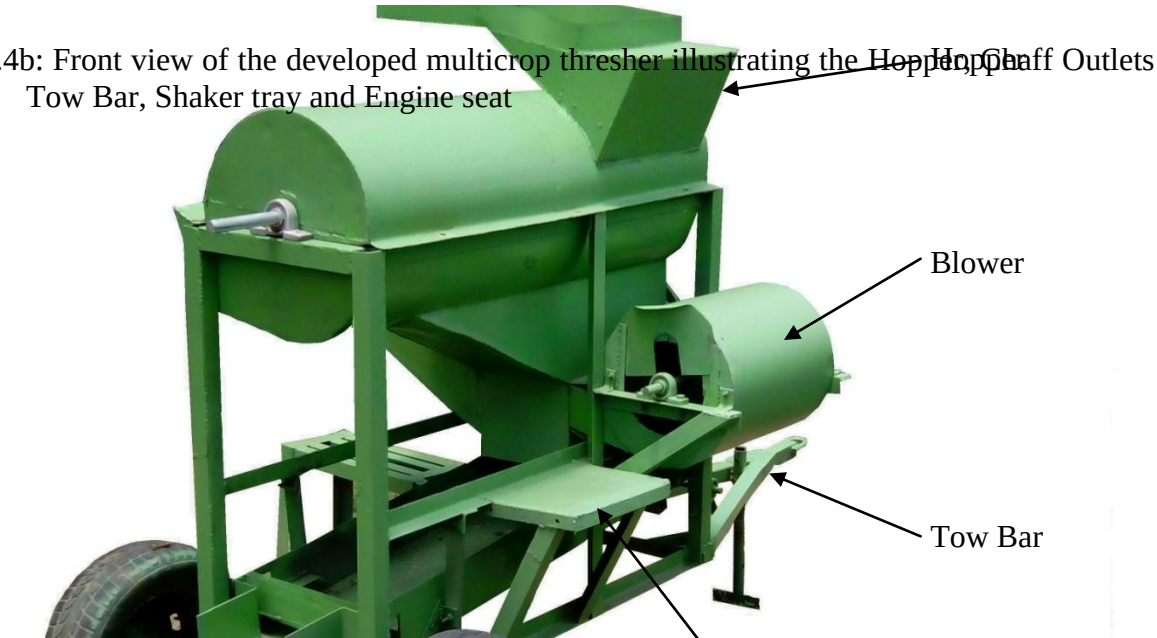


Plate 3.5a: Isometric view of the developed multicrop thresher from the back illustrating the Operator's Stand, Blower, Tow bar, Shaker mechanism, Hopper and Rear Wheels

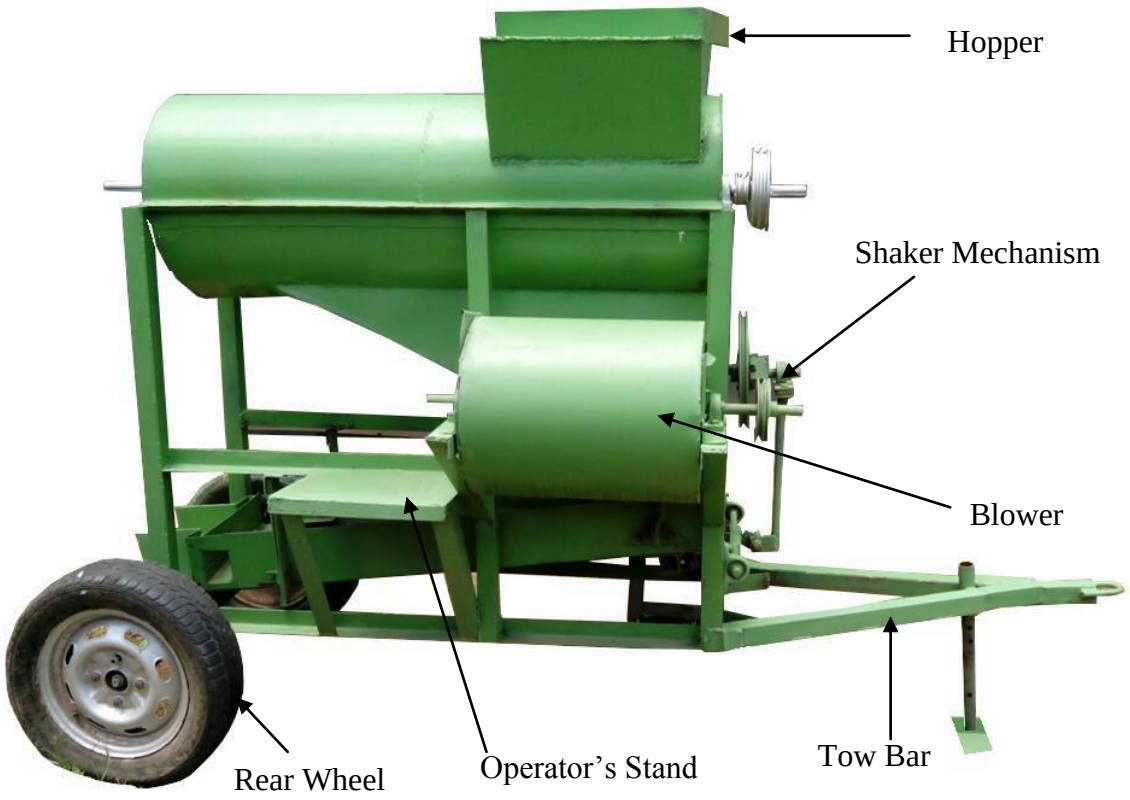


Plate 3.5b: Rear view of the developed multicrop thresher illustrating the Operator's Stand, Blower, Tow bar, Shaker mechanism, Hopper and Rear Wheels

3.31 Performance Tuning

Performance tuning was carried out to improve the initial performance of all components of the multicrop thresher that were critical to its overall performance. The performance tuning

process involved measuring, evaluating, design re-iteration, re-construction and re-evaluation until a set goal was reached.

Goals that were set before modification include:

i. Threshing efficiency to be greater than 98 %.

ii. Cleaning efficiency to be greater than 90 %.

iii. Grain damage to be less than 1 %.

iv. Grain loss to be less than 10 % for both crops.

v. Output to be greater than 350 kg/hr for millet and greater than 150 kg/hr for soybean.

The steps taken in the performance tuning process were as follows:

i. the performance of the multicrop thresher was assessed by initial performance evaluation before modification.

ii. the data of the performance evaluation was analyzed and the initial result noted.

iii. the parts of the thresher that were critical for improving the performance were identified as the bottleneck.

iv. goals were set.

v. these parts of the thresher were modified to remove the bottlenecks one at a time, checking to ensure that the modifications had not disrupted the way the machine function.

vi. the performance of the thresher was re-evaluated after the modifications were completed.

vii. the modifications that made the performance better were adopted; but those that made the performance worse were rejected and the machine was put back the way it was.

These bottlenecks were removed one at a time by modification and testing with millet and soybean crops as test materials. In the performance tuning process output capacity, threshing and cleaning efficiencies were maximized while grain damage and grain loss were minimized until the set goals were reached. When the performance tuning was completed the overall performance of the multicrop thresher was evaluated.

3.32 Performance Evaluation

The machine was evaluated in the Department of Agricultural Engineering, Ahmadu Bello University, Zaria.

3.32.1 Test materials

The test materials were: unthreshed soybean crop (samsoy-2 soybean variety) and unthreshed millet crop (SOSAT C88 Millet variety).

3.32.2 Test apparatus

The test apparatus were: mettler balance (model pn 1210), 7Hp (5.22 kW) 4-stroke water cooler diesel engine, diesel, digital tachometer (tz5000 model), digital stop watch, digital scale (with 0.01g sensitivity) and oven.

The performance evaluation of the machine involved the following parameter:

i. moisture content (%)

ii. output capacity (kg/hr)

iii. threshing efficiency (%)

iv. cleaning efficiency (%)

v. scattered grain loss (%)

vi. grain damage (%)

3.32.3 Determination of crop moisture content

The crop moisture content on wet basis (in the range 10 - 16 %) was determined by oven-dry method according to ASAE standard S358.2 thus:

$$M_{wb} = \frac{(W_w - W_d)}{W_w} x100 \qquad (3.26)$$

Where,

W_w = mass of wet samples before drying (g)

W_d = mass of sample after drying (g)

M_{wb}= moisture content on wet basis (%)

3.32.4 **Determination of output capacity**

The output capacity of the machine was evaluated according to Mohammed (2009):

$$C = \frac{Q_T}{t} \tag{3.27}$$

Where,

C = output capacity (kg/hr).

Q_T = mass of whole grain collected in unit time (kg).

t = threshing time (hr)

3.32.5 **Determination of threshing efficiency**

The threshing efficiency of the machine was evaluated according to Mohammed (2009):

$$E_T = 100 - \left(\frac{U_M}{T_M}\right) x100 \tag{3.28}$$

Where,

E_T = threshing efficiency (%)

U_M = mass of unthreshed material in unit time (kg)

T_M = mass of total material input in unit time (kg)

3.32.6 **Determination of cleaning efficiency**

The cleaning efficiency of the machine was evaluated according to Mohammed (2009):

$$\eta_C = \left(\frac{B}{D}\right) x100 \tag{3.29}$$

Where,

η_C = cleaning efficiency (%)

B = mass of whole clean grain in unit time at grain outlet (kg)

D = mass of whole material collected in unit time at the grain outlet (kg)

3.32.7 Determination of scattered grain loss

The scattered grain loss of the machine was evaluated according to Mohammed (2009):

$$S_g = \left(\frac{E}{T_G}\right) x100 \qquad (3.30)$$

Where,

S_g =scattered grain loss (%)

E = mass of scattered grain collected in unit time (kg)

T_G = total grain input per unit time by mass (kg)

3.32.8 Determination of grain damage

The grain damage of the machine was evaluated according to Mohammed (2009):

$$D_g = \left(\frac{G}{100}\right) x100 \qquad (3.31)$$

Where,

D_g = grain damage (%)

G = mass of visually damaged grain isolated in 100 grams of threshed sample (g)

Plates 3.6a and 3.6b are illustrations of soybean and millet grains respectively collected during performance evaluation.



Plate 3.6a: Illustration of soybean grains collected during performance evaluation.



Plate 3.6b: Illustration of millet grains collected during performance evaluation

3.33 Data Collection

Several trial operations were conducted to determine the point at which the thresher will be unable to consume the materials fed into it at a swoop. During the trials it was observed that feeding the thresher with millet at 6 kg / min and with soybean at 4 kg / min when running below 550 rpm leads to frequent stalling of the prime-mover. At 550 rpm there was no stalling of the prime-mover. Successive increment of 2 kg and 100 rpm drum speed was made until it was noticed that when the threshing speed was increased beyond 909 rpm, the vibration caused by the shaker was intolerable. Also it was observed that feeding the thresher with millet at 14 kg / min and with soybean at 12 kg / min when running at 909 rpm there was no stalling. But when fed above 14 kg/min with millet and above 12 kg / min with soybean when running at 909 rpm leads to build up of un-threshed material in the threshing chamber and hence frequent stalling of the prime-mover. Therefore five levels of speed were chosen with 550 rpm being the minimum and 909 rpm being the maximum. Also five levels of feed rate were chosen with 4 kg / min and 6 kg / min being the minimum values for soybean and millet respectively, while 12 kg / min and 14 kg / min were the maximum values for soybean and millet respectively. The desired threshing speeds were obtained by regulating the prime mover throttle. A digital tachometer was used to monitor the drum speed and a stop watch was used to record the time of feeding.

As the materials were harvested from farm the initial moisture content wet bases was determined to be 18.2 %. This moisture content was considered not good for threshing as most of the materials pass out un-threshed when fed into the machine. So the material was closely monitored daily until its moisture content reaches 15.8 % wet basis where threshing was possible. The moisture content was varied as the crop dried naturally. The materials to be threshed were first weighed according to feed rate and then sun dried for two hours to warm them. Samples were randomly selected from each and taken to the laboratory for moisture content determination. Three replications were made for each threshed sample and a two days interval was given between threshing to allow the crop to dry naturally to different moisture

content. During threshing, sacks were placed at both chaff outlets. One was placed at the top chaff outlet to collect chaff, unthreshed materials and grain losses. Another was placed at the blower outlet to collect chaff and grain losses. Also one was placed at the grain outlet to collect threshed grains, broken grains and chaff. The contents of the sacks were emptied, winnowed manually and weighed to obtain the weights of clean grains, unthreshed materials, chaff, broken grains and grain losses. 3000 kg of soybean crop and 3750 kg of millet were used for the experiments. Plates 3.7a and 3.7b illustrate soybean and millet experimental materials respectively sun dried prior to threshing.



Plate 3.7a: Illustration of soybean experimental materials sun dried for few hours to warm them prior to threshing.



Plate 3.7b: Illustration of millet experimental materials sun dried for few hours to warm them prior to threshing.

3.34 Experimental Treatments

For both crops the multicrop thresher was subjected to three experimental treatments

Thus the following treatments were considered for millet threshing:

i. Moisture content (M) at 5 levels: M_1 = 10.6 %, M_2 = 11.9 %, M_3 = 13.2 %, M_4 = 14.3 % and M_5 = 15.8 %.

ii. Cylinder speed (S) at 5 levels: S_1 = 550 rpm (12.1 m/s), S_2 = 650 rpm (14.3 m/s), S_3 = 750 rpm (16.5 m/s), S_4 = 850 rpm (18.7 m/s) and S_5 = 909 rpm (20 m/s).

iii. Feed rate (F) at 5 levels: F_1 = 6 kg/min, F_2 = 8 kg/min, F_3 = 10 kg/min, F_4 = 12 kg/min and F_5 = 14 kg/min

Thus the following treatments were considered for soybean threshing:

i. Moisture content (M) at 5 levels: M_1 = 10.8 %, M_2 = 12.2 %, M_3 = 13.5 %, M_4 = 14.6 % and M_5 = 15.4 %.

ii. Cylinder speed (S) at 5 levels: S_1 = 550 rpm (12.1 m/s), S_2 = 650 rpm (14.3 m/s), S_3 = 750 rpm (16.5 m/s), S_4 = 850 rpm (18.7 m/s) and S_5 = 909 rpm (20 m/s).

iii. Feed rate (F) at 5 levels: F_1 = 4 kg/min, F_2 = 6 kg/min, F_3 = 8 kg/min, F_4 = 10 kg/min and F_5 = 12 kg/min

3.35 Experimental Design

A complete randomized design (CRD) was used. The analysis of variance (ANOVA) is shown in Appendix B.

3.36 Experimental Layout

A layout of 5 x 5 x 5 factorial experiment involving 5 levels of cylinder speeds (S_1, S_2, S_3, S_4, S_5), 5 levels of Feed rates (F_1, F_2, F_3, F_4, F_5) and 5 levels of moisture contents (M_1, M_2, M_3, M_4, M_5), in three replications RI, RII, and RIII is shown in Appendix C

3.37 Data Analysis

SAS Statistical package was used to analyze the data. The difference between the means and variables was compared using ANOVA and Duncan's multiple range tests.

3.38 Development of Threshing Efficiency Mathematical Model

Mathematical models for predicting threshing efficiency, threshing loss and output capacity of the multicrop thresher were developed. In this study, dimensional analysis was used; because it offers a method for reducing complex physical problems to the simplest form prior to obtaining a quantitative answer. The Buckingham's π-theorem was adopted.

If $\lambda = F(A_1, A_2, ..., A_n)$ (3.32)

Then $\lambda = f(\pi_1, \pi_2, \ldots, \pi_{r<n})$ (3.33)

Where:

λ = dependent variable.

$A_1, A_2, \ldots, A_n$= independent variables.

$\pi_1, \pi_2, \ldots, \pi_{r<n}$= non dimensional groups of A_i's.

F, f = functional relationships of A_n's and π_r's respectively.

Step-by-step method of dimensional analysis according to David (2013) was used to develop the threshing efficiency model.

Step 1: Identify the relevant variables.

Threshing efficiency E_T (%) evaluates the percentage of grains detached from the crop by the beaters of the machine. The relevant variables identified to influence the rate of detachment of grains per second were as follows: Mass of beater, M_b (kg), Velocity of peripheral cylinder, V_c (m/s), Mass of crop fed, M_f (kg), Height of the threshing chamber, h (m), Concave clearance, C_c (m), Length of threshing cylinder, L_c (m), Number of beaters, N_b (dimensionless), Dueling time

of crop within the threshing chamber, t (s), and Moisture content of the crop, M_c (% wb), (dimensionless). Thus, $E_T = f(M_b, V_c, M_f, h, C_c, L_c, t, N_b, M_c)$

Step 2: Write down their dimensions.

The threshing efficiency function relevant variables and their dimensions are shown in Table 3.2.

Table 3.2: Threshing efficiency function relevant variables and their dimensions

Variable	Symbol	S.I Unit	Dimension [M][L][T]
Threshing Efficiency	E_T	-	1
Mass of beater	M_b	kg	M
Velocity of peripheral cylinder	V_c	m/s	ML^{-1}
Mass of crop fed	M_f	kg	M
Height of the threshing chamber	h	m	L
Concave clearance	C_c	m	L
Length of threshing cylinder	L_c	m	L
Dueling time of crop in the threshing chamber	t	min	T
Moisture content of crop	M_c	-	1
Number of beaters	N_b	-	1

Step 3: Establish the number of independent dimensions and non dimensional groups.

Number of relevant variables n = 10

Number of independent dimensions m = 3 (M, L, T)

Number of nondimensional groups formed = n – m = 10 – 3 = 7

Step 4: Choose m dimensionally independent scaling variables.

Mass of crop fed, M_f (M), Concave clearance, C_c (L) and Dueling time of crop within the threshing chamber, t (T) were chosen.

Step 5: Create the π_s by nondimensionalizing the remaining variables.

$\pi_1 = E_T$ (3.34)

$\pi_2 = N_b$ (3.35)

$\pi_3 = M_c$ (3.36)

$$\pi_4 = (M_b)(M_f)^a (C_c)^b (t)^c$$

Considering the dimension of both sides

$$M^0 L^0 T^0 = (M)(M)^a (L)^b (T)^c$$

$$M: 0 = 1 + a \Rightarrow a = -1$$

$$L: 0 = b \Rightarrow b = 0$$

$$T: 0 = c \Rightarrow c = 0$$

Substitute a, b and c in π_4 above:

$$\pi_4 = \frac{M_b}{M_f} \quad (3.37)$$

$$\pi_5 = (V_c)(M_f)^a (C_c)^b (t)^c$$

Considering the dimension of both sides

$$M^0 L^0 T^0 = (LT^{-1})(M)^a (L)^b (T)^c$$

$$M: 0 = a \Rightarrow a = 0$$

$$L: 0 = 1 + b \Rightarrow b = -1$$

$$T: 0 = -1 + c \Rightarrow c = 1$$

Substitute a, b and c in π_5 above:

$$\pi_5 = \frac{V_c t}{C_c} \tag{3.38}$$

$$\pi_6 = (h)(M_f)^a (C_c)^b (t)^c$$

Considering the dimension of both sides

$$M^0 L^0 T^0 = (L)(M)^a (L)^b (T)^c$$

$$M: 0 = a \Rightarrow a = 0$$

$$L: 0 = 1 + b \Rightarrow b = -1$$

$$T: 0 = c \Rightarrow c = 0$$

Substitute a, b and c in π_6 above:

$$\pi_6 = \frac{h}{C_c} \tag{3.39}$$

$$\pi_7 = (L_c)(M_f)^a (C_c)^b (t)^c$$

Considering the dimension of both sides

$$M^0 L^0 T^0 = (L)(M)^a (L)^b (T)^c$$

$$M: 0 = a \Rightarrow a = 0$$

$$L: 0 = 1 + b \Rightarrow b = -1$$

$$T: 0 = c \Rightarrow c = 0$$

Substitute a, b and c in π_7 above:

$$\pi_7 = \frac{L_c}{C_c} \tag{3.40}$$

Step 6: Rearrange for convenience. We are free to replace any of the pi's by a power of that pi, or by a product with the other pi's provided we retain the same number of independent dimensionless groups.

Thus, rearranging the pi terms we have:

$$\pi_8 = \frac{\pi_2}{\pi_3} = \frac{N_b}{M_c} \tag{3.41}$$

$$\pi_9 = \frac{\pi_7}{\pi_6} = \frac{L_c}{C_c} \times \frac{C_c}{h} = \frac{L_c}{h} \tag{3.42}$$

$$\pi_{10} = \pi_4 \times \pi_5 = \frac{M_b V_c t}{M_f C_c} \tag{3.43}$$

$$\pi_{11} = \pi_8 \times \pi_9 = \frac{N_b L_c}{M_c h} \tag{3.44}$$

Step 7: Set out the non dimensional relationship.

The three pi terms that were used in the model formulation are: π_1, π_{10} and π_{11}.

These pi terms were related as follows:

$$\pi_1 = f(\pi_{10}, \pi_{11}) \tag{3.45}$$

Hence,

$$E_T = f\left(\frac{M_b V_c t}{M_f C_c}, \frac{N_b L_c}{M_c h}\right) \tag{3.46}$$

3.38.1 **Determination of component equations**

The component equations were formed from experimental data on the pi- terms. Shafii *et al.* (1996) stated that in order to verify that equation (3.46) is correct, at least 2m-3 tests need to be conducted, where m is the number of pi terms.

Hence, (2x3) - 3 = 3 tests was conducted to establish three component equations as follows: $(\pi_1)_{\overline{11}}$ was held constant at $\overline{\pi}_{11}$ and π_{10} was varied to give the component equation $(\pi_1)_{\overline{11}}$, $(\pi_1)_{\overline{10}}$ was held constant at $\overline{\pi}_{10}$ and π_{11} was varied to give the component equation $(\pi_1)_{\overline{10}}$, $(\pi_{10})_{\overline{1}}$ was held constant at $\overline{\pi}_1$ and π_{11} was varied to give the component equation $(\pi_{10})_{\overline{1}}$ as shown on Fig. 3.1, 3.2 and 3.3 respectively. The regression equations of the graphs represent the component equations. The constant values of the pi terms $\overline{\pi}_1$, $\overline{\pi}_{10}$ and $\overline{\pi}_{11}$ were determined by calculating the average of the pi term data. The pi terms data for threshing efficiency model are given in Table 3.3

Table 3.3: Pi terms data for threshing efficiency model

$\pi_1 = E_T$		$\pi_{10} = \frac{M_b V_c t}{M_f C_c}$		$\pi_{11} = \frac{N_b L_c}{M_c h}$	
99.98	97.79	62.67	37.60	9.11	6.76
99.97	97.72	58.59	31.33	9.11	6.76
99.96	97.66	47.00	29.30	8.12	6.76
99.95	97.63	43.95	35.16	8.12	6.76
99.94	97.56	43.95	43.95	7.32	6.76
99.93	97.52	37.60	31.02	9.11	6.76
99.91	97.47	35.16	25.11	9.11	6.76
99.87	97.38	62.67	58.59	7.32	6.76
99.86	97.35	35.16	47.00	9.11	6.76
99.85	97.31	58.59	25.85	7.32	6.76
99.83	97.01	29.30	22.16	9.11	6.76
99.82	96.71	35.16	37.60	8.12	6.12
99.81	96.70	31.02	31.33	9.11	6.12
99.78	96.65	31.33	62.67	7.32	6.76
99.72	96.52	26.86	26.86	7.32	6.12
99.71	96.44	31.02	29.30	8.12	6.12
99.69	96.41	25.85	25.11	9.11	6.12
99.65	96.39	25.11	35.16	9.11	6.12
99.61	96.23	25.85	43.95	8.12	6.12
99.59	95.99	29.30	47.00	7.32	6.12
99.56	95.95	25.11	31.02	8.12	6.12
99.54	95.82	25.85	58.59	7.32	6.12
99.52	95.74	22.16	25.85	9.11	6.12
99.48	95.68	25.11	22.16	7.32	6.12
99.45	95.11	22.16	62.67	8.12	6.12
99.42		22.16		7.32	
$\bar{\pi}_1 = 98.28$		$\bar{\pi}_{10} = 36.18$		$\bar{\pi}_{11} = 7.34$	

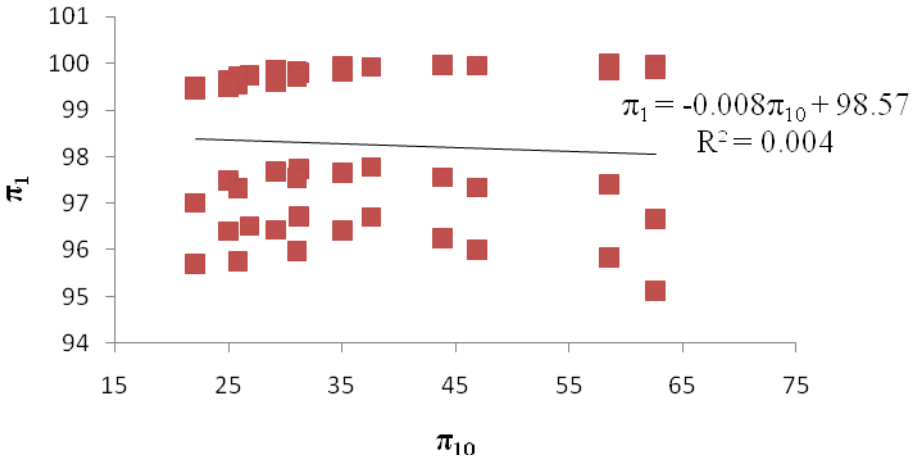


Fig 3.1: Plot of π_1 against π_{10} with π_{11} constant

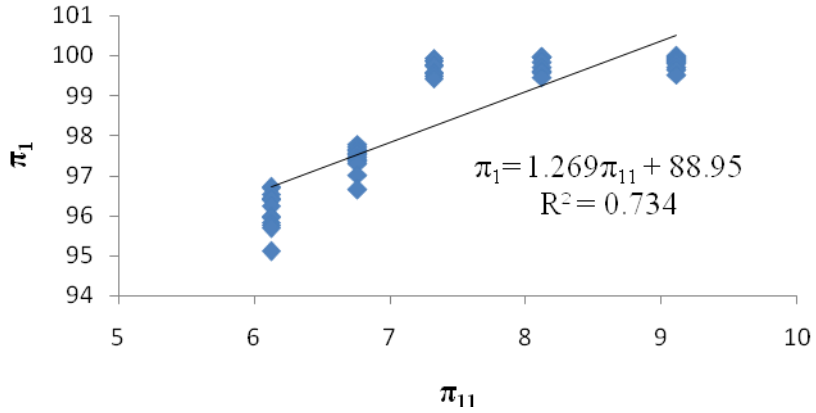


Fig 3.2: Plot of π_1 against π_{11} with π_{10} constant

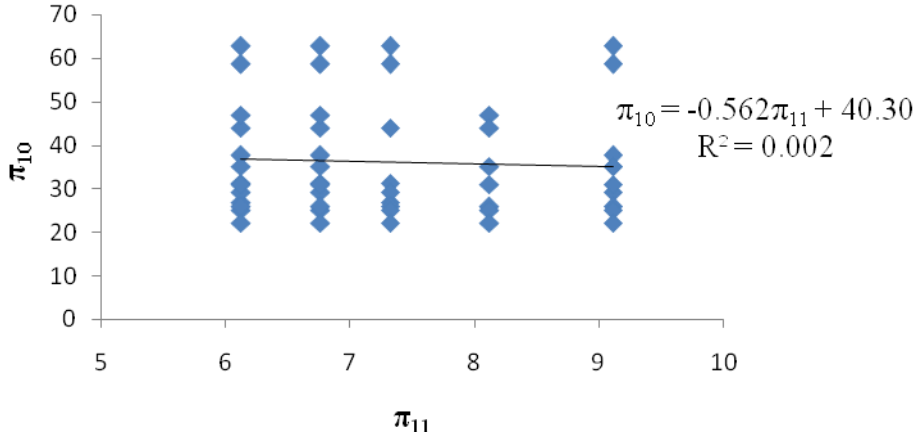


Fig 3.3: Plot of π_{10} against π_{11} with π_1 constant

3.38.2 **Component equations combination criteria**

Murphy (1950) stated that the component equations may be combined by either summation or multiplication to form the general prediction equation. The selection depends on which criteria a set of component equations satisfies. He stated that when a set of component equations plot to form a plane surface on space (linear space) it will have the form $y = a + bx$, such equation would be valid for combination as summation.

The general prediction equation with *s* pi terms will be:

$$\pi_1 = f_1(\pi_2, \bar{\pi}_3 ... \bar{\pi}_s) + f_2(\bar{\pi}_2, \pi_3, ... \bar{\pi}_s) + f_s(\bar{\pi}_2, \bar{\pi}_3, ... \bar{\pi}_s) - C \quad (3.47)$$

Where,

C = constant of summation subtracted from the sum of the component equations.

$f_1(\pi_2, \bar{\pi}_3), f_2(\bar{\pi}_2, \pi_3), f_{s-1}(\bar{\pi}_2, \bar{\pi}_3, ... \bar{\pi}_s)$ = component equation functions.

$\bar{\pi}_2, \bar{\pi}_3$ = constant values of the pi terms.

Whereas those equations that plot to form curved surface in logarithmic space, will have the form $y = ax^b$, such would be valid for combination as product.

The general prediction equation with *s* pi terms will be:

$$\pi_1 = C.f_1(\pi_2, \bar{\pi}_3 ... \bar{\pi}_s) \times f_2(\bar{\pi}_2, \pi_3, ... \bar{\pi}_s) \times f_{s-1}(\bar{\pi}_2, \bar{\pi}_3, ... \bar{\pi}_s) \quad (3.48)$$

Where,

C = constant of multiplication.

$f_1(\pi_2, \bar{\pi}_3), f_2(\bar{\pi}_2, \pi_3), f_{s-1}(\bar{\pi}_2, \bar{\pi}_3, ... \bar{\pi}_s)$ = component equation functions.

$\bar{\pi}_2, \bar{\pi}_3$ = constant values of the pi terms.

3.38.3 **Determination of the constant (C)**

The constant for S number of pi terms is given as:

$$C = (S-2) f(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4, ... \bar{\pi}_s)$$

Where,

C = constant of summation or multiplication.

S = number of pi terms

$\bar{\pi}_2, \bar{\pi}_3$ = constant values of the pi terms.

When the number of pi terms is 3, the expression of the constant term becomes:

$C = f_1(\bar{\pi}_2, \bar{\pi}_3)$, or $C = f_2(\bar{\pi}_2, \bar{\pi}_3)$

Murphy (1950) stated that constants calculated from either of the component equations are approximately equal. Thus the constant can be determined from either of the equations.

3.38.4 **Determination of prediction equation**

Since the component equations above were linear, it favoured combination by summation to give the prediction equation. The prediction equation involed 3 pi terms, thus the general equation is given by:

$$\pi_1 = f_1(\pi_2, \bar{\pi}_3) + f_2(\bar{\pi}_2, \pi_3) - C \quad (3.49)$$

$$f_1(\pi_2, \bar{\pi}_3) = -0.008\,\pi_{10} + 98.57 \quad (3.50)$$

$$f_2(\bar{\pi}_2, \pi_3) = 1.269\,\pi_{11} + 88.95 \quad (3.51)$$

Substituting equations (3.50) and (3.51) in equation (3.49) we have:

$$\pi_1 = -0.008\,\pi_{10} + 1.269\,\pi_{11} + 98.57 + 88.95 - C$$

$$\pi_1 = -0.008\,\pi_{10} + 1.269\,\pi_{11} + 187.52 - C \quad (3.52)$$

But $\bar{\pi}_{10} = 36.18$ and $\bar{\pi}_{11} = 7.34$

Substituting $\bar{\pi}_{10}$ in equation (3.50) or $\bar{\pi}_{11}$ in equation (3.51), C was determined as follows:

$C = -0.008(36.18) + 98.57 = 98.28$ or $C = 1.269(7.34) + 88.95 = 98.27$

Substituting C in equation (3.52) the prediction equation was determined as follows:

$$\pi_1 = -0.008\pi_{10} + 1.269\pi_{11} + 187.52 - 98.28$$

$$\pi_1 = -0.008\pi_{10} + 1.269\pi_{11} + 89.24 \quad (3.53)$$

Substituting equations (3.34), (3.43) and (3.44) in equation (3.53) the threshing efficiency mathematical model was given by:

$$E_T = -0.008\left(\frac{M_b V_c t}{M_f C_c}\right) + 1.269\left(\frac{N_b L_c}{M_c h}\right) + 89.24 \quad (3.54)$$

Where,

E_T = threshing efficiency (%)

M_b = mass of beater (0.188 kg)

V_c= velocity of peripheral cylinder (m/s)

t = dueling time of crop in the threshing chamber (1min)

M_f = total mass of crop fed (kg)

C_c = concave clearance (m)

N_b = number of beaters (38).

L_c = length of threshing cylinder (1.195 m)

M_c = moisture content of the crop (% wb)

h = height of the threshing chamber (0.47 m)

3.39 Development of Threshing Loss Mathematical Model

Threshing loss includes the unthreshed grain loss, plus the scattered grain loss. The scattered grain loss (S_g) includes: threshed grains sucked out with chaff at the top chaff outlet, plus threshed grains falling out of the hopper, threshed grains blown away with chaff by the blower, threshed grains falling from the shaker. The percentage of scattered grain loss (S_g) for both crops were obtained by conducting field experiments on the multicrop thresher with the crops and collecting the grains scattered all around the machine to determine its percentage.

Since the scattered grains were those lost from different parts of the machine as the grains flow down the thresher it was easier to determine it by field experiment than by calculations. The ANOVA for scattered grain loss indicates that the mean percentages for both crops were: (S_g= 9.67 % for millet and S_g = 3.98 % for soybean). To determine the percentage of unthreshed grains, the variables of importance were identified to be similar to those given in Table 3.2.

The percentage of unthreshed grains (G_u) was determined from the following relationship:

$$G_u = 100 - E_T \tag{3.55}$$

Substituting equation (3.54) into equation (3.55) we have:

$$G_u = 100 - \left[-0.008\left(\frac{M_b V_c t}{M_f C_c}\right) + 1.269\left(\frac{N_b L_c}{M_c h}\right) + 89.24 \right]$$

$$G_u = 100 + 0.008\left(\frac{M_b V_c t}{M_f C_c}\right) - 1.269\left(\frac{N_b L_c}{M_c h}\right) - 89.24$$

$$G_u = 0.008\left(\frac{M_b V_c t}{M_f C_c}\right) - 1.269\left(\frac{N_b L_c}{M_c h}\right) + 10.76 \tag{3.56}$$

The threshing loss function (L_T) was determined from the following relationship:

$$L_T = S_g + G_u \tag{3.57}$$

Where:

L_T = threshing loss (%)

S_g = scattered grains (%)

G_u = unthreshed grains (%)

Substituting equation (3.56) into equation (3.57) the threshing loss model was given by:

$$L_T = S_g + 0.008\left(\frac{M_b V_c t}{M_f C_c}\right) - 1.269\left(\frac{N_b L_c}{M_c h}\right) + 10.76 \tag{3.58}$$

Where:

L_T = threshing loss (%)

S_g = scattered grains (%) (S_g= 9.67 % for millet, S_g = 3.98 % for soybean)

M_b = mass of beater (0.188 kg)

V_c= velocity of peripheral cylinder (m/s)

t = dueling time of crop in the threshing chamber (1min)

M_f = total mass of crop fed (kg)

C_c = concave clearance (m)

N_b = number of beaters (38).

L_c = length of threshing cylinder (1.195 m)

M_c = moisture content of the crop (% wb)

h = height of the threshing chamber (0.47 m)

3.40 Development of Output Capacity Mathematical Model

Output capacity evaluates the quantity of clean grain collected at the grain outlet of the multicrop thresher for the total quantity of crop fed per hour. That is, output equals the total grain threshed from the crop fed minus the threshing loss. To determine the total grain threshed from the crop fed through the hopper, the variables of importance were identified to be similar to those given in Table 3.2. To determine the threshing loss, the unthreshed grain loss and the scattered grain loss were added together. The output capacity function (O_c) was developed from the Effect of the mass of crop fed, threshing efficiency, threshing loss and grain to crop ratio.

The output capacity function was developed as follows:

When the mass of crop fed per second was = M_f (kg/s)

The output per second was given by:

$$O_c = M_f (E_T - L_T)(G_r / C_r)/100 \quad (3.59)$$

When the mass of crop fed per hour was = $3600 M_f$ (kg/hr)

The output per hour was given by:

$$O_c = 36M_f(E_T - L_T)(G_r / C_r) \quad (3.60)$$

Hence, the output mathematical model was given by:

$$O_c = 36M_f(E_T - L_T)(G_r / C_r)$$

Where:

O_c = output capacity (kg/hr)

M_f = mass of crop fed per second (kg/s)

E_T = threshing efficiency (%)

L_T = threshing loss (%)

G_r / C_r = grain to crop ratio. (G_r / C_r = 0.25 for soybean and 0.55 for millet)

3.41 Model Verification

The objective of the model verification was to ensure that the model was correct and that it was able to perform its respective task. In the implementation of the model it was tested for errors using input data of field experiments and the errors found were fixed.

3.41.1 Verification of dimensions of threshing efficiency model

The dimensions (length (L), mass (M), and time (T)) on both sides of the equality sign of the threshing efficiency model was verified if they were the same as follows:

$$E_T = -0.008\left(\frac{M_b V_c t}{M_f C_c}\right) + 1.269\left(\frac{N_b L_c}{M_c h}\right) + 89.24$$

Where,

E_T = threshing efficiency (%)

M_b = mass of beater (0.188 kg)

V_c= velocity of peripheral cylinder (m/s)

t = dueling time of crop in the threshing chamber (1min)

M_f = total mass of crop fed (kg)

C_c = concave clearance (m)

N_b = number of beaters (38).

L_c = length of threshing cylinder (1.195 m)

M_c = moisture content of the crop (% wb)

h = height of the threshing chamber (0.47 m)

Thus,

$[E_T] = 1$

$$\left[\frac{M_b V_c t}{M_f C_c}\right] = \frac{M.L.T^{=1}.T}{M.L}. = \frac{M.L}{M.L} = 1$$

$$\left[\frac{N_b L_c}{M_c h}\right] = \frac{1.L}{1.L} = \frac{L}{L} = 1$$

Hence, the dimension on the left hand side of the equality sign equals the dimension on the right hand side of the equality sign.

3.41.2 **Verification of threshing efficiency determination with the model**

One of the treatments that were given to the multicrop thresher during field experiments was used for testing the model. From Table 4.3a, the combination of cylinder speed, feed rate and moisture content of 14.3 m/s, 12 kg/min and 11.9 % respectively gave measured threshing efficiency of 99.37 %. This treatment was given to the model and the predicted threshing efficiency was compared with the measured.

The model was used to predict the threshing efficiency of the multicrop thresher as follows:

E_T = 99.37 %, M_b = 0.188 (kg), V_c= 14.3 (m/s), t = 1 (min), M_f = 12 (kg), C_c = 0.01 (m), N_b = 38, L_c = 1.195 (m), M_c = 11.9 (% wb), h = 0.47 (m).

Thus:

$$E_T = -0.008\left(\frac{M_b V_c t}{M_f C_c}\right) + 1.269\left(\frac{N_b L_c}{M_c h}\right) + 89.24$$

$$99.37\% = -0.008\left(\frac{0.188 \times 14.3 \times 1}{12 \times 0.01}\right) + 1.269\left(\frac{38 \times 1.195}{11.9 \times 0.47}\right) + 89.24$$

$$99.37\% = -0.008\left(22.4033\right) + 1.269\left(8.1191\right) + 89.24$$

$$99.37\% = -0.1792267 + 10.3031093 + 89.24$$

$$99.37\% \approx 99.36\%$$

The measured threshing efficiency of the machine (E_T = 99.37 %) was approximately equals to the predicted threshing efficiency of the model (E_T = 99.36 %).

3.42 Model Validation

Half of the measured data was used for model development, while the other half of the data was used for model validation. Predictive validation was used for this study. The developed model was used to predict the multicrop thresher performance with the same treatments given during field experiments. Then, the measured and predicted threshing efficiencies were plotted.

3.42.1 Model validation experimental treatments

The threshing efficiency model was subjected to three experimental treatments:

i Moisture content (M) at 5 levels: M_1 = 10.6 %, M_2 = 11.9 %, M_3 = 13.2 %, M_4 = 14.3 % and M_5 =15.8 %.

ii. Cylinder speed (S) at 3 levels: S_1 = 550 rpm (12.1 m/s), S_2 = 650 rpm (14.3 m/s), S_3 = 750 rpm (16.5 m/s)

iii Feed rate (F) at 5 levels: F_1 = 6 kg/min, F_2 = 8 kg/min, F_3 = 10 kg/min, F_4 = 12 kg/min and F_5 = 14 kg/min

3.42.2 **Measures of the model performance**

Reddy *et al.* (1995) reported that a common statistical technique to judge the performance of models is to plot measured against predicted values and fit a straight line through the data with a zero intercept. The values of slope and coefficient of determination (r^2) are then used as indices of agreement.

Wilmot (1982) suggested that Bias and Root Mean Square Error (RMSE), equations (3.61) and (3.62) were amongst the best overall measures of a model performance.

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}\left(P_i - M_i\right) \tag{3.61}$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_i - M_i\right)^2} \tag{3.62}$$

Where,

P_i and M_i = predicted and measured values of the variable of interest respectively

N = the number of observations.

Thus,

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}\left(P_i - M_i\right) = \frac{42.91}{58} = 0.74\%$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_i - M_i\right)^2} = \sqrt{\frac{53.2195}{58}} = 0.96$$

The discrepancy between the measured and predicted values of the model was determined using Mean Square Deviation (MSD), Square Bias (SB) and lack of correlation weighted by the standard deviation (LCS), equations (3.63), (3.64) and (3.65) Kobayashi and Salam (2000).

$$\text{MSD} = \frac{1}{n}\sum_{i=1}^{n}\left(P_i - M_i\right)^2 \tag{3.63}$$

$$SB = \left(\overline{P} - \overline{M}\right)^2 \quad (3.64)$$

$$LCS = 2\ x\ SD_p\ x\ SD_m\ x\ (1- r) \quad (3.65)$$

Where,

$\overline{P}$ and $\overline{M}$ = average predicted and measured values respectively.

SD_p and SD_m = standard deviations of predicted and measured values respectively.

r = the correlation coefficient between predicted and measured values.

Thus,

$$\text{MSD} = \frac{1}{n}\sum_{i=1}^{n}\left(P_i - M_i\right)^2 = \frac{53.2195}{58} = 0.92\%$$

$$SB = \left(\overline{P} - \overline{M}\right)^2 = \left(98.351 - 98.234\right)^2 = 0.014\%$$

$$LCS = 2\ x\ SD_p\ x\ SD_m\ x\ (1- r) = 2 \times 1.169718 \times 1.745122 \times (1 - 0.732) = 1.1\%$$

The model performance was quantified by calculating the Standard Error (SE) and Average Absolute Deviation (AAD), equations (3.66) and (3.67) Yusuf (2001).

Thus:

$$SE = \frac{\sqrt{\sum\left(y_m - y_p\right)^2}}{n} \quad (3.66)$$

$$AAD = \frac{\sum\left|y_m - y_p\right|}{n} \quad (3.67)$$

Where,

y_m and y_p = measured and predicted values respectively.

n = number of observed values.

Thus,

$$SE = \frac{\sqrt{\sum\left(y_m - y_p\right)^2}}{n} = \frac{\sqrt{53.2195}}{58} = 0.13\ \%$$

$$AAD = \frac{\sum\left|y_m - y_p\right|}{n} = \frac{42.91}{58} = 0.74\ \%$$

The Coefficient of Efficiency was determined by equation (3.68) (Logates and Mc Cabe, 1999):

$$E = 1 - \frac{\sum_{i=1}^{N} |M_i - P_i|}{\sum_{i-1}^{N} |M_i - \overline{M}|} \qquad (3.68)$$

Where,

M_i = measured data

P_i = predicted data.

Thus,

$$E = 1 - \frac{\sum_{i=1}^{N} |M_i - P_i|}{\sum_{i-1}^{N} |M_i - \overline{M}|} = 1 - \frac{42.91}{90.32} = 1 - 0.475 = 0.53$$

A paired t-test was conducted at 0.01 level of significance with tabular value equals to 1.96 as follows:

$$t = \frac{\frac{\sum d}{N}}{\sqrt{\frac{\sum d^2 - \frac{\left(\sum d\right)^2}{N}}{N(N-1)}}} \qquad (3.69)$$

Where,

d = deviations.

N = number of variables.

Thus,

$$t = \frac{0.74}{7.295} = 0.101$$

3.43 Optimization of Threshing Performance of the Thresher

Optimization of threshing performance of the multicrop thresher aimed at maximizing or minimizing some performance characteristics of the multicrop thresher so as to achieve a higher threshing efficiency at low grain loss and low grain damage. MATLAB optimization software was used for the optimization process. On the MATLAB software some specified variables of the threshing efficiency model were maximized while others were minimized without violating their constraint, while keeping all others constant and within their constraints. A MATLAB optimization tool "optimtool" was used to run the problem. On the tool, the solver, the constraints and the optimization options were first selected before clicking on the start button to run the optimization. The optimization tool optimtool was chosen because it provides a convenience interface to all optimization routings including those of Genetic Algorithm and Direct search toolbox functions. The optimization tool also made it easier to:

i. Define and modify the problem quickly

ii. Use the correct syntax for optimization functions

iii. Import and export from the MATLAB workspace

iv. Generate code containing configurations for the solver used and options

v. Change parameters of the optimization during the execution of certain Algorithm and direct search Toolbox Functions

The optimization processes involved in MATLAB were as follows:

i. Problem formulation

ii. Defining the problem in the MATLAB toolbox syntax

iii. Running the optimization

iv. Optimization result

3.44 Problem Formulation

The optimization problem was formulated by stating a set of performance characteristics that were defined as the performance vector (x). Hence, Velocity of peripheral cylinder (V_c), Mass of crop fed (M_f) and Moisture content of the crop (M_c) were chosen as the performance vectors. The optimization aim at obtaining optimum combination of these performance vectors subject to their constraints. The objective function to be optimized was the function $f(x)$ subject to nonlinear inequality and linear equality constraints $g(x)$. A constrained optimization was done and the method that was used for the optimization was based on the procedure recommended by Glenn (1950), Yusuf (2003) and Rao (2009) in the following sequence for a constrained optimization thus:

i. The objective functions were determined and the quantity to be optimized (maximized or minimized) and its functional dependence on the independent variables were stated.

ii. The constraint on the independent variables for which an optimum was determined was specified.

3.44.1 Identification of objective functions and design variables

The objective function to be optimized was the threshing efficiency function $f(x)$ on equation (3.54) subject to constraint functions $g(x)$.

$$E_T = -0.008\left(\frac{M_b V_c t}{M_f C_c}\right) + 1.269\left(\frac{N_b L_c}{M_c h}\right) + 89.24$$

Thus,

$$f(x) = -0.008\left(\frac{M_b V_c t}{M_f C_c}\right) + 1.269\left(\frac{N_b L_c}{M_c h}\right) + 89.24 \qquad (3.70)$$

Where,

$f(x)$ = threshing efficiency (%)

M_b = mass of beater (0.188 kg)

V_c= velocity of peripheral cylinder (m/s)

t = dueling time of crop in the threshing chamber (1min)

M_f = total mass of crop fed (kg)

C_c = concave clearance (m)

N_b = number of beaters (38).

L_c = length of threshing cylinder (1.195 m)

M_c = moisture content of the crop (% wb)

h = height of the threshing chamber (0.47 m)

The design variables were the machine, crop and operational parameters critical for improving or reducing the thresher's performance. These variables were: Velocity of peripheral cylinder, V_c(m/s), Mass of beater, M_b (kg), Mass of crop fed per second, M_f (kg), Height of threshing chamber, h (m), Acceleration due to gravity, g (m/s^2), Concave clearance, C_c (m), Length of threshing cylinder, L_c (m), Number of beaters, N_b, and Moisture content of the crop, M_c (% wb).

The design vector which minimizes or maximizes $f(x)$ was stated as:

$$x = \begin{Bmatrix} V_c \\ M_f \\ M_c \end{Bmatrix}$$

Thus $f(x)$ becomes:

$$f(V_c, M_f, M_c) = -0.008\left(\frac{M_b V_c t}{M_f C_c}\right) + 1.269\left(\frac{N_b L_c}{M_c h}\right) + 89.24 \qquad (3.71)$$

Where,

$f(V_c, M_f, M_c)$ = the objective function to be optimized

(V_c, M_f, M_c) = the design vectors/variables

3.44.2 **Identification of independent and dependent variables**

For this study the design variables were the independent variables and are listed as follows:

i. Velocity of peripheral cylinder, V_c (m/s)

ii. Mass of beater, M_b (kg)

iii. Mass of crop fed per second, M_f (kg)

iv. The height of threshing chamber, h (m)

v. Dueling time of crop in the threshing chamber (1min)

vi. Concave clearance, C_c (m)

vii. Length of threshing cylinder, L_c (m)

viii. Number of beaters, N_b

ix. Moisture content of the crop, M_c (% wb)

However the objective functions was the dependent variables and is listed as follows:

i. Threshing efficiency, $f(V_c, M_f, M_c)$ (%)

ii. Cleaning efficiency, $f(V_c, M_f, M_c)$ (%)

iii. Grain damage, $f(V_c, M_f, M_c)$ (%)

iv. Threshing loss, $f(V_c, M_f, M_c)$ (%)

v. Output capacity, $f(V_c, M_f, M_c)$ (kg/hr)

3.44.3 **Specification of the constraints on the independent variables**

The constraints $g(x)$ on the variables was divided into nonlinear inequality and equality constraints.

The nonlinear inequality constraints were:

i. $12.1 \leq V_c \leq 20$ (m/s)

ii. $6 \leq M_f \leq 14$ (kg) for millet, $4 \leq M_f \leq 12$ (kg) for soybean

iii. $10.6 \leq M_c \leq 15.8$ (%) wet basis

The equality constraints were:

i. C_c = 0.01 m for millet, C_c = 0.02m for soybean

ii. L_c = 1.195 m

iii. $h = 0.47$ m

iv. $N_b = 38$

v. $M_b = 0.188$ kg

vi. t = 1 min

3.44.4 **Determination of optimum point for each design vector**

The optimum point for each design vectors (V_c, M_f, and M_c) subject to given constraint $g(V_c, M_f,$ and $M_c)$ was determine using equations of D. M. R. Relationship established above:

Regression equations for determination of optimum speed (V_c) for millet

Threshing Efficiency	Vs Speed	$f_1(V_c) = -0.005V_c^2 + 0.224V_c + 96.38$
Cleaning Efficiency	Vs Speed	$f_2(V_c) = 0.004V_c^2 + 0.031V_c + 92.78$
Grain loss	Vs Speed	$f_3(V_c) = 0.002V_c^2 - 0.017V_c + 9.162$
Grain Damage	Vs Speed	$f_4(V_c) = 0.0001V_c^2 + 0.0001V_c + 0.112$
Output Capacity	Vs Speed	$f_5(V_c) = -0.529V_c^3 + 23.47\ V_c^2 - 313.4V_c + 1489$

Regression equations for determination of optimum Mass Fed (M_f) for millet

Threshing Efficiency	Vs Mass Fed	$f_6(M_f) = -0.005M_f^2 + 0.028M_f + 98.78$
Cleaning Efficiency	Vs Mass Fed	$f_7(M_f) = 0.012M_f^2 - 0.514M_f + 98.44$
Grain loss	Vs Mass Fed	$f_8(M_f) = 0.119M_f + 8.49$
Grain Damage	Vs Mass Fed	$f_9(M_f) = 0.001M_f^2 - 0.018M_f + 0.241$
Output Capacity	Vs Mass Fed	$f_{10}(M_f) = 0.114M_f^2 + 0.020M_f + 312.5$

Regression equations for determination of optimum Moisture Content (M_c) for millet

Threshing Efficiency	Vs Moisture Content	$f_{11}(M_c) = -0.176M_c^2 + 3.914M_c + 78.08$
Cleaning Efficiency	Vs Moisture Content	$f_{12}(M_c) = -0.340M_c^2 + 7.089M_c + 61.40$
Grain loss	Vs Moisture Content	$f_{13}(M_c) = -0.143M_c^2 + 2.854M_c - 2.615$
Grain Damage	Vs Moisture Content	$f_{14}(M_c) = 0.023M_c^2 - 0.52M_c + 2.929$
Output Capacity	Vs Moisture Content	$f_{15}(M_c) = -0.599M_c^2 + 10.78M_c + 288$

Regression equations for determination of optimum speed (V_c) for soybean

Threshing Efficiency	Vs Speed	$f_{16}(V_c) = 0.04V_c + 98.61$
Cleaning Efficiency	Vs Speed	$f_{17}(V_c) = 0.530V_c + 78.32$
Grain loss	Vs Speed	$f_{18}(V_c) = 0.024V_c^2 - 0.615V_c + 7.457$
Grain Damage	Vs Speed	$f_{19}(V_c) = -0.055V_c + 1.044$
Output Capacity	Vs Speed	$f_{20}(V_c) = -0.383V_c^2 + 14.71V_c - 16.37$

Regression equations for determination of optimum Mass Fed (M_f) for soybean

Threshing Efficiency	Vs Mass Fed	$f_{21}(M_f) = -0.04M_f + 99.58$
Cleaning Efficiency	Vs Mass Fed	$f_{22}(M_f) = -0.78M_f + 92.42$
Grain loss	Vs Mass Fed	$f_{23}(M_f) = 0.007M_f^2 - 0.249M_f + 5.408$
Grain Damage	Vs Mass Fed	$f_{24}(M_f) = -0.055M_f + 1.044$
Output Capacity	Vs Mass Fed	$f_{25}(M_f) = 15.15M_f - 2.786$

Regression equations for determination of optimum Moisture Content (M_c) for soybean

Threshing Efficiency	Vs Moisture Content	$f_{26}(M_c) = -0.206M_c^2 + 4.933M_c + 70.74$
Cleaning Efficiency	Vs Moisture Content	$f_{27}(M_c) = -1.538M_c^2 + 36.09M_c - 117.6$
Grain loss	Vs Moisture Content	$f_{28}(M_c) = -0.198M_c^2 + 4.469M_c - 19.87$
Grain Damage	Vs Moisture Content	$f_{29}(M_c) = 0.150M_c^2 - 3.704M_c + 22.79$
Output Capacity	Vs Moisture Content	$f_{30}(M_c) = -2.595M_c^2 + 61.45M_c - 232.9$

A multi-objective programming problem such as the one above was solve in MATLAB by finding x which minimizes $f_1(x)$, $f_2(x)$,…, $f_k(x)$. Where; $f_1(x)$, $f_2(x)$,…, $f_k(x)$ denote the objective function to be minimized simultaneously. The function $f(x)$ was also treated in MATLAB as a constrained optimization problem. Constrained optimization problems in MATLAB used the Karush-Kuhn-Tucker (KKT) equation. The KKT equation is necessary conditions for optimality for a constrained optimization problem. If the problem is a convex programming problem, that is

$f(x)$ and $g_i(x)$, i =1,…,m are convex function, then KKT equation are both necessary and sufficient for a global solution point. A KKT general problem description was stated as:

$$\min f(x), \tag{3.72}$$

Subject to

$g_i(x) = 0$ $i = 1,\ldots,m_e$,
$g_i(x) \leq 0$ $i = m_e + 1,\ldots,m$,

Where,

x = the vector of length n design parameter

$f(x)$ = the objective function, which returns a scalar value

$g_i(x)$ = returns a vector of length m containing the values of the equality and inequality constraints evaluated at x.

There are several optimization toolbox solvers in MATLAB that address problems with constrained single and multiple objective functions. They include: ga Genetic Algorithm, fgoalattain, fminimax etc. All the solvers have inbuilt algorithms in MATLAB.

The MATLAB fgoalattain solver was used for the optimization. The goal attainment process is described below.

3.44.5 **MATLAB Goal attainment method**

The MATLAB goal attainment method used was that of Gembicki, 1974. This involves expressing a set of design goals, $F^* = \{F^*_1, F^*_2,\ldots,F^*_m\}$, which is associated with a set of objectives, $F(x) = \{F_1(x), F_2(x),\ldots,F_m(x)\}$. The problem formulation allows the objectives to be under – or overachieved, enabling the designer to be relatively imprecise about initial design goals. The relative degree of under – or overachievement of the goals was controlled by a vector of weighting coefficients, $w = \{w_1, w_2,\ldots,w_m\}$, and is expressed as a standard optimization problem using the following formulation.

$$\underset{\gamma \in \Re,\, x \in \Omega}{\text{minimize}}\ \gamma \qquad (3.73)$$

such that

$$F_i(x) - w_i\gamma \le F_i^*, \quad i = 1,\ldots,m.$$

The term $w_i\gamma$ introduces an element of slackness into the problem, which otherwise imposes that the goals be rigidly met. The weighting vector, *w*, enables the designer to express a measure of the relative tradeoffs between the objectives. For instance, setting the weighting vector *w* equal to the initial goals indicates that the same percentage under – or overachievement of the goals, *F**, was achieved. A constraint was incorporated into the design by setting a particular weighting factor to zero (i.e., $w_i = 0$). Fig.3.5 is a geometric representation of the goal attainment method in two dimensions.

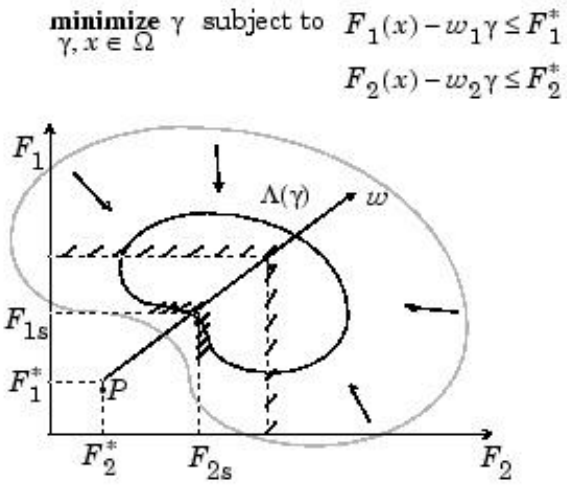


Fig.3.4: Geometric representation of the goal attainment method in two dimensions

Specification of the goals, {F_1*, F_2*}, defines the goal point, *P*. the weighting vector defines the direction of search from *P* to the feasible function space, $\Lambda(\gamma)$. During the optimization γ was varied, which changes the size of the feasible region. The constraint boundaries converge to the unique solution point F_{1s}, F_{2s}.

In algorithm improvements for the goal attainment method a more appropriate merit function was achieved by posing equation (3.73) as a minimax problem.

Thus:

$$\underset{x\in\Re^n}{\text{minimize}} \ \max_i\{\Lambda_i\}, \tag{3.74}$$

where

$$\Lambda_i = \frac{F_i(x) - F_i^*}{w_i}, \ i = 1,\ldots,m.$$

Following the argument of Brayton *et al.*, 1979 for minimax optimization using sequential programming, we have the merit function:

$$\Psi(x) = f(x) + \sum_{i=1}^{m_e} r_i \cdot g_i(x) + \sum_{i=m_e+1}^{m} r_i \cdot \max[0, g_i(x)] \tag{3.75}$$

Using the merit function of equation (3.74) for the goal attainment problem of equation (3.73) gives

$$\psi(x,\gamma) = \gamma + \sum_{i=1}^{m} r_i \cdot \max\left\{0, F_i(x) - w_i\gamma - F_i^*\right\}. \tag{3.76}$$

When the merit function of equation (3.75) was used as the basis of a line search procedure, although $\psi(x,\gamma)$ might decrease for a step in a given search direction, the function Λ_i might paradoxically increase. This was accepting degradation in the worst case objective. Since the worst case objective was responsible for the value of the objective function γ, this was accepting a step that ultimately increases the objective function to be minimized. Conversely, $\psi(x,\gamma)$ might increase when max Λ_i decreases, implying a rejection of a step that improves the worst case

objective. According to Brayton *et al.,* 1979 a solution was therefore to set $\psi(x)$ equal to the worst case objective.

Thus;

$$\psi(x) = \max_i \Lambda_i . \tag{3.77}$$

Combining equations (3.75) and (3.76) gives:

$$\psi(x) = \sum_{i=1}^{m} \begin{cases} r_i \cdot \max\left\{0, F_i(x) - w_i\gamma - F_i^*\right\} & \text{if } w_i = 0 \\ \max_i \Lambda_i, \; i = 1,\ldots,m \end{cases} \tag{3.78}$$

3.44.6 **Minimizing the maximum objective method**

fminimax also uses a goal attainment method. It takes goals of 0, and weights of 1. With this formulation, the goal attainment problem becomes;

$$\min_i \max_x \left(\frac{f_i(x) - goal_i}{weight_i} \right) = \min_i \max_x f_i(x), \tag{3.79}$$

which is a minimax problem.

The optimum point of the function $f(x)$ subject to given constraint $g(x)$ can also be computed analytically as follows**:**

$$f(x) = -0.008\left(\frac{M_b V_c t}{M_f C_c}\right) + 1.269\left(\frac{N_b L_c}{M_c h}\right) + 89.24 \tag{3.80}$$

$$g_i(x) \leq, = \text{or} \geq b_i \tag{3.81}$$

Let's consider maximizing a function $Z = f(x)$ (3.82)

Subject to a given constraints function $g_i(x) = b_i$ (3.83)

Where,

x = the vector of length n design parameter

$f(x)$ = the objective function, which returns a scalar value

g_i (x) = returns a vector of length m containing the values of the equality and inequality constraints evaluated at x.

b_i = the upper and lower limit of the independent variable

Assumed that $f(x)$ has a constrained local maximum $x = x^*$.

At $x = x^*$ we have;

$$df \equiv \sum_j \frac{\partial f}{\partial x_j} dx_j = 0 \tag{3.84}$$

and

$$dg_i \equiv \sum_j \frac{\partial g_i}{\partial x_j} dx_j = 0 \tag{3.85}$$

Multiplying the constraints in equation (3.85) by a constant λ_i and summing all the resulting equations, we have the Lagrange function defined as follows:

$$F(x,\lambda) \equiv f(x) + \sum \lambda_i \left(b_i - g_i(x)\right) \tag{3.86}$$

Where,

F = Lagrange function

λ_i = Lagrange multiplier as a component of the m-vector λ.

Hence,

$$dF \equiv \sum_j \frac{\partial F}{\partial x_j} dx_j = 0 \tag{3.87}$$

Since there were m independent constraints listed above, then only n-m of the variables x_j were independent.

Let the variables be

$$x_{m+1}, \ldots, x \tag{3.88}$$

Optimizing the independent variables under the constraints above, an arbitrary value was chosen for λ_i such that:

$$\frac{\partial F}{\partial x_i} = 0 \tag{3.89}$$

Equation (3.79) becomes:

$$\frac{\partial F}{\partial x_{m+1}} dx_{m+1} + ... + \frac{\partial F}{\partial x_n} dx_n = 0 \tag{3.90}$$

Since the variables ($x_{m+1},\ldots,x_n$) were independent and different, we vary each of them in turn after another and obtain the following equation:

$$\frac{\partial F}{\partial x_{m+1}} = ... = \frac{\partial F}{\partial x_n} = 0 \tag{3.91}$$

Thus from equations (3.83) and (3.84) we have the stationary or optimal point given by:

$$\frac{\partial F}{\partial x_j} \equiv \frac{\partial f}{\partial x_j} - \sum_i \lambda_i \frac{\partial g_i}{\partial x_j} = 0 \tag{3.92}$$

3.45 Defining the problem in MATLAB optimization toolbox syntax

To use the optimization toolbox 'optimtool':

i. The objective function $f(x)$ was first defined in the MATLAB code as an M-file or anonymous function.

ii. The constraints function $g(x)$ was also defined in MATLAB code as separate M-files or anonymous functions.

iii. A problem structure was created on the MATLAB workspace as a separate M-file.

iv. The problem and options were imported from the MATLAB workspace to the optimization tool.

v. The solution was exported from the optimization tool to the MATLAB workspace.

The M-files were created using the MATLAB Editor / Debugger. From the file menu at the top of the MATLAB command windows, New › M-file was selected to open the MATLAB editor. The threshing efficiency objective function was then transformed into MATLAB code by typing on the text editor to create an M-file. The M-file was then imported into the MATLAB

workspace by selecting File › Import into workspace. The name of the M-file was made to match the name of the objective function on the optimtool so that the tool could easily trace and read the function file. The MATLAB M-files are written below.

An M-files thresheff.m for the objective function was written as follows:

```
Function f = thresheff (Vc, Mf, Mc)
f = -0.008(MbVct/MfCc) + 1.269(NbLc/Mch) + 89.24
f = thresheff (Vc, Mf, Mc)
f (Vc) = (f1(Vc), f2(Vc), f3(Vc), f4(Vc), f5(Vc));
f (Mf) = (f1(Mf), f2(Mf), f3(Mf), f4(Mf), f5(Mf));
f (Mc) = (f1(Mc), f2(Mc), f3(Mc), f4(Mc), f5(Mc));
```

An M-files confun.m for the inequality and equality constraints functions was written as follows:

```
Function [c, ceq] = confun (Vc,Mf,Mc,Nb,Lc,Mb,Cc,t,h)
% nonlinear inequality constraints
c = - Vc + 12.1 <= 0;
c = Vc - 20 <= 0;
c = - Mf + 6 <= 0;
c = Mf - 14 <= 0;
c = - Mc + 10.6 <= 0;
c = Mf - 15.8 <= 0;
% linear equality constraints
ceq = Nb - 38 = 0;
ceq = Lc - 1.195 = 0;
ceq = Mb - 0.188 = 0;
ceq = Cc - 0.01 = 0;
ceq = h - 1 = 0;
```

```
ceq = h - 0.47 = 0;
x0 = [-1,1]; % make a starting guess at the solution
options = optimset ('Display','iter','Largescale','on')
x = fgoalattain(thresheff,x0,goal,weight)
x = fgoalattain(thresheff,x0,goal,weight,A,b)
x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq)
x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq,lb,ub)
x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq,lb,ub,
confun)
x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq,lb,ub,
confun,... options)
x = fgoalattain(problem)
[x,fval] = fgoalattain(@thresheff,x0,[],[],[],[],[],[],@confun,
options)
[x,fval,attainfactor] = fgoalattain(...)
[x,fval,attainfactor,exitflag] = fgoalattain(...)
[x,fval,attainfactor,exitflag,output] = fgoalattain(...)
[x,fval,attainfactor,exitflag,output,lambda] = fgoalattain(...)
```

The solver was used to find the minimum of the function $F(x)$ as follows:

$$\underset{x,\gamma}{\text{minimize}}\,\gamma \quad \text{such that} \begin{cases} F(x) - weight \cdot \gamma \le goal \\ c(x) \le 0 \\ ceq(x) = 0 \\ A \cdot x \le b \\ Aeq \cdot x = beq \\ lb \le x \le ub. \end{cases} \tag{3.93}$$

x, weight, goal, b, beq, lb, and ub are vectors, A and Aeq are matrices, and c(x), ceq(x), and F(x) are functions that return vectors. F(x), c(x), and ceq(x) can be linear or nonlinear functions.

MATLAB Toolbox Syntax:

x = fgoalattain(thresheff,x0,goal,weight)

x = fgoalattain(thresheff,x0,goal,weight,A,b)

x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq)

x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq,lb,ub)

x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq,lb,ub,confun)

x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq,lb,ub,confun,... options)

x = fgoalattain(problem)

[x,fval] = fgoalattain(...)

[x,fval,attainfactor] = fgoalattain(...)

[x,fval,attainfactor,exitflag] = fgoalattain(...)

[x,fval,attainfactor,exitflag,output] = fgoalattain(...)

[x,fval,attainfactor,exitflag,output,lambda] = fgoalattain(...)

Description:

x = fgoalattain(thresheff,x0,goal,weight) tries to make the objective functions supplied by fun attain the goals specified by goal by varying x, starting at x0, with weight specified by weight.

x = fgoalattain(thresheff,x0,goal,weight,A,b) solves the goal attainment problem subject to the linear inequalities A*x = b.

x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq) solves the goal attainment problem subject to the linear equalities Aeq*x = beq as well. Set A = [] and b = [] if no inequalities exist.

x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq,lb,ub) defines a set of lower and upper bounds on the design variables in x, so that the solution is always in the range lb = x = ub.

x = fgoalattain(thresheff,x0,goal,weight,A,b,Aeq,beq,lb,ub,confun) subjects the goal attainment problem to the nonlinear inequalities c(x) or linear equality constraints ceq(x) defined in confun.

fgoalattain optimizes such that c(x) = 0 and ceq(x) = 0. Set lb = [] and/or ub = [] if no bounds exist.

x = fgoalattain(fun,x0,goal,weight,A,b,Aeq,beq,lb,ub,confun,... options) minimizes with the optimization options specified in the structure options. Optimset was used to set these options.

x = fgoalattain(problem) finds the minimum for problem, where problem is a structure described in Input Arguments.

The structure problem was created by exporting a problem from Optimization Tool

[x,fval] = fgoalattain(...) returns the values of the objective functions computed in fun at the solution x.

[x,fval,attainfactor] = fgoalattain(...) returns the attainment factor at the solution x.

[x,fval,attainfactor,exitflag] = fgoalattain(...) returns a value exitflag that describes the exit condition of fgoalattain.

[x,fval,attainfactor,exitflag,output] = fgoalattain(...) returns a structure output that contains information about the optimization.

[x,fval,attainfactor,exitflag,output,lambda] = fgoalattain(...) returns a structure lambda whose fields contain the Lagrange multipliers at the solution x.

3.46 Running the Optimization

To run the optimization, the problem structure was created and modified in optimtool by exporting the problem information to the MATLAB workspace. An option structure was created using the "optimset" function or the export option of optimtool. The optimtool solver starts the optimization tool with the specified solver. For this study, the fgoalattain solver was used to perform the optimization. In the optimtool interface the solver, toolbox function and constraints were selected, the optimization options were specified before clicking on the start button to run the optimization. The goal attainment problem was solved by minimizing the multi-objective functions $f(x)$ simultaneously. The result of the optimization was displayed in an output.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Output Capacity for Millet Crop

Output capacity evaluates the quantity of clean millet grains collected at the grain outlet of the multicrop thresher for the total quantity of crop fed per hour. The millet grains collected ranges from 166.6 kg/hr to 520.6 kg/hr when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with output at various moisture contents and constant feed rates are illustrated in Fig. 4(a, b, c, d and e). It indicates that output capacity increase as speed increase. This may be due to increase kinetic energy transfer from beater to crop causing more grains to be detarched. However at constant speed and feed rate output capacity decreases as moisture content increase. This was as a result of cohesive and adhesive forces that exist in crop with high moisture content that keeps the grains in place resulting to reduction in grain detarchment and output capacity.

The variation of feed rate with output at various moisture contents and constant speed are illustrated in Fig. 4.1(a, b, c, d and e). It indicates that output capacity increases as feed rate increase. The reason was increase in the quantity of crop entering the hopper. However at a constant speed and feed rate output capacity decreases as moisture content increases. These results were similar to those of Sinha *et al.* (2009) and Osueke (2013). Therefore output capacity is directly proportional to speed and feed rate but inversely proportional to moisture contents. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of output capacity for millet crop is shown in Table 4. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.1(a, b and c). The result shows that in the variation

of speed, feed rate and moisture content with output capacity there were significant differences between the means at 1 % level of significance. This implies as speed increase to another level output capacity increase significantly (Table 4.1a); as feed rate increase to another level output capacity increase significantly (Table 4.1b); as moisture content decrease to another level output capacity increase significantly (Table 4.1c). Appendix D represents measured values of output capacity at five levels of cylinder speed, feed rate and crop moisture content for millet crop.

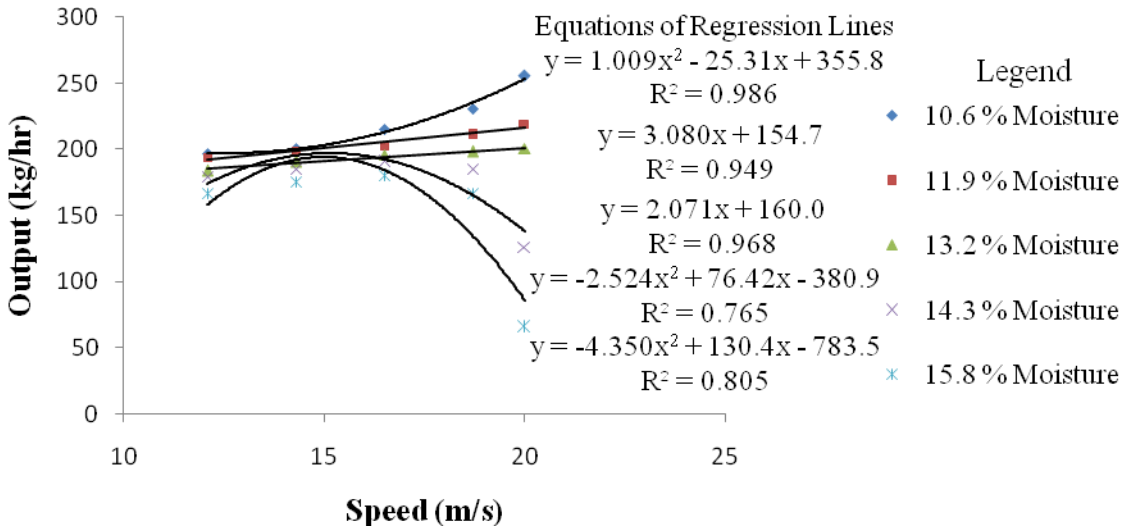


Fig. 4a: Variation of speed with output at various moisture content and constant feed rate of 6 kg/min for millet crop

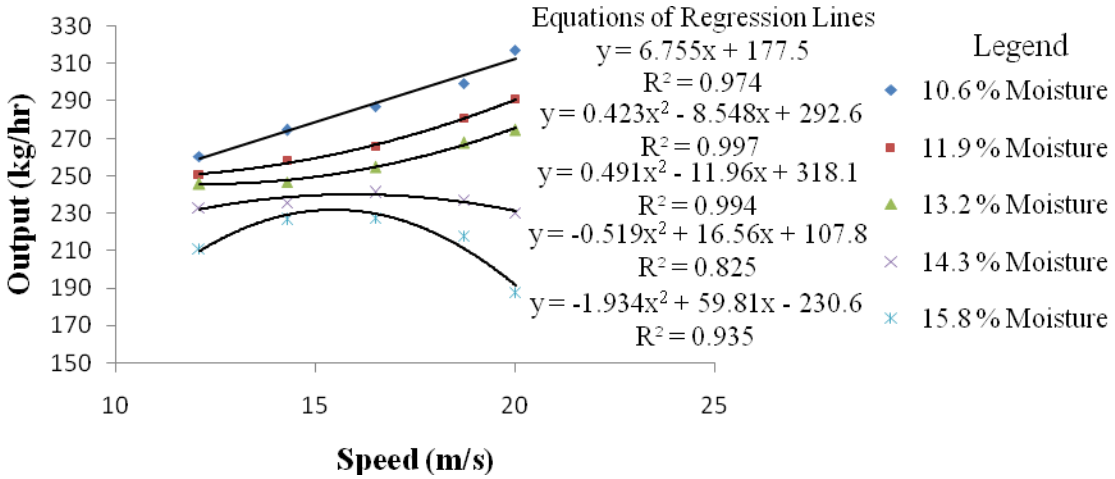


Fig. 4b: Variation of speed with output at various moisture content and constant feed rate of 8 kg/min for millet crop

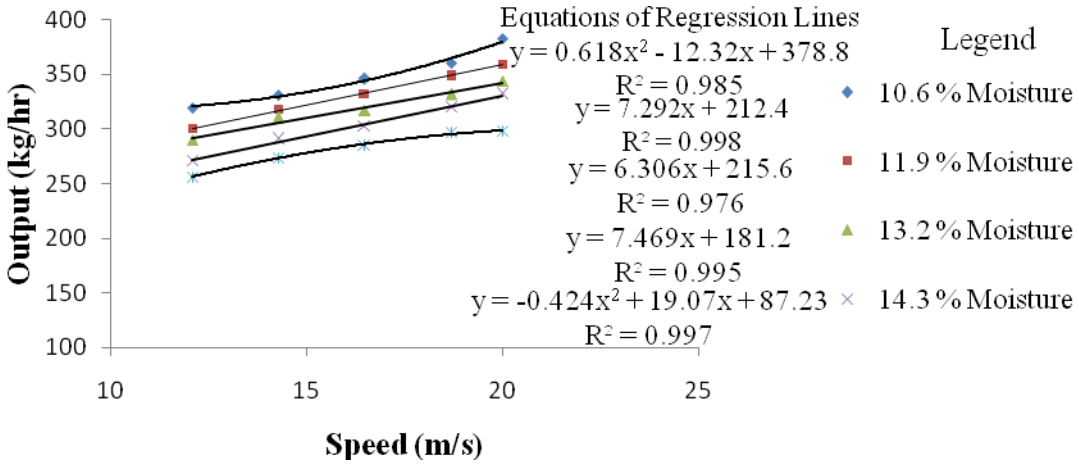


Fig. 4c: Variation of speed with output at various moisture content and constant feed rate of 10 kg/min for millet crop

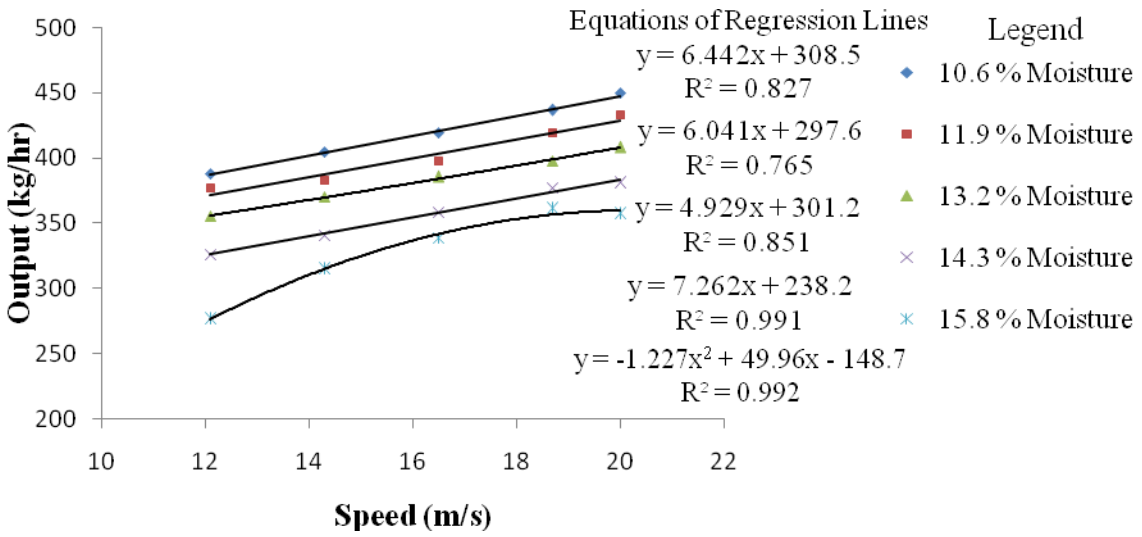


Fig. 4d: Variation of speed with output at various moisture content and constant feed rate of 12 kg/min for millet crop

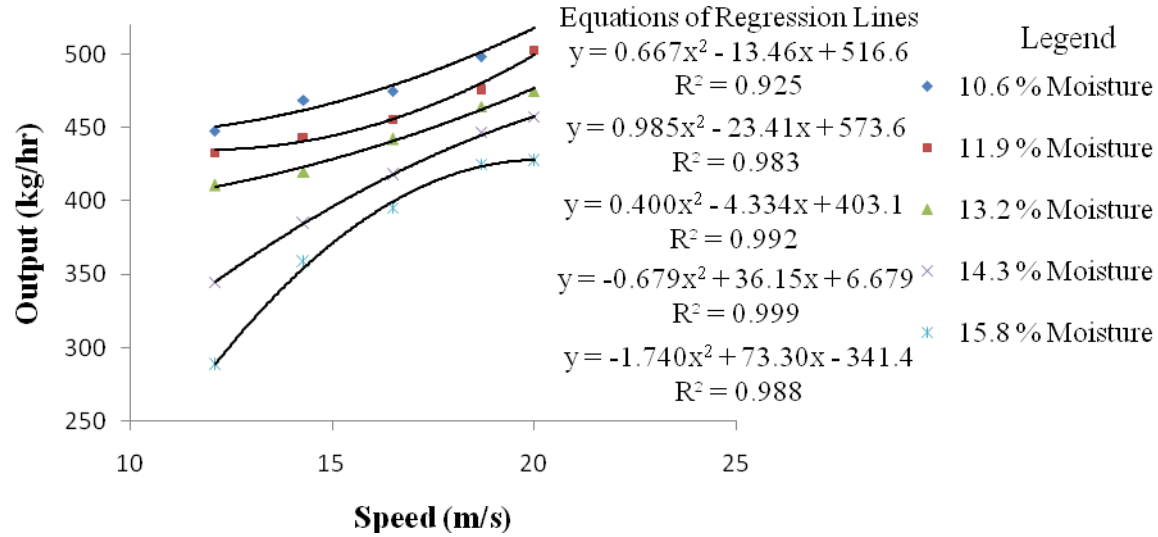


Fig. 4e: Variation of speed with output at various moisture content and constant feed rate of 14 kg/min for millet crop

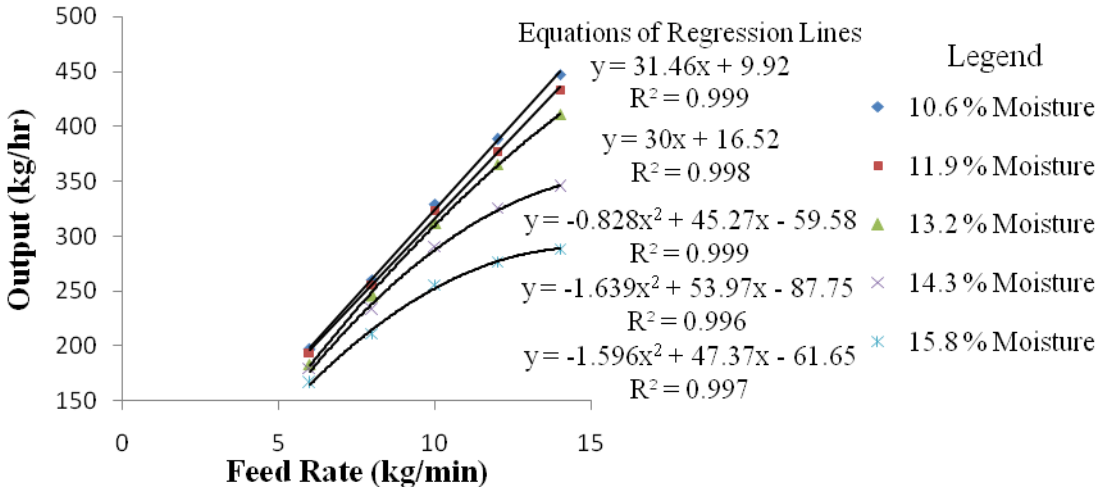


Fig. 4.1a: Variation of feed rate with output at various moisture contents and constant speed of 12.1 m/s for millet crop

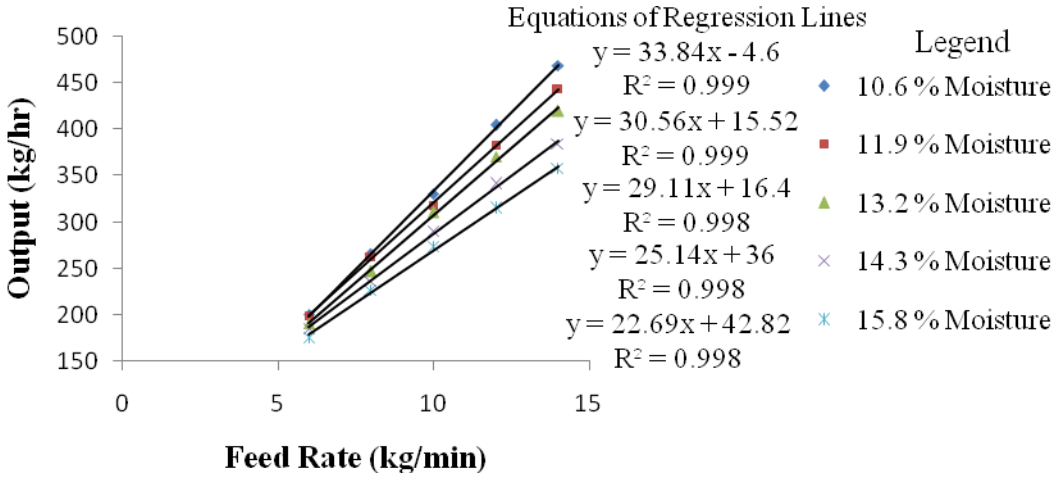


Fig. 4.1b: Variation of feed rate with output at various moisture contents and constant speed of 14.3 m/s for millet crop

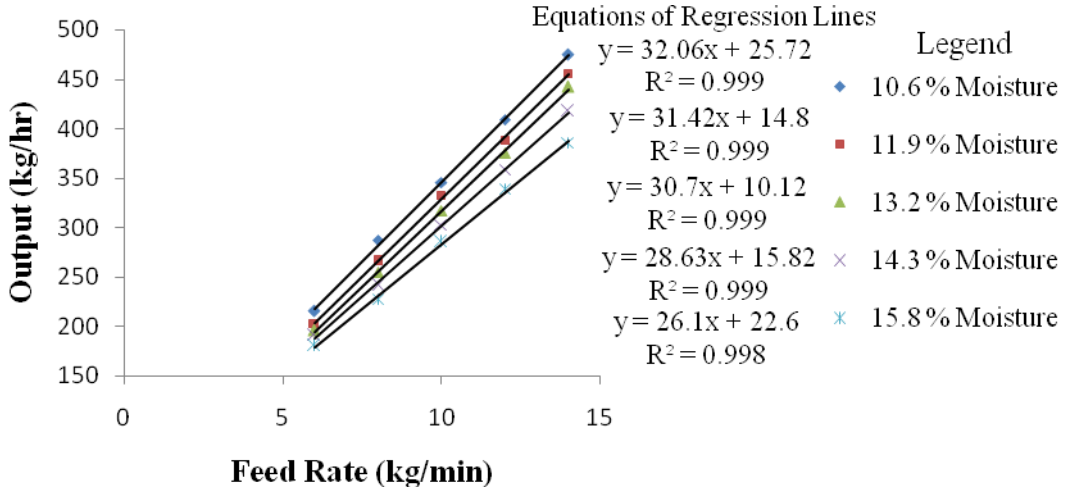


Fig. 4.1c: Variation of feed rate with output at various moisture contents and constant speed of 16.5 m/s for millet crop

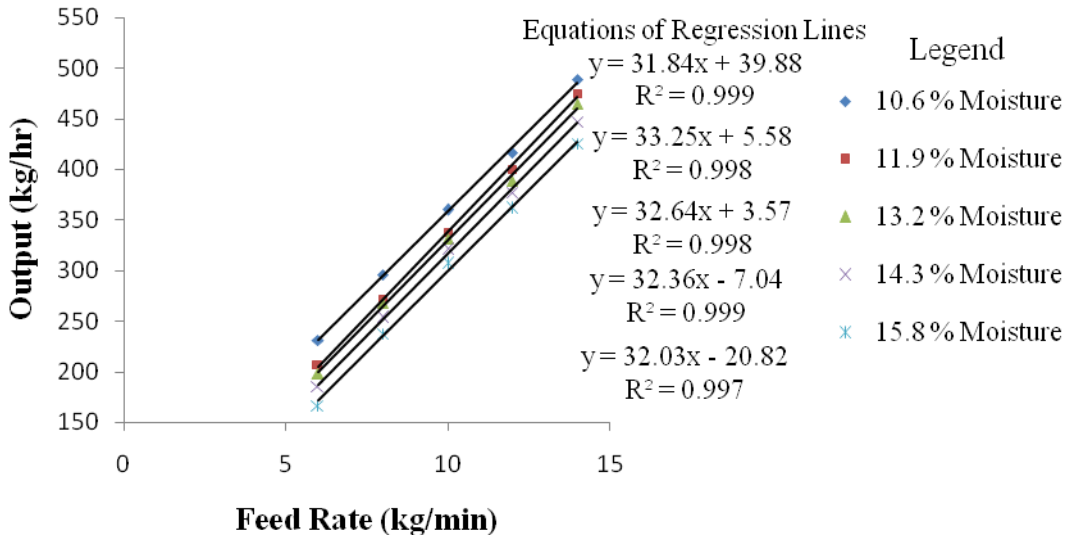


Fig. 4.1d: Variation of feed rate with output at various moisture contents and constant speed of 18.7 m/s for millet crop

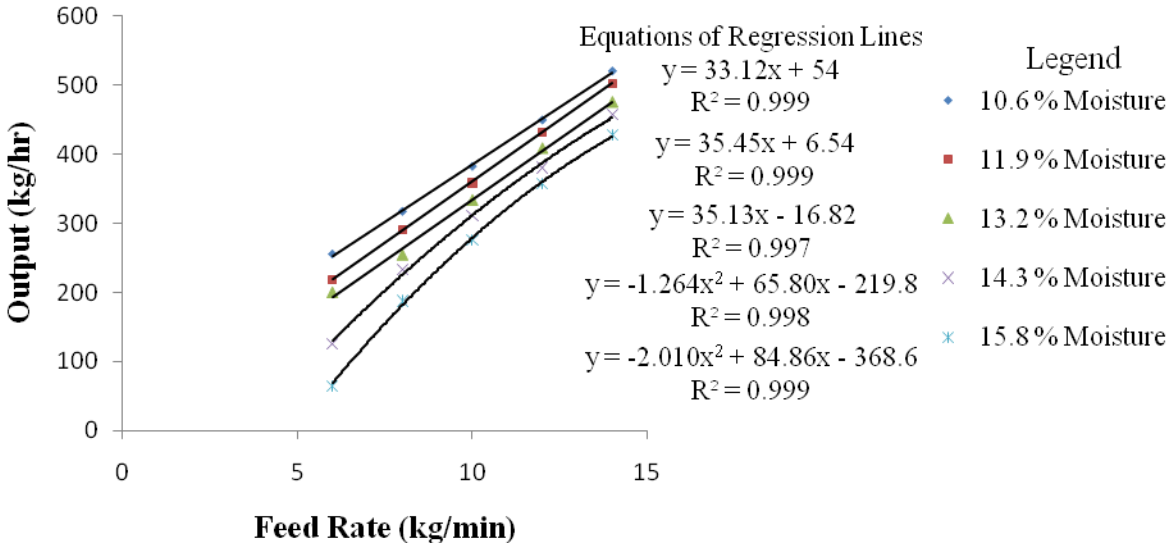


Fig. 4.1e: Variation of feed rate with output at various moisture contents and constant speed of 20 m/s for millet crop

Table 4: ANOVA of output capacity for millet crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	1.47		
Moisture (M)	4	32850.78	8212.70	10056.3 **
Speed (S)	4	3197133.97	799283.49	978706 **
Feed rate (F)	4	16764.92	4191.23	5132.07 **
M × S	16	2274.61	142.16	174.08 **
M × F	16	1465.07	91.57	112.12 **
F × S	16	25563.07	1597.69	1956.34 **
M × S × F	64	3763.91	58.81	72.01 **
Error	248	202.54	0.82	
Total	374	3280020.32		

** = Significant at 1 % probability level

Table 4.1a: D. M. R. T. for variation of speed with output capacity for millet crop

Duncan Grouping	Mean Output (kg/hr)	N	Speed (m/s)
A	194.45	75	12.1
B	261.53	75	14.3
C	324.69	75	16.5
D	377.95	75	18.7
E	371.95	75	20.0

Alpha= 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0.817

Number of Means	2	3	4	5
Critical Range	0.29	0.31	0.32	0.33

Table 4.1b: D. M. R. T. for variation of feed rate with output capacity for millet crop

Duncan Grouping	Mean Output (kg/hr)	N	Feed Rate (kg/min)
A	317.18	75	6
B	319.13	75	8
C	324.84	75	10
D	329.28	75	12
E	335.14	75	14

Alpha= 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0.817

Number of Means	2	3	4	5
Critical Range	0.29	0.31	0.32	0.33

Table 4.1c: D. M. R. T. for variation of crop moisture content with output capacity for millet crop

Duncan Grouping	Mean Output (kg/hr)	N	Moisture Content (%)
A	334.78	75	10.6
B	331.25	75	11.9
C	327.57	75	13.2
D	317.71	75	14.3
E	309.26	75	15.8

Alpha= 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0.817

Number of Means	2	3	4	5
Critical Range	0.29	0.31	0.32	0.33

This test controls the Type I comparison wise error rate, not the experiment wise error rate. Any two means with the same letter are not significantly different at 1 % level of significance.

4.2 Threshing Efficiency for Millet Crop

Threshing efficiency evaluates the percentage of grains detached from the crop by the beaters of the multicrop thresher. It ranges from 94.02 % to 99.98 % for millet when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with threshing efficiency at various moisture contents and constant feed rates are illustrated in Fig. 4.2(a, b, c, d and e). It indicates that threshing efficiency increases as speed increase. This may be due to increase kinetic energy transfer from beater to crop causing more grains to be detarched. However at constant speed, threshing efficiency decreases as moisture content increase. The reason was the existence of cohesive / adhesive forces in crop with high moisture content that keeps the grains in place resulting to reduction in threshing efficiency.

The variation of feed rate with threshing efficiency at various crop moisture contents and constant speed are illustrated in Fig. 4.3(a, b, c, d and e). It indicates that threshing efficiency decreases as feed rate increase. This was because of reduction in speed as the load intensity on the beaters increase as more crops are fed. However at a constant feed rate, threshing efficiency decreases as moisture content increase. This may be due to cohesive and adhesive forces that exist in crop with high moisture content that keeps the grains in place resulting to reduction in threshing efficiency. These results were similar to those of Sinha *et al.* (2009); Osueke (2013) and Saeidirad *et al.* (2013). Therefore threshing efficiency is directly proportional to speed but inversely proportional to feed rate and moisture contents. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of threshing efficiency for millet crop is shown in Table 4.2. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.3(a, b and c). The result shows that in the variation of speed, feed rate and moisture content with threshing efficiency there were significant

differences between the means at 1 % level of significance. This implies as speed increase to another level threshing efficiency increase significantly (Table 4.3a); as feed rate increase to another level threshing efficiency decrease significantly (Table 4.3b); as moisture content decrease to another level threshing efficiency increase significantly (Table 4.3c). Appendix F represents measured values of threshing efficiency at five levels of cylinder speed, feed rate and crop moisture content for millet crop.

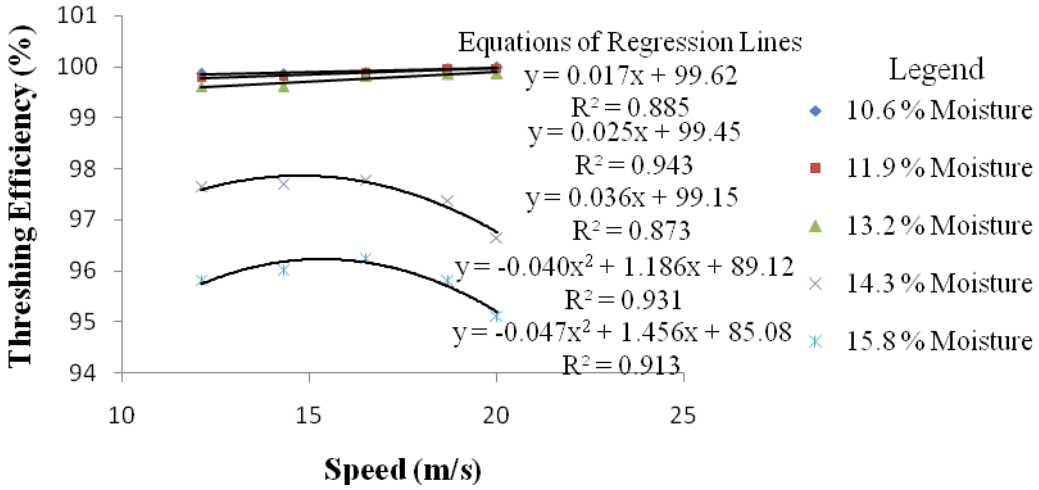


Fig. 4.2a: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 6 kg/min for millet crop

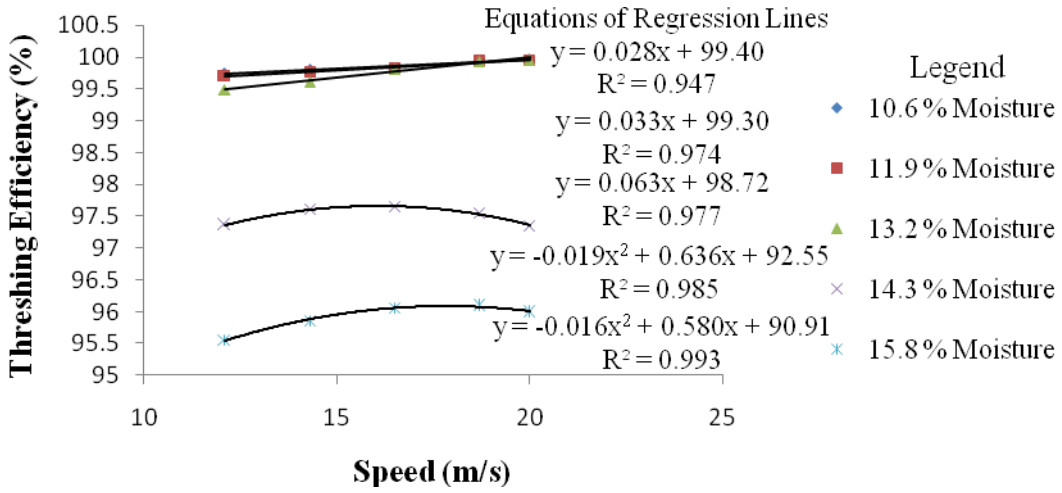


Fig. 4.2b: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 8 kg/min for millet crop

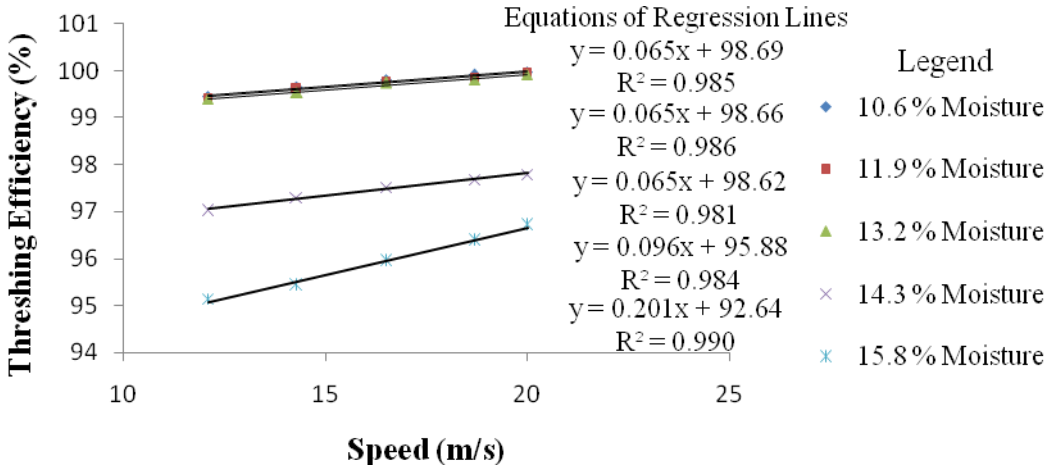


Fig. 4.2c: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 10 kg/min for millet crop

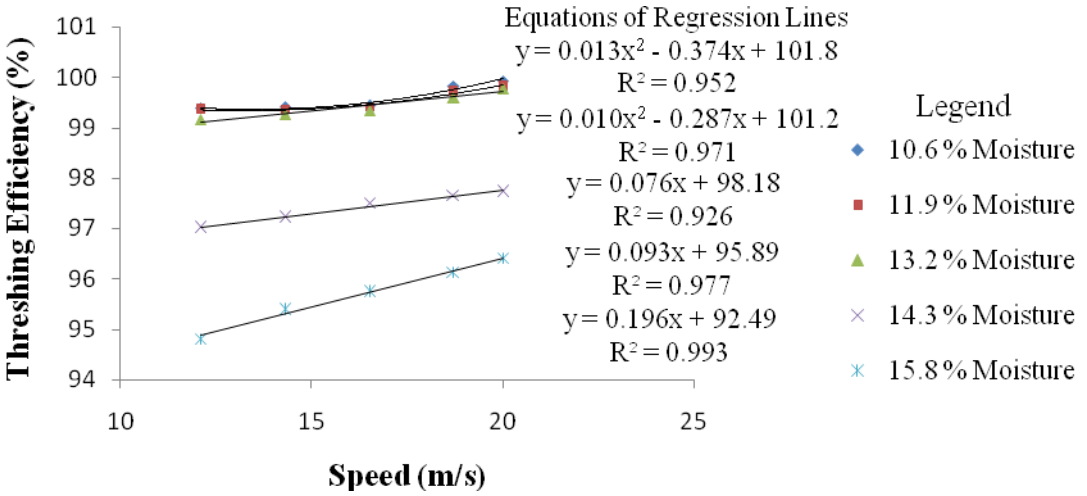


Fig. 4.2d: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 12 kg/min for millet crop

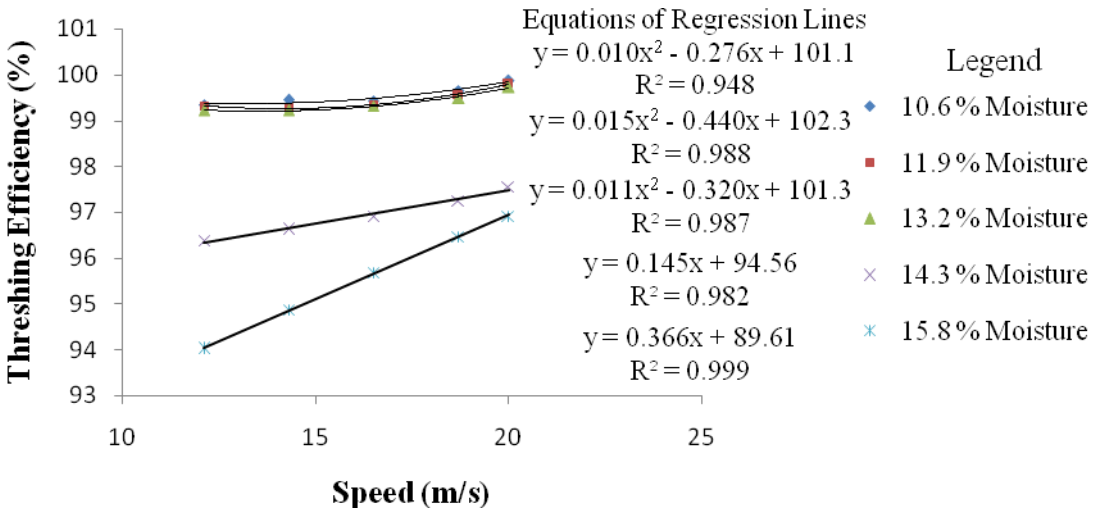


Fig. 4.2e: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 14 kg/min for millet crop

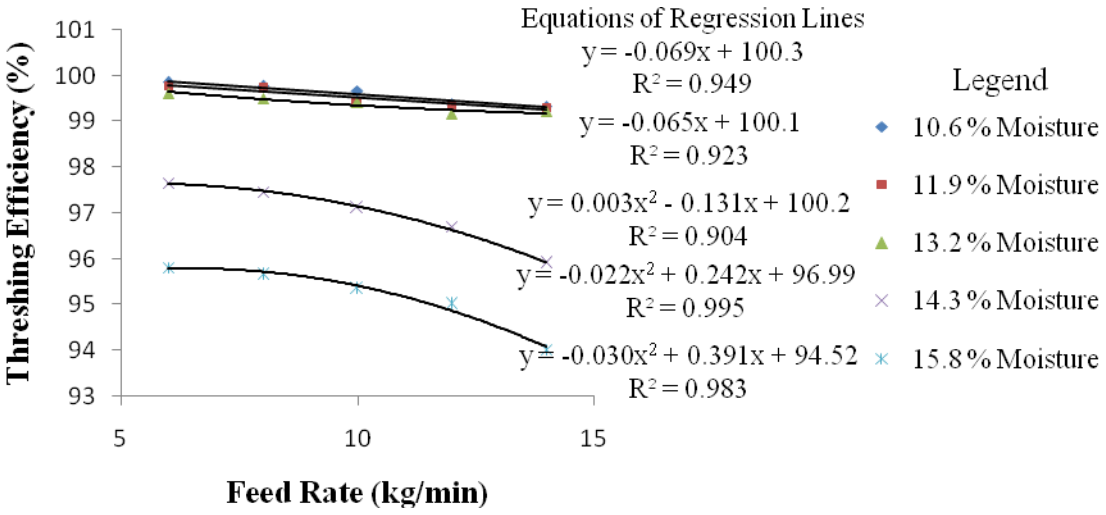


Fig. 4.3a: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 12.1 m/s for millet crop

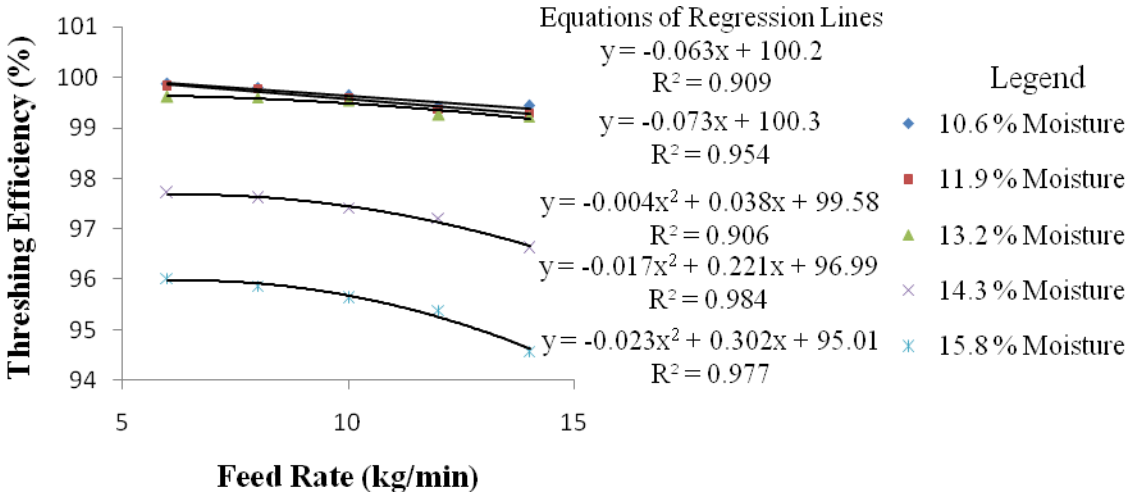


Fig. 4.3b: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 14.3 m/s for millet crop

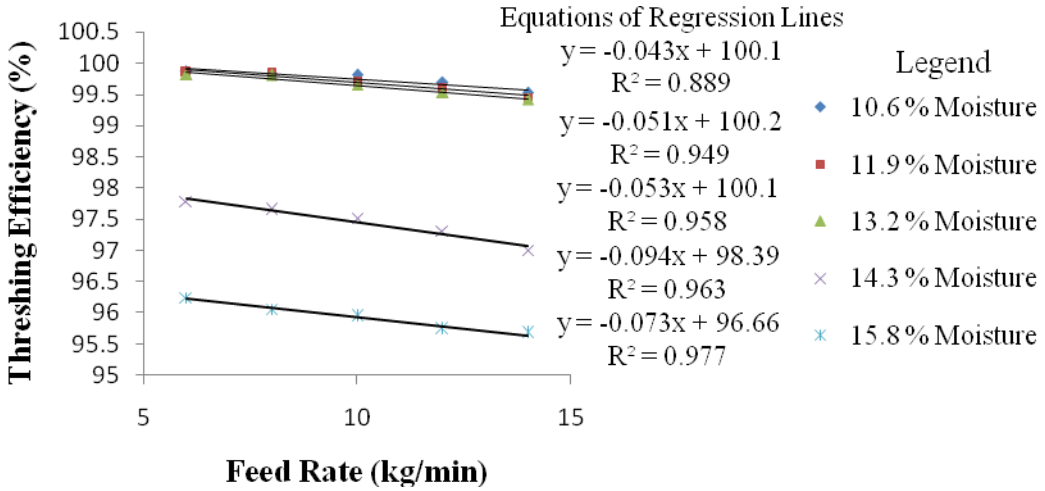


Fig. 4.3c: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 16.5 m/s for millet crop

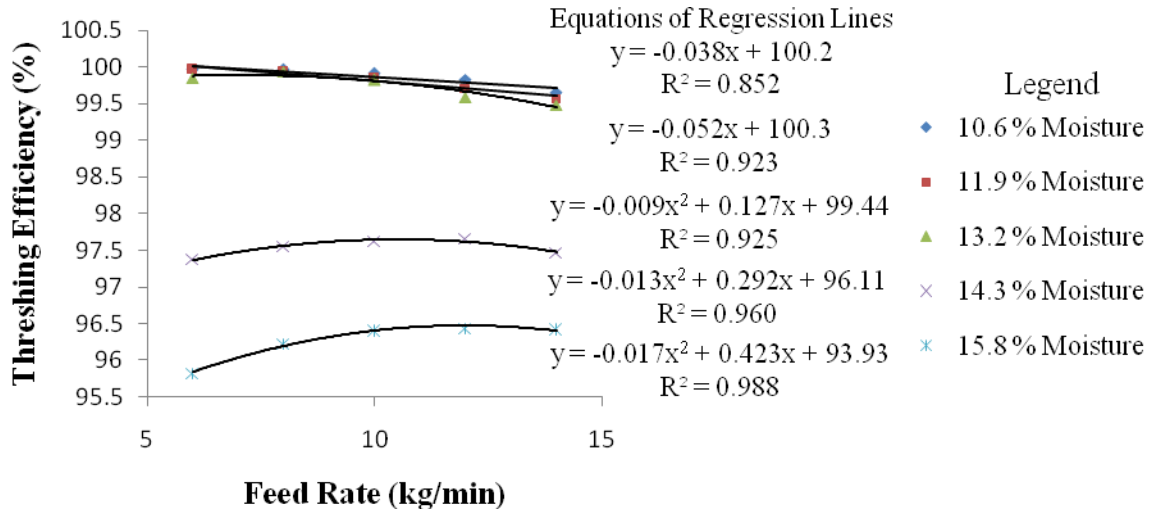


Fig. 4.3d: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 18.7 m/s for millet crop

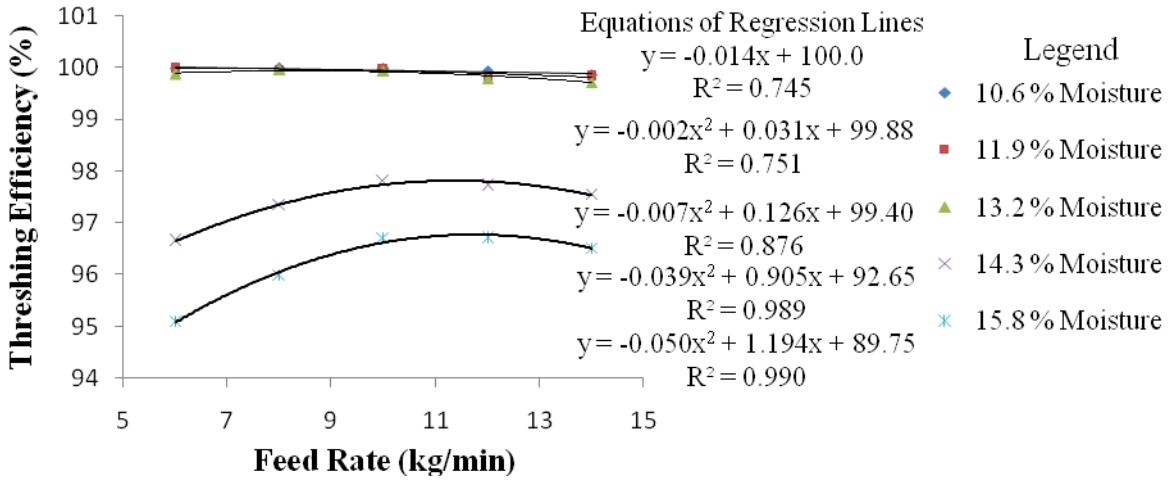


Fig. 4.3e: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 20 m/s for millet crop

Table 4.2: ANOVA of threshing efficiency for millet crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.003		
Moisture (M)	4	812.649	203.162	46041.8**
Speed (S)	4	7.271	1.818	411.93**
Feed rate (F)	4	16.259	4.065	921.19**
M × S	16	2.793	0.175	39.56**
M × F	16	8.705	0.544	123.30**
F × S	16	3.761	0.235	53.27**
M × S × F	64	6.600	0.103	23.37**
Error	248	1.094	0.004	
Total	374	859.136		

** = Significant at 1 % probability level

Table 4.3 a: D. M. R.T. for variation of speed with threshing efficiency for millet crop

Duncan Grouping	Mean Threshing Efficiency (%)	N	Speed (m/s)
A	98.28	75	12.1
B	98.48	75	14.3
C	98.57	75	16.5
D	98.64	75	18.7
E	98.67	75	20.0

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0.004

Number of Means	2	3	4	5
Critical Range	0.021	0.022	0.023	0.024

Table 4.3 b: D. M. R.T. for variation of feed rate with threshing efficiency for millet crop

Duncan Grouping	Mean Threshing Efficiency (%)	N	Feed Rate (kg/min)
A	98.77	75	6
B	98.70	75	8
C	98.58	75	10
D	98.38	75	12
E	98.21	75	14

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0.004

Number of Means	2	3	4	5
Critical Range	0.021	0.022	0.023	0.024

Table 4.3 c: D. M. R.T. for variation of crop moisture content with threshing efficiency for millet crop

Duncan Grouping	Mean Threshing Efficiency (%)	N	Moisture Content (%)
A	99.73	75	10.6
B	99.69	75	11.9
C	99.64	75	13.2
D	97.41	75	14.3
E	96.17	75	15.8

Alpha = 0.05, Error Dgrees of Freedom = 248, Error Mean Square = 0.004

Number of Means	2	3	4	5
Critical Range	0.021	0.022	0.023	0.024

This test controls the Type I comparison wise error rate, not the experiment wise error rate. Any two means with the same letter are not significantly different at 1 % level of significance.

4.3 Cleaning Efficiency for Millet Crop

Cleaning efficiency evaluates the percentage of clean grain collected at the grain outlet. It indicates the effectiveness of the sieves, the blower and the shaker to separate grains from chaff as they flow to the bottom of the thresher. It ranges from 84.27 % to 99.71 % for millet when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with cleaning efficiency at various moisture contents and constant feed rates are illustrated in Fig. 4.4(a, b, c, d and e). It indicates that cleaning efficiency increases as speed increase. This may be due to increase in air flow rate of the blower as speed increases. However at constant speed, cleaning efficiency decreases as moisture content increase. The reason was the existence of cohesive / adhesive forces and small mass difference between grains and chaff with high moisture content resulting to grains being blown away with chaff hence reduction in cleaning efficiency.

The variation of feed rate with cleaning efficiency at various moisture contents and constant speed are illustrated in Fig. 4.5(a, b, c, d and e). It indicates that cleaning efficiency decreases as feed rate increase. This was because of increasing load intensity on the sieves as multiple particles act as obstruction to grain flow resulting to more grains blown away with chaff. Also at a constant feed rate, cleaning efficiency decreases as moisture content increase. These results were similar to those of Simonyan and Yiljep (2008); Osueke (2013). Therefore cleaning efficiency is directly proportional to speed but inversely proportional to feed rate and crop moisture content. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of cleaning efficiency for millet crop is shown in Table 4.4. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.5(a, b and c). The result shows that in the variation

of speed, feed rate and moisture content with cleaning efficiency there were significant differences between the means at 1 % level of significance. This implies as speed increase to another level cleaning efficiency increase significantly (Table 4.5a); as feed rate increase to another level cleaning efficiency decrease significantly (Table 4.5b); as moisture content decrease to another level cleaning efficiency increase significantly (Table 4.5c). Appendix H represents measured values of cleaning efficiency at five levels of cylinder speed, feed rate and crop moisture content for millet crop.

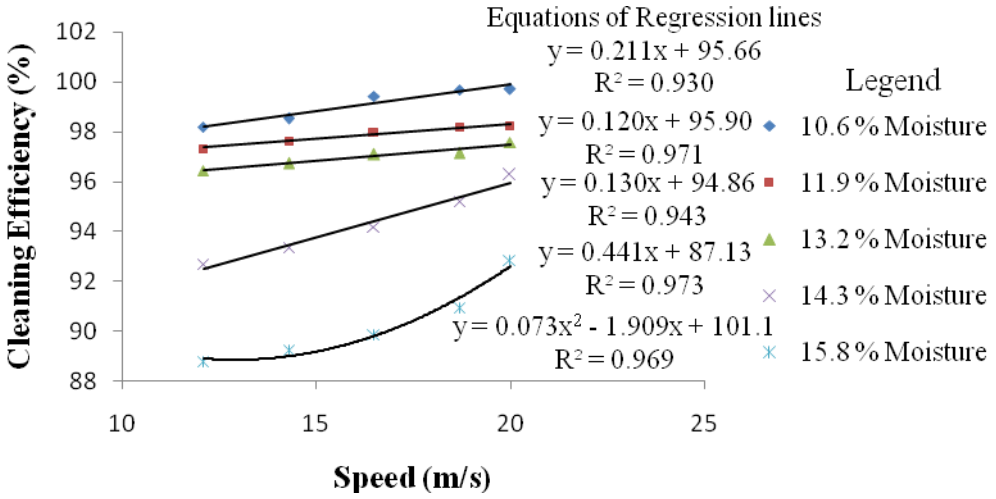


Fig. 4.4a: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 6 kg/min for millet crop

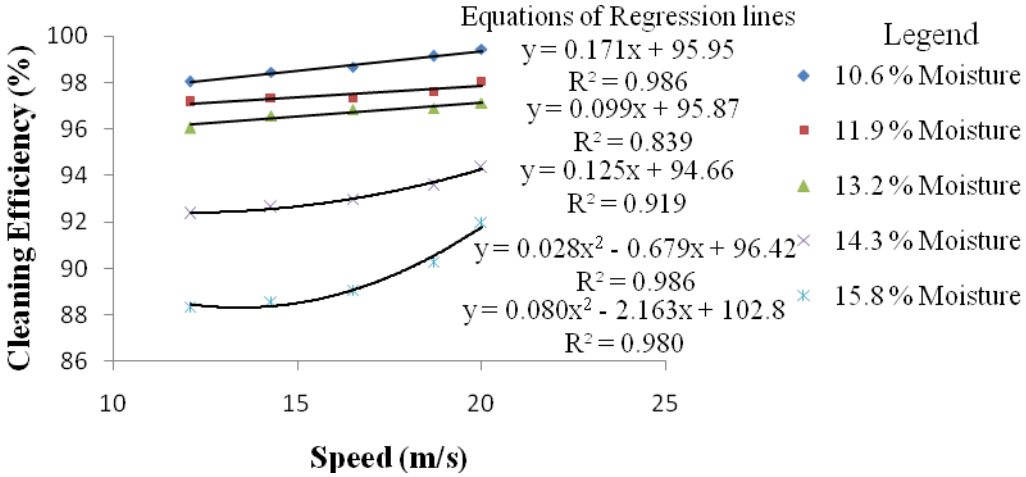


Fig. 4.4b: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 8 kg/min for millet crop

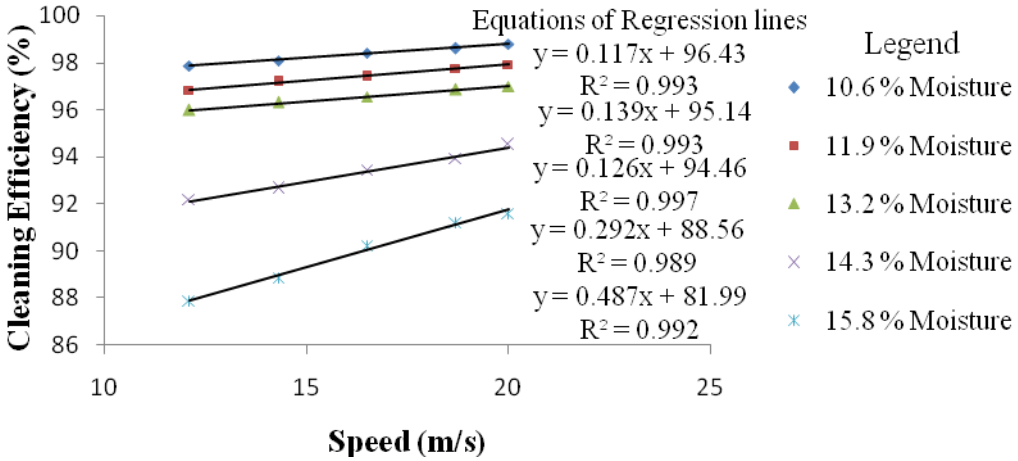


Fig. 4.4c: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 10 kg/min for millet crop

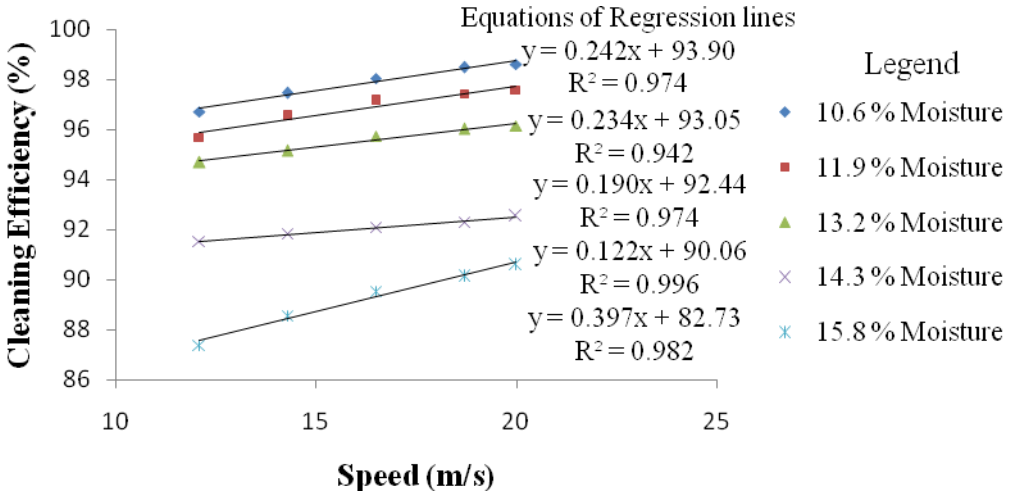


Fig. 4.4d: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 12 kg/min for millet crop

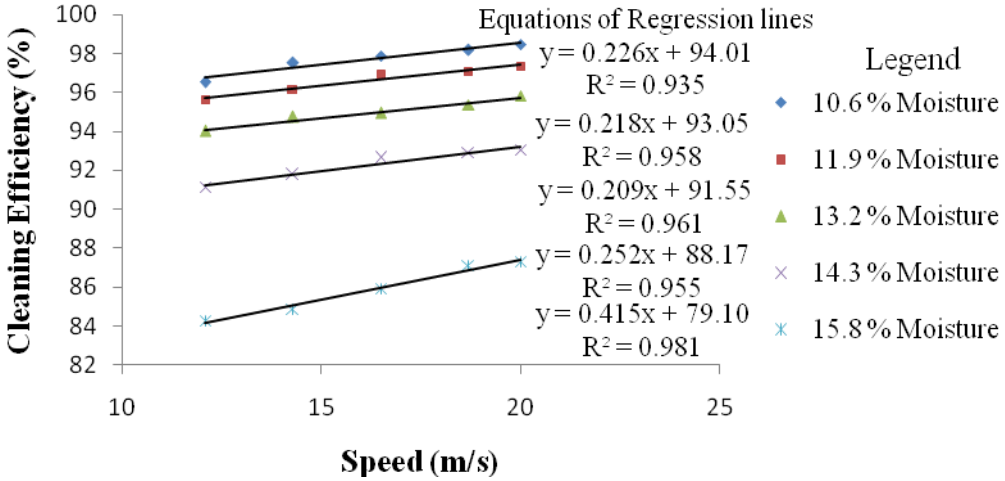


Fig. 4.4e: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 14 kg/min for millet crop

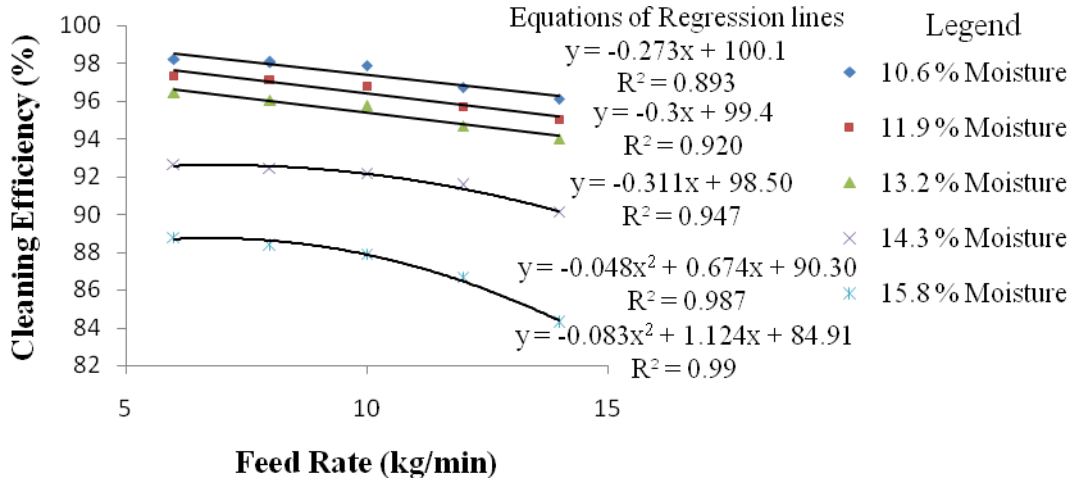


Fig. 4.5a: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 12.1 m/s for millet crop

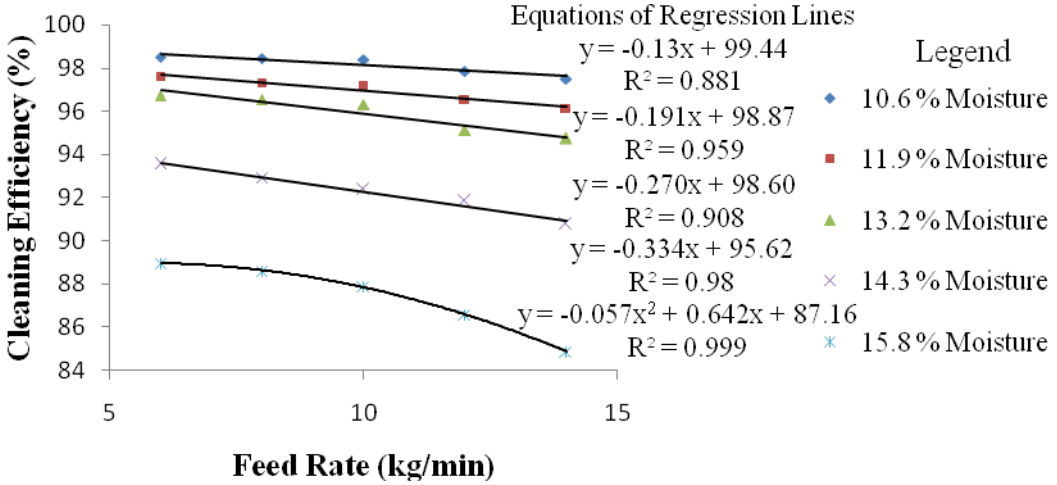


Fig. 4.5b: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 14.3 m/s for millet crop

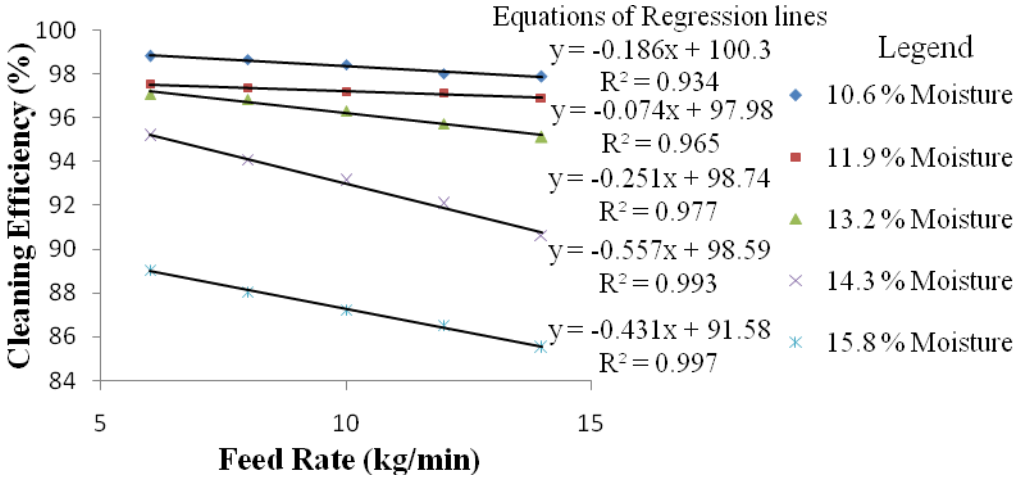


Fig. 4.5c: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 16.5 m/s for millet crop

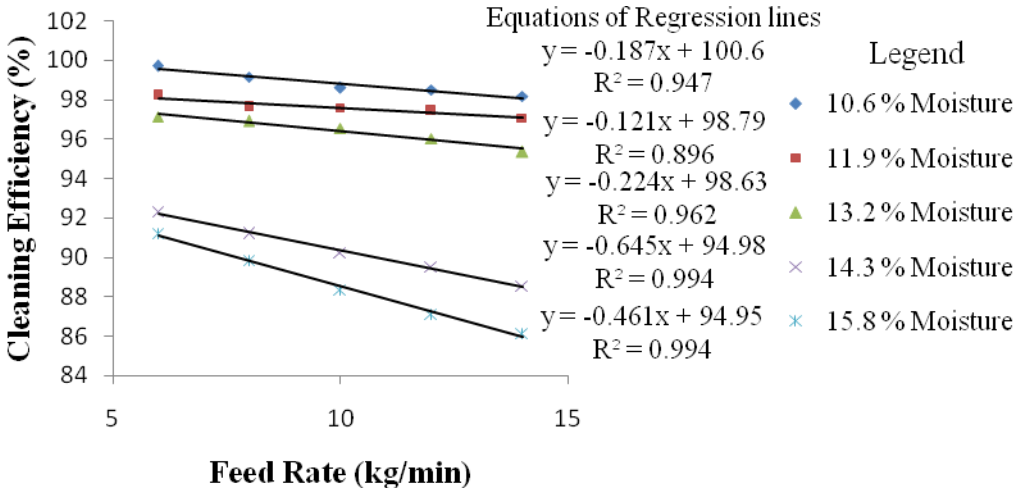


Fig. 4.5d: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 18.7 m/s for millet crop

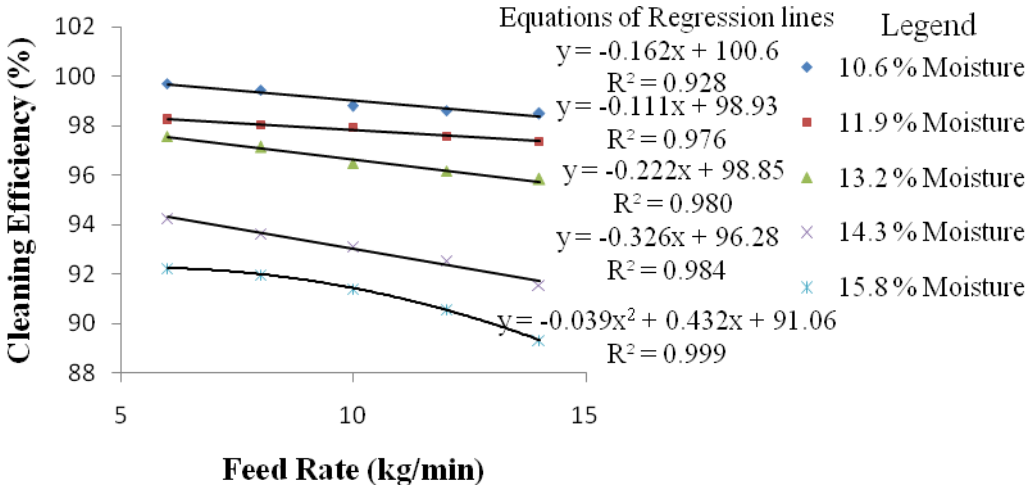


Fig. 4.5e: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 20 m/s for millet crop

Table 4.4: ANOVA of cleaning efficiency for millet crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.01		
Moisture (M)	4	4850.31	1212.58	55341.7**
Speed (S)	4	112.61	28.15	1284.85**
Feed rate (F)	4	192.62	48.16	2197.83**
M × S	16	97.67	6.10	278.60 **
M × F	16	74.05	4.63	211.23 **
F × S	16	44.49	2.78	126.90 **
M × S × F	64	92.03	1.44	65.63 **
Error	248	5.43	5.43	
Total	374	5469.23	5469.23	

** = Significant at 1 % probability level

Table 4.5 a: D. M. R.T for variation of speed with cleaning efficiency for millet crop

Duncan Grouping	Mean Cleaning Efficiency (%)	N	Speed (m/s)
A	93.87	75	12.1
B	94.31	75	14.3
C	94.62	75	16.5
D	94.88	75	18.7
E	95.42	75	20.0

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0.022

Number of Means	2	3	4	5
Critical Range	0.048	0.050	0.052	0.053

Table 4.5 b: D. M. R.T. for variation of feed rate with cleaning efficiency for millet crop

Duncan Grouping	Mean Cleaning Efficiency (%)	N	Feed Rate (kg/min)
A	95.83	75	6
B	94.81	75	8
C	94.58	75	10
D	94.12	75	12
E	93.72	75	14

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0.022

Number of Means	2	3	4	5
Critical Range	0.048	0.050	0.052	0.053

Table 4.5 c: D. M. R.T. for variation of crop moisture content with cleaning efficiency for millet crop

Duncan Grouping	Mean Cleaning Efficiency (%)	N	Moisture Content (%)
A	98.35	75	10.6
B	97.24	75	11.9
C	96.29	75	13.2
D	92.66	75	14.3
E	88.52	75	15.8

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0.022

Number of Means	2	3	4	5
Critical Range	0.048	0.050	0.052	0.053

This test controls the Type I comparison wise error rate, not the experiment wise error rate. Any two means with the same letter are not significantly different at 1 % level of significance.

4.4 Scattered Grain Loss for Millet Crop

Scattered grain (S_g) includes: threshed grains sucked out with chaff at the top chaff outlet, plus threshed grains falling out of the hopper, plus threshed grains blown away with chaff by the blower, plus threshed grains falling from the shaker during threshing and cleaning. It ranges from 5.77 % to 12.18 % for millet when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with scattered grain loss at various moisture contents and constant feed rates are illustrated in Fig. 4.6(a, b, c, d and e). It indicates that scattered grain loss increases as speed increase. This may be due to increase in machine vibration and air flow rate of the blower above optimum. However at constant speed, scattered grain loss decreases as moisture content increase. This may be due to cohesive and adhesive forces that exist in crops with high moisture content that keeps the grains and chaff together resulting to reduction in grain loss.

The variation of feed rate with scattered grain loss at various moisture contents and constant speeds are illustrated in Fig. 4.7(a, b, c, d and e). It indicates that scattered grain loss decreases as feed rate increase. This may be due to increase load intensity on the beaters causing the machine rotation, vibration and air flow rate to be low. Also at a constant feed rate, scattered grain loss decreases as moisture content increase. These results were similar to those of Simonyan and Yiljep (2008). Therefore scattered grain loss is directly proportional to speed but inversely proportional to feed rate and moisture content. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of scattered grain loss for millet crop is shown in Table 4.6. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.7(a, b and c). The result shows that in the variation of speed, feed rate and moisture content with scattered grain loss there were significant

differences between the means at 1 % level of significance. This implies as speed increase to another level scattered grain loss increase significantly (Table 4.7a); as feed rate increase to another level scattered grain loss decrease significantly (Table 4.7b); as moisture content decrease to another level scattered grain loss increase significantly (Table 4.7c). Appendix J represents measured values of scattered grain loss at five levels of cylinder speed, feed rate and crop moisture content for millet crop.

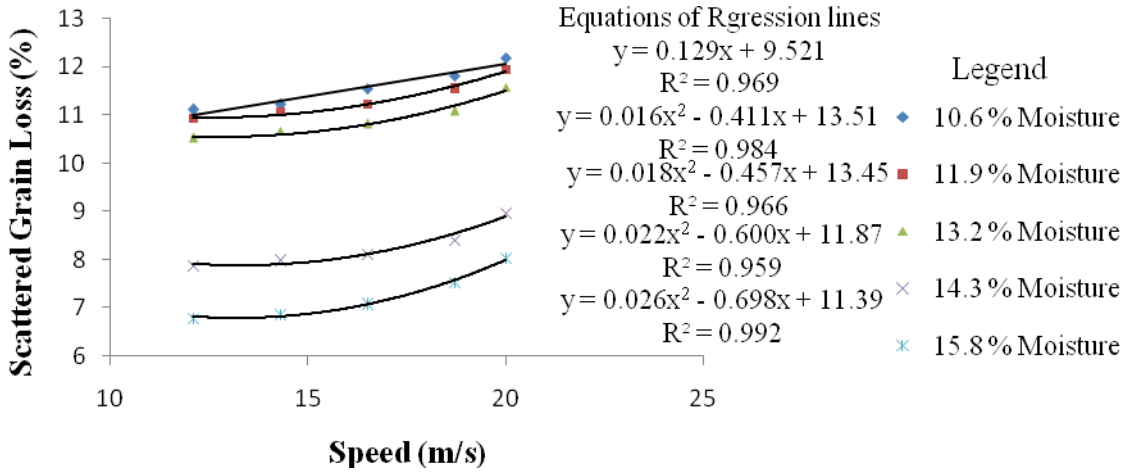


Fig. 4.6a: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 6 kg/min for millet crop

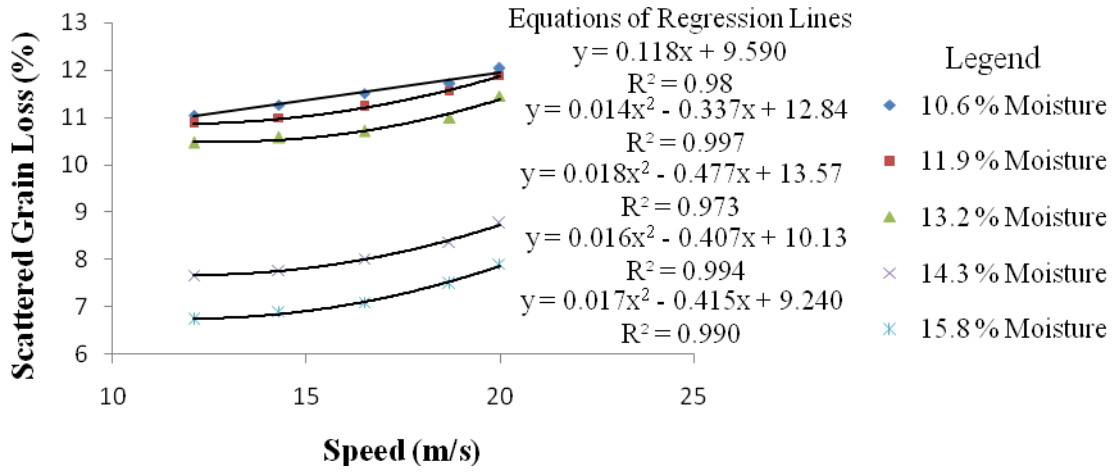


Fig. 4.6b: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 8 kg/min for millet crop

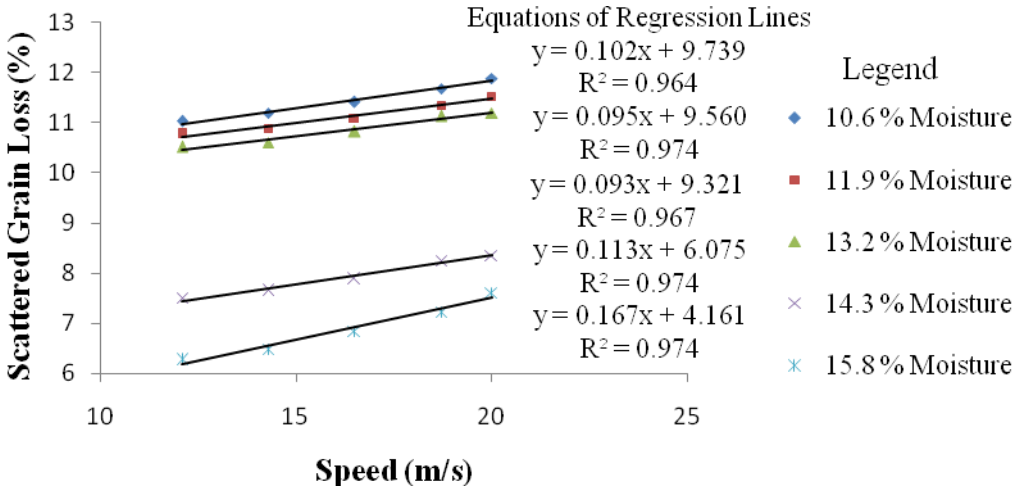


Fig. 4.6c: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 10 kg/min for millet crop

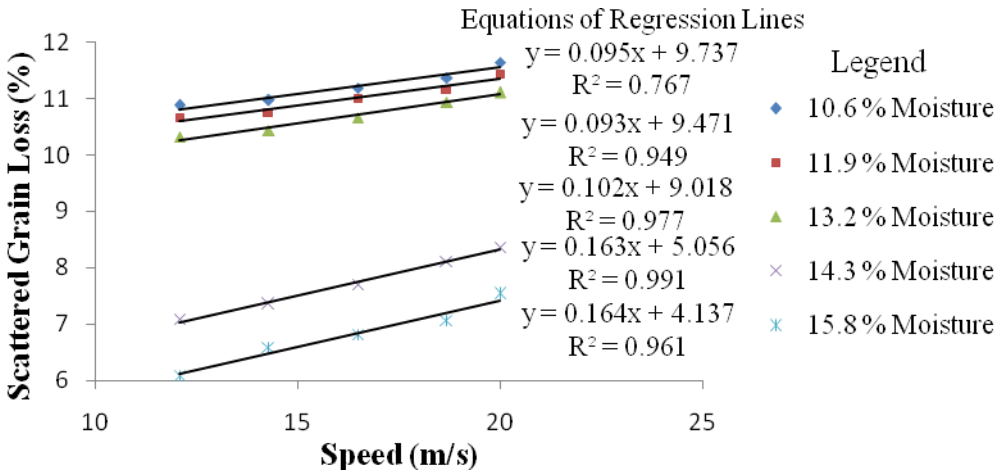


Fig. 4.6d: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 12 kg/min for millet crop

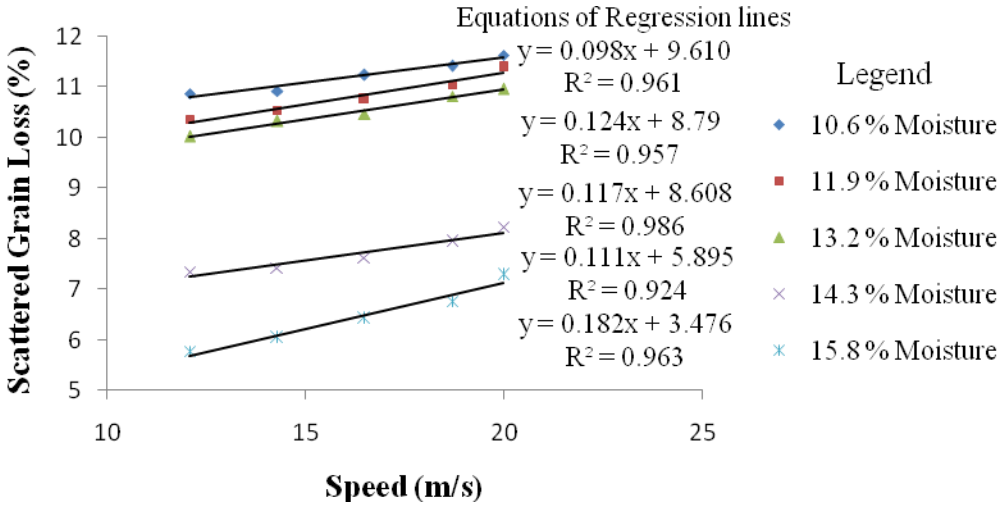


Fig. 4.6e: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 14 kg/min for millet crop

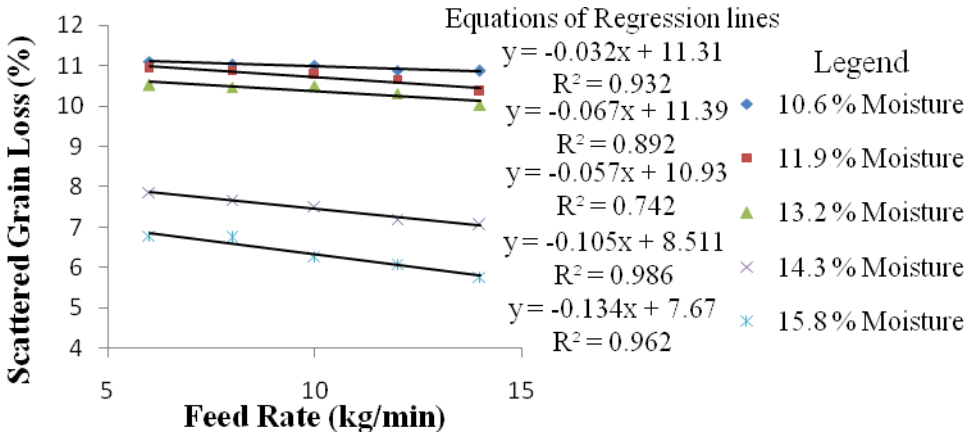


Fig. 4.7a: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 12.1 m/s for millet crop

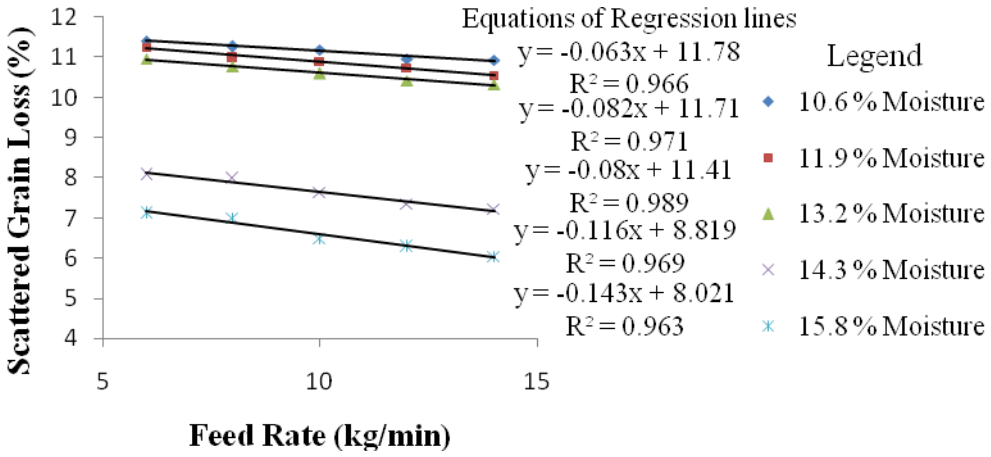


Fig. 4.7b: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 14.3 m/s for millet crop

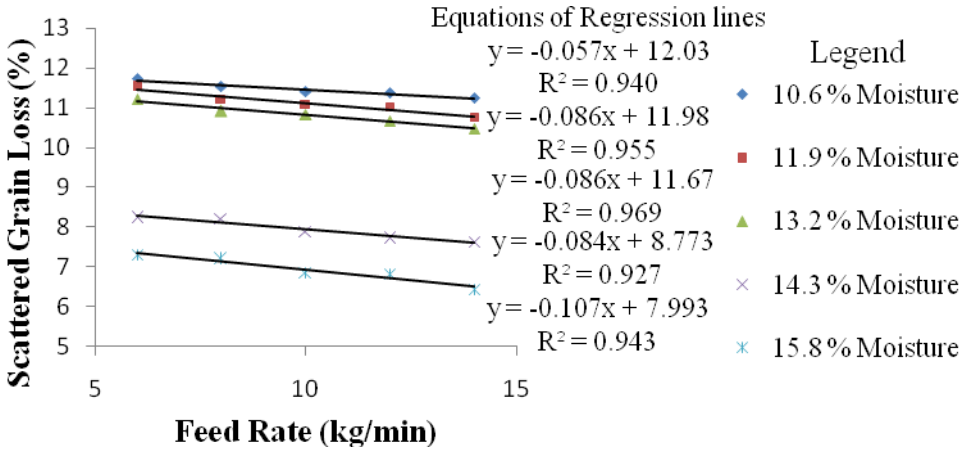


Fig. 4.7c: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 16.5 m/s for millet crop

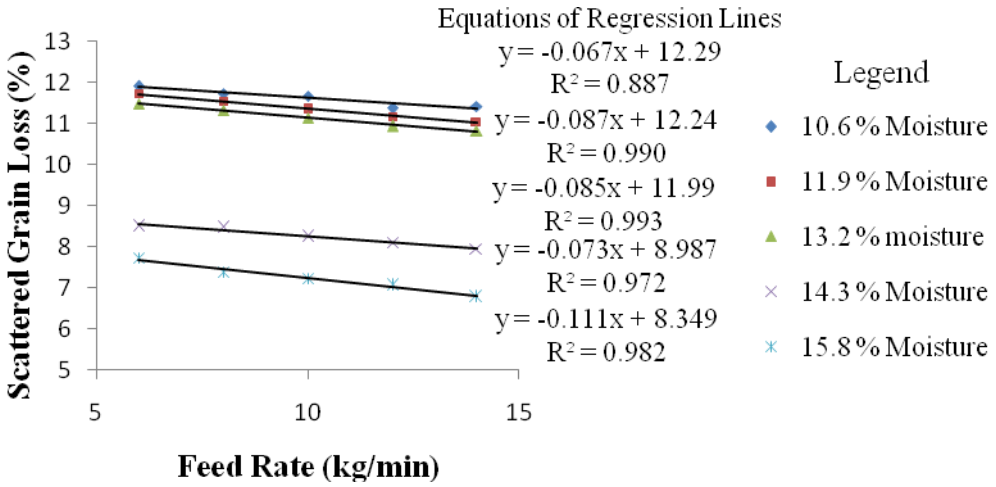


Fig. 4.7d: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 18.7 m/s for millet crop

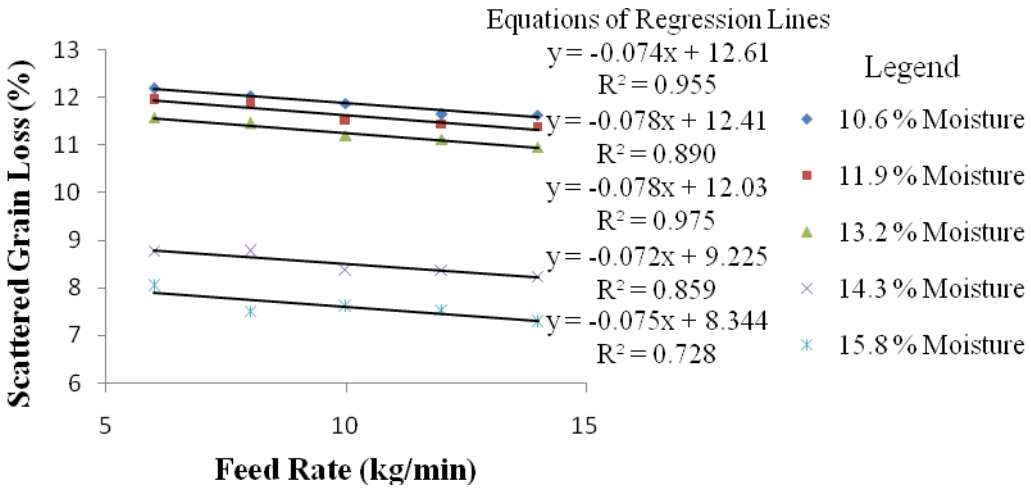


Fig. 4.7e: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 20 m/s for millet crop

Table 4.6: ANOVA of scattered grain loss for millet crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	1239.92	309.98	1.453E7**
Speed (S)	4	17.92	4.48	209943**
Feed rate (F)	4	42.85	10.71	502106**
M × S	16	0.74	0.05	2159.33 **
M × F	16	2.23	0.14	6539.99 **
F × S	16	0.69	0.04	2010.32 **
M × S × F	64	3.13	0.05	2288.87 **
Error	248	0.01	0.00	
Total	374	1307.47		

** = Significant at 1 % probability level

Table 4.7 a: D. M. R.T. for variation of speed with scattered grain loss for millet crop

Duncan Grouping	Mean Grain Loss (%)	N	Speed (m/s)
A	9.37	75	12.1
B	9.52	75	14.3
C	9.67	75	16.5
D	9.82	75	18.7
E	9.99	75	20.0

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0.015	0.016	0.016	0.017

Table 4.7 b: D.M.R.T. for variation of feed rate with scattered grain loss for millet crop

Duncan Grouping	Mean Grain Loss (%)	N	Feed Rate (kg/min)
A	9.19	75	14
B	9.47	75	12
C	9.67	75	10
D	9.91	75	8
E	10.16	75	6

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0.015	0.016	0.016	0.017

Table 4.7 c: D.M.R.T. for variation of crop moisture content with scattered grain loss for millet crop

Duncan Grouping	Mean Grain Loss (%)	N	Moisture Content (%)
A	11.39	75	10.6
B	11.18	75	11.9
C	10.83	75	13.2
D	7.94	75	14.3
E	7.04	75	15.8

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0.015	0.016	0.016	0.017

This test controls the type I comparison wise error rate, not the experiment wise error rate.

Any two means with the same letter are not significantly different at 1 % level of significance.

4.5 Grain Damage for Millet Crop

Grain damage evaluates all the broken grains present within the clean grains collected at the output. It was as a result of direct impact between the beaters of the threshing cylinder and the crop fed. It ranges from 0.001 % to 0.62 % for millet when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with grain damage at various moisture contents and constant feed rates are illustrated in Fig. 4.8(a. b, c, d and e). It indicates that grain damage increase as speed increases. This may be due to increase in collision rate between grains and beaters. However at constant speed, grain damage decreases as moisture content increase from 10.6 % to 13.2 % for millet; then increase constantly as moisture content increase above 13.5 %. The variation of feed rate with grain damage at various moisture contents and constant speeds are illustrated in Fig. 4.9(a. b, c, d and e). It indicates that grain damage decrease as feed rate increases. This may be due to increase in cushion phenomenon as more crops are fed hence reducing the intensity of collision on the grains. Also at a constant feed rate, grain damage decrease greatly as moisture content decreases from 15.8 % to 13.5 %, and then increase gently as moisture content decreases from 13.2 % to 10.6 % for millet. These results were similar to those of Saeidirad *et al.* (2013) and Osueke (2013). Therefore grain damage is directly proportional to speed but inversely proportional to feed rate. The reason for this behaviour was because as moisture content decreases from 15.8 % to 13.5 %, softer grains that were breaking easily with increase in speed became elastic and grain damage reduces drastically. However as moisture content decreases from 13.5 % to 10.6 %, grains that were elastic became brittle and grain damage increases a little. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of grain damage for millet crop is shown in Table 4.8. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple

Range Test (DMRT) are shown in Tables 4.9(a, b and c). The result shows that in the variation of speed, feed rate and moisture content with grain damage there were significant differences between the means at 1 % level of significance. This implies as speed increase to another level grain damage increase significantly (Table 4.9a); as feed rate increase to another level grain damage decrease significantly (Table 4.9b); as moisture content decrease from 15.8 % to 13.5 % grain damage decrease significantly (Table 4.9c); as moisture content decrease further from 13.5 % to 10.6 % grain damage increase significantly (Table 4.9c). Appendix L represents measured values of grain damage at five levels of cylinder speed, feed rate and crop moisture content for millet crop.

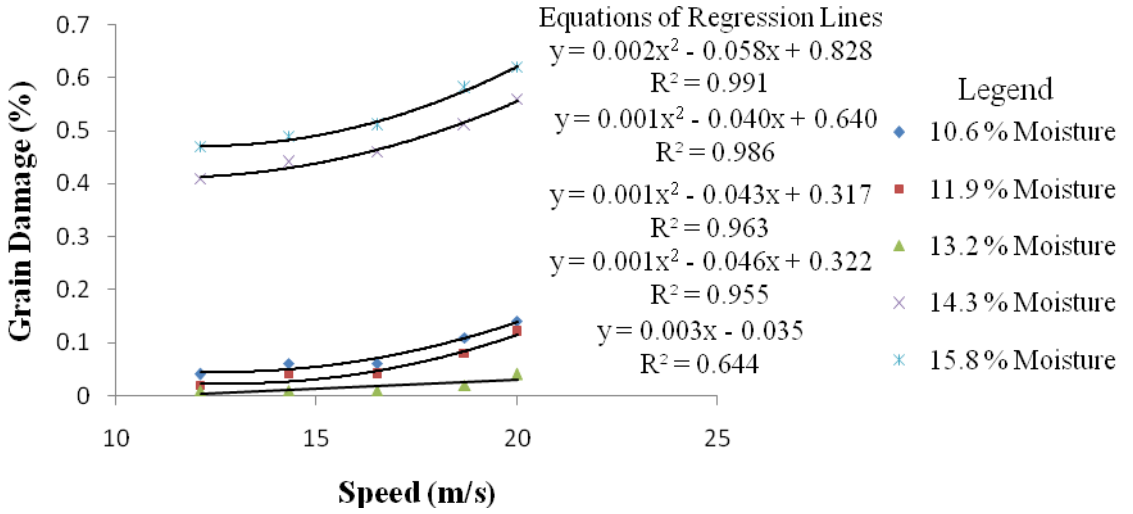


Fig. 4.8a: Variation of speed with grain damage at various moisture content and constant feed rate of 6 kg/min for millet crop

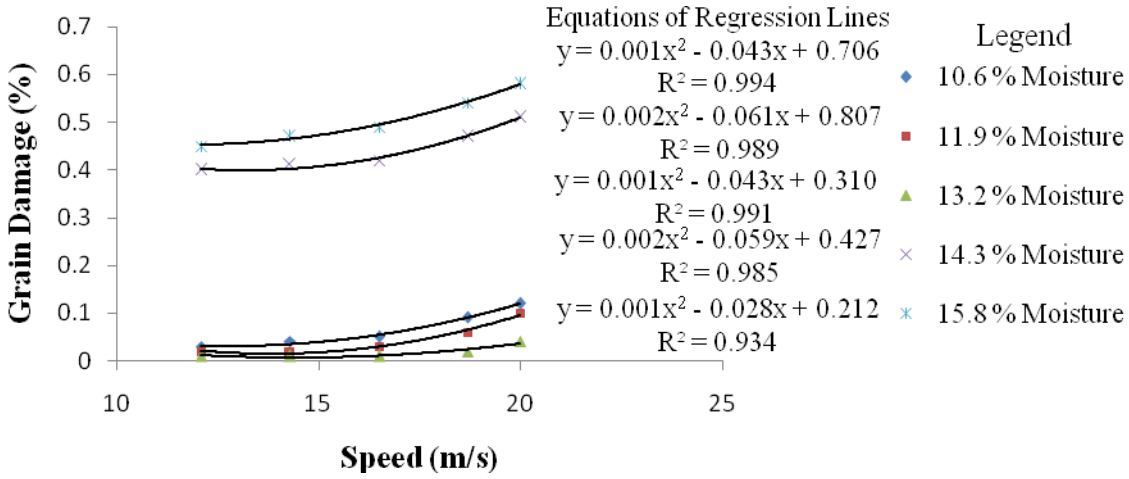


Fig. 4.8b: Variation of speed with grain damage at various moisture content and constant feed rate of 8 kg/min for millet crop

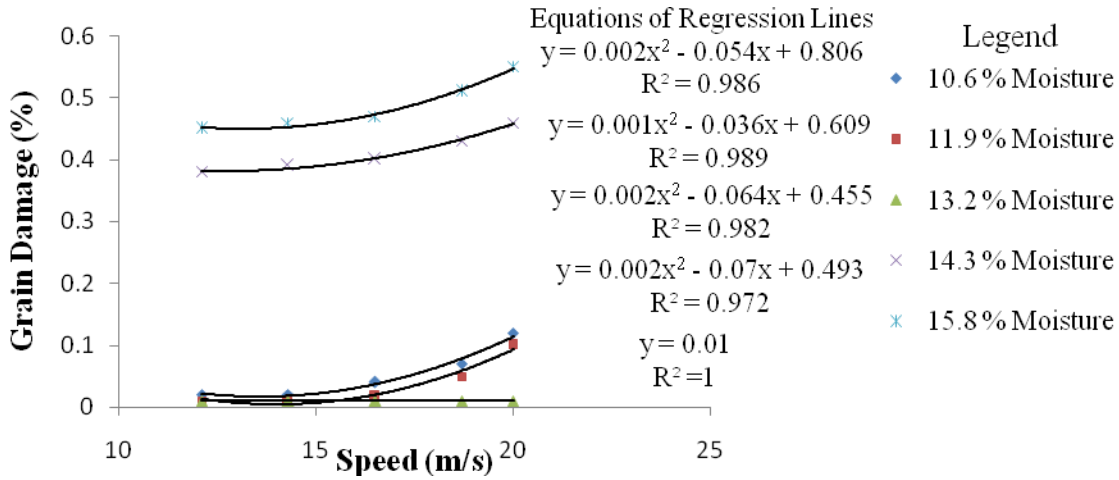


Fig. 4.8c: Variation of speed with grain damage at various moisture content and constant feed rate of 10 kg/min for millet crop

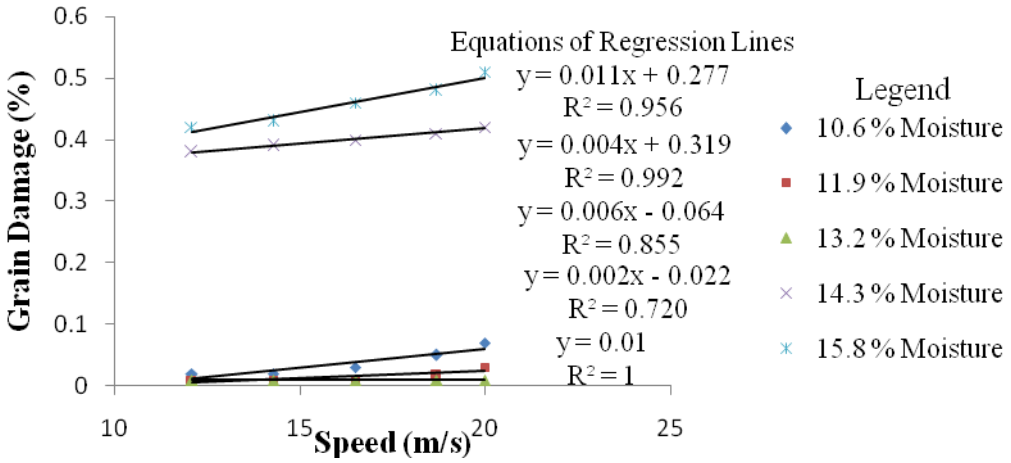


Fig. 4.8d: Variation of speed with grain damage at various moisture content and constant feed rate of 12 kg/min for millet crop

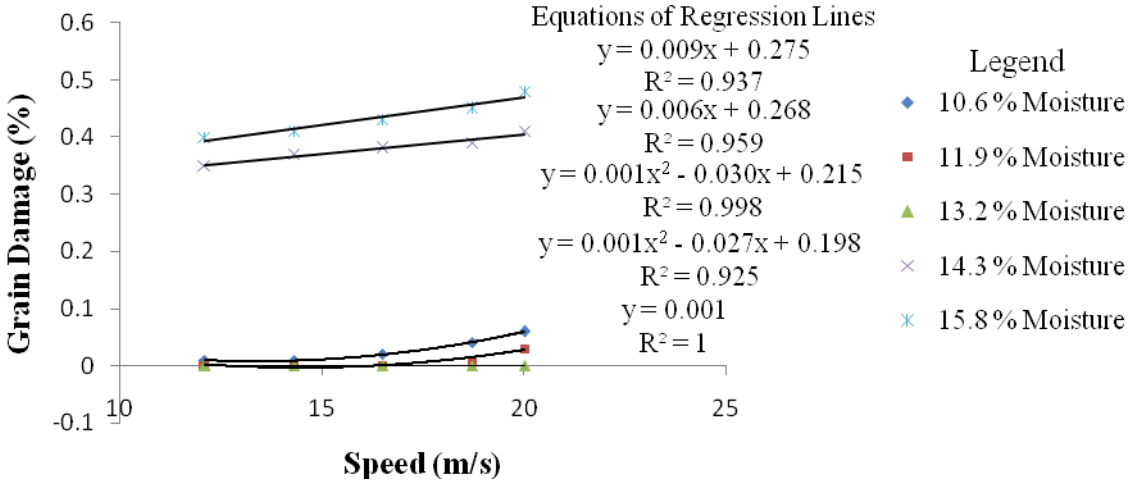


Fig. 4.8e: Variation of speed with grain damage at various moisture content and constant feed rate of 14 kg/min for millet crop

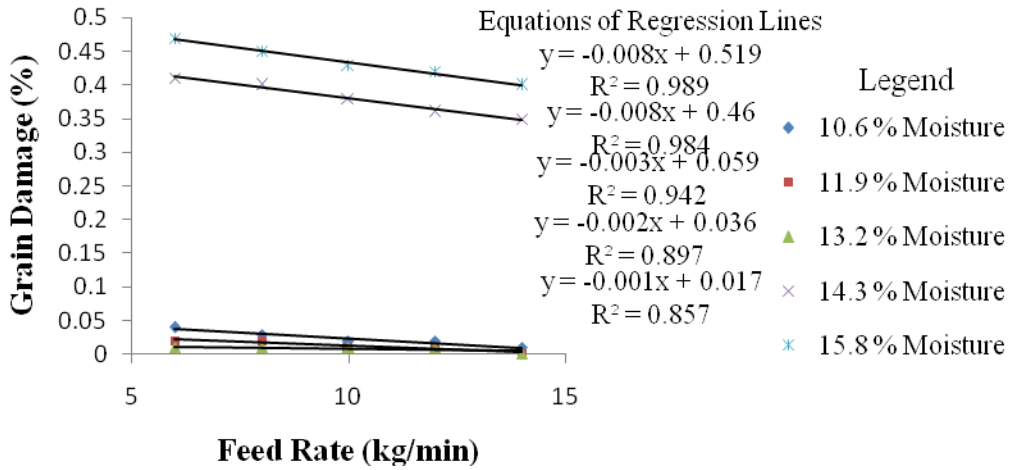


Fig. 4.9a: Variation of feed rate with grain damage at various moisture contents and constant speed of 12.1 m/s for millet crop

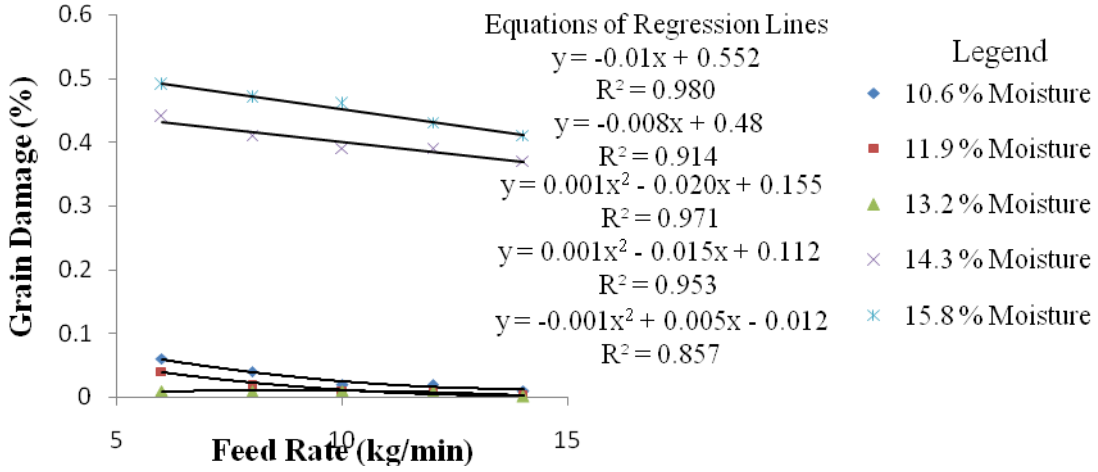


Fig. 4.9b: Variation of feed rate with grain damage at various moisture contents and constant speed of 14.3 m/s for millet crop

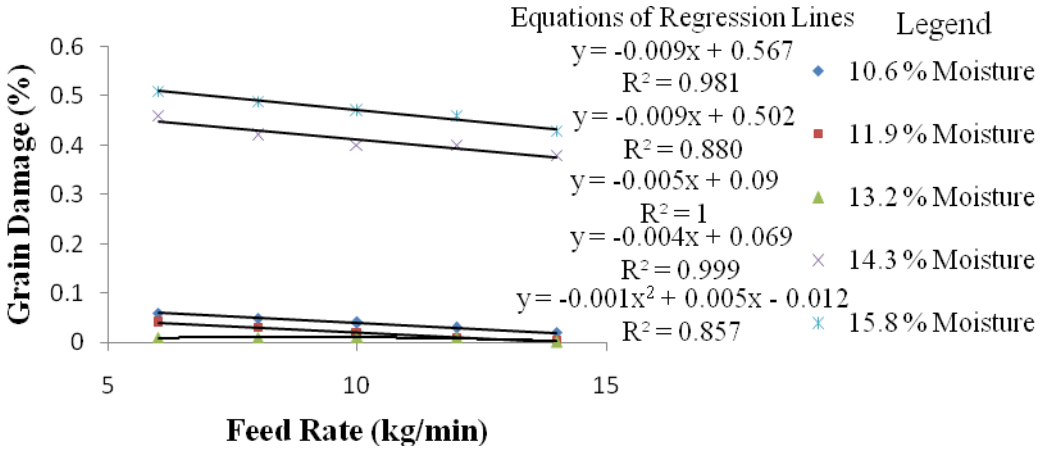


Fig. 4.9c: Variation of feed rate with grain damage at various moisture contents and constant speed of 16.5 m/s for millet crop

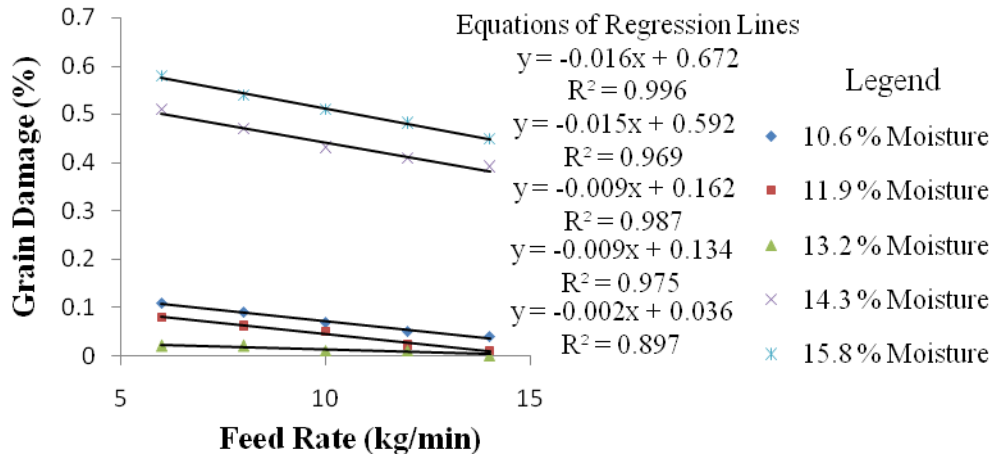


Fig. 4.9d: Variation of feed rate with grain damage at various moisture contents and constant speed of 18.7 m/s for millet crop

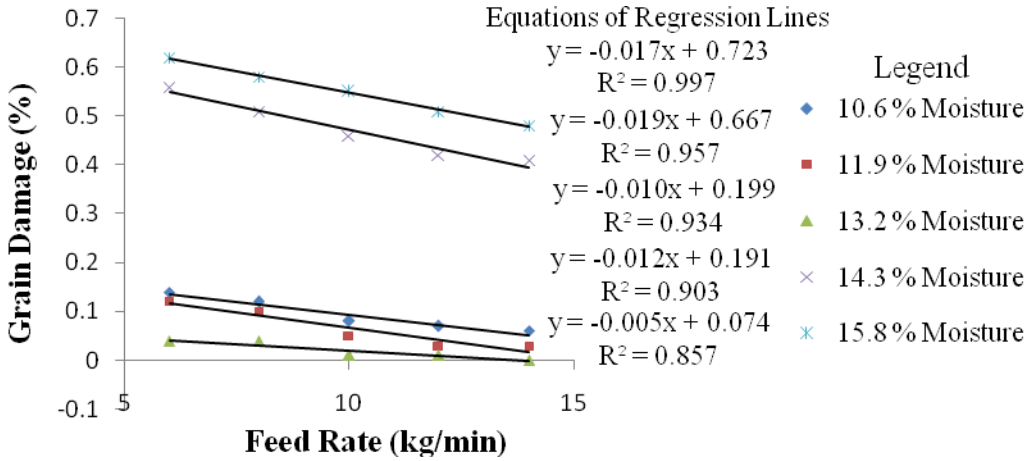


Fig. 4.9e: Variation of feed rate with grain damage at various moisture contents and constant speed of 20 m/s for millet crop

Table 4.8: ANOVA of grain damage for millet crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	15.77	3.941	3.03E14**
Speed (S)	4	0.22	0.054	9.47E18**
Feed rate (F)	4	0.26	0.064	8.61E13**
M × S	16	0.07	0.004	1.27E17**
M × F	16	0.06	0.004	4.67E12**
F × S	16	0.03	0.002	6.91E14**
M × S × F	64	0.02	0.001	5.39E16**
Error	248	0.00	0.00	
Total	374	16.42		

** = Significant at 1 % probability level

Table 4.9 a: D. M. R.T. for variation of speed with grain damage for millet crop

Duncan Grouping	Mean Grain Damage (%)	N	Speed (m/s)
A	0.16	75	12.1
B	0.18	75	14.3
C	0.20	75	16.5
D	0.22	75	18.7
E	0.24	75	20.0

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.9 b: D. M. R.T. for variation of feed rate with grain damage for millet crop

Duncan Grouping	Mean Grain Damage (%)	N	Feed Rate (kg/min)
A	0.175	75	14
B	0.186	75	12
C	0.189	75	10
D	0.208	75	8
E	0.249	75	6

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.9 c: D. M. R.T. for variation of crop moisture content with grain damage for millet crop

Duncan Grouping	Mean Grain Damage (%)	N	Moisture Content (%)
A	0.058	75	10.6
B	0.038	75	11.9
C	0.012	75	13.2
D	0.250	75	14.3
E	0.490	75	15.8

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

This test controls the type I comparison wise error rate, not the experiment wise error rate.

Any two means with the same letter are not significantly different at 1 % level of significance.

4.6 Output Capacity for Soybean Crop

Output capacity evaluates the quantity of clean soybean grains collected at the grain outlet of the multicrop thresher for the total quantity of crop fed per hour. The soybean grains collected ranges from 42 kg/hr to 205 kg/hr when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with output at various moisture contents and constant feed rates are illustrated in Fig. 4.10(a, b, c, d and e). It indicates that output capacity increase as speed increase. This may be due to increase kinetic energy transfer from beater to crop causing more grains to be detarched. However at constant speed, output capacity decreases as moisture content increase. This was as a result of cohesive and adhesive forces that exist in crop with high moisture content that keeps the grains in place resulting to reduction in grain detarchment and output capacity.

The variation of feed rate with output at various moisture contents and constant speed are illustrated in Fig. 4.11(a, b, c, d and e). It indicates that output capacity increases as feed rate increase. The reason was increase in the quantity of crop entering the hopper. However, at constant speed and feed rate output capacity decreases as moisture content increases. These results were similar to those of Sinha *et al.* (2009) and Osueke (2013). Therefore output capacity is directly proportional to speed and feed rate but inversely proportional to moisture contents. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of output capacity for soybean crop is shown in Table 4.10. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.11(a, b and c). The result shows that in the variation of speed, feed rate and moisture content with output capacity there were significant differences between the means at 1 % level of significance. This implies as speed

increase to another level output capacity increase significantly (Table 4.11a); as feed rate increase to another level output capacity increase significantly (Table 4.11b); as moisture content decrease to another level output capacity increase significantly (Table 4.11c). Appendix E represents measured values of output capacity at five levels of cylinder speed, feed rate and crop moisture content for soybean crop.

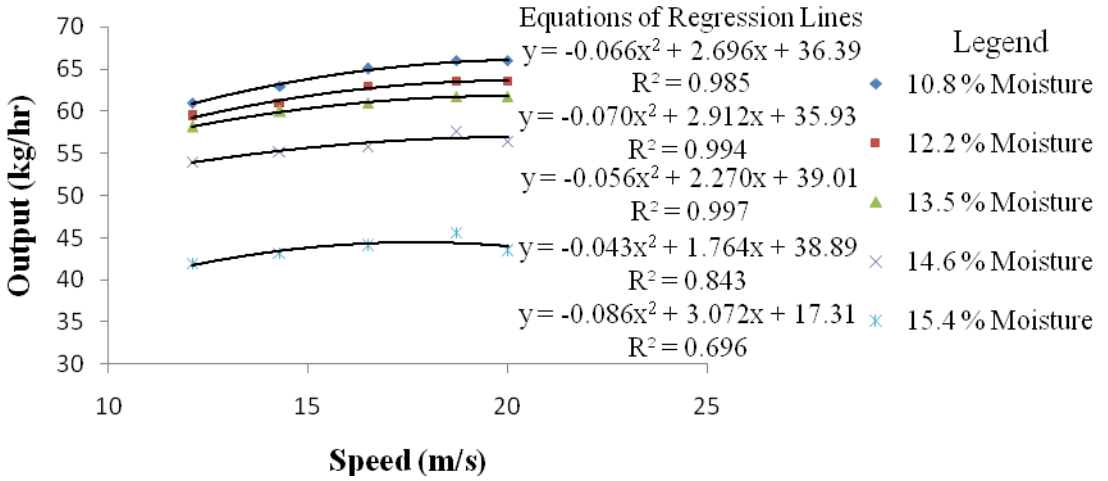


Fig. 4.10a: Variation of speed with output at various moisture content and constant feed rate of 4 kg/min for soybean crop

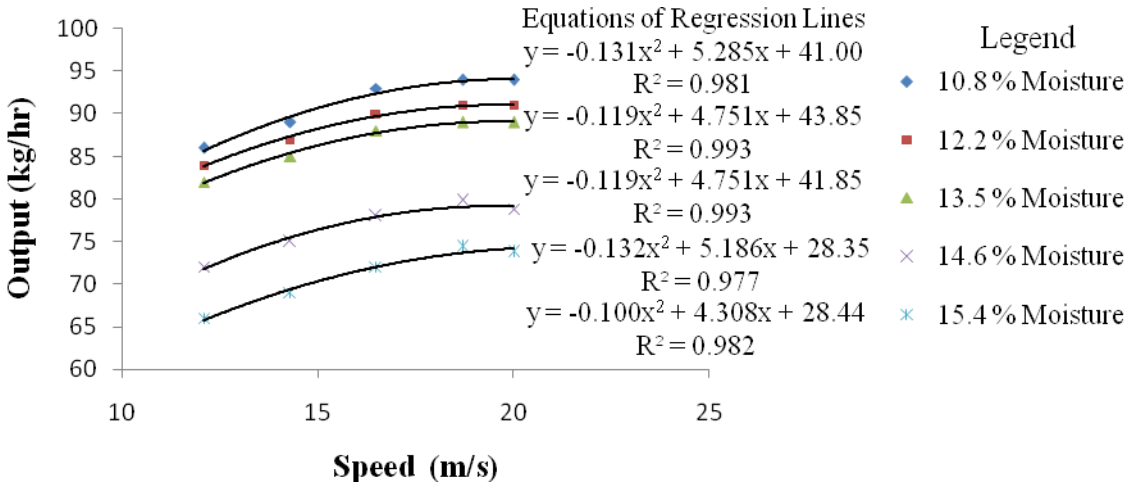


Fig. 4.10b: Variation of speed with output at various moisture content and constant feed rate of 6 kg/min for soybean crop

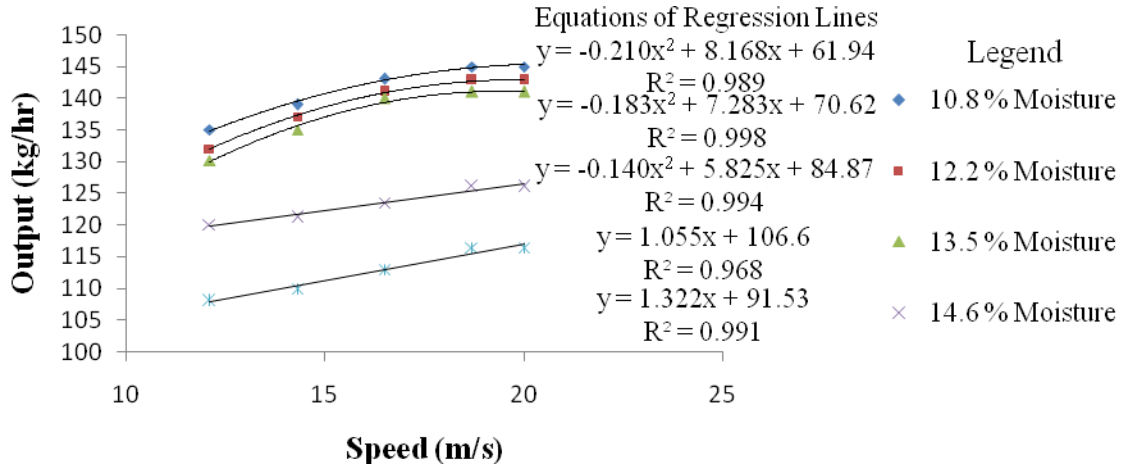


Fig. 4.10c: Variation of speed with output at various moisture content and constant feed rate of 8 kg/min for soybean crop

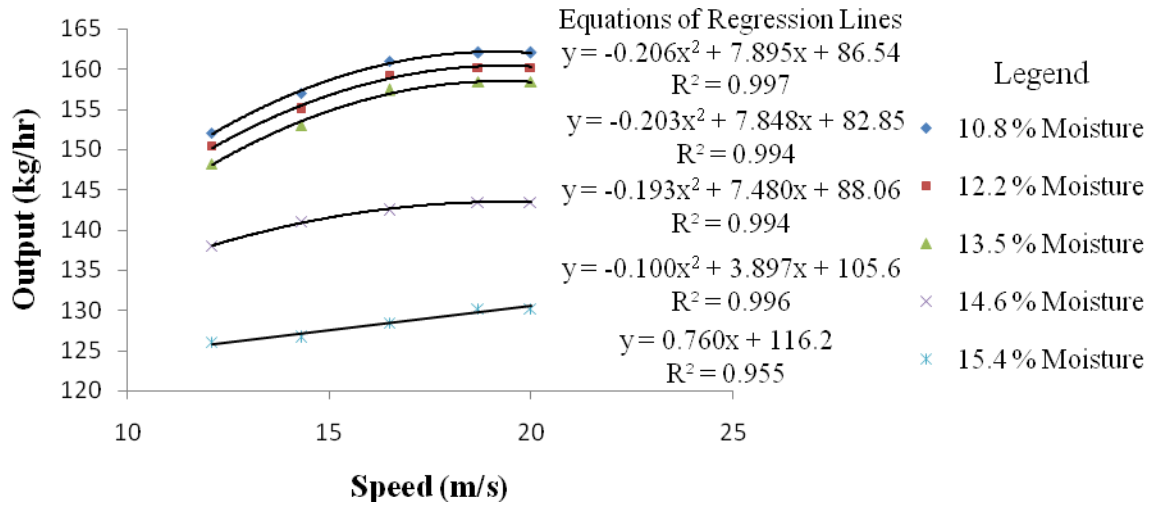


Fig. 4.10d: Variation of speed with output at various moisture content and constant feed rate of 10 kg/min for soybean crop

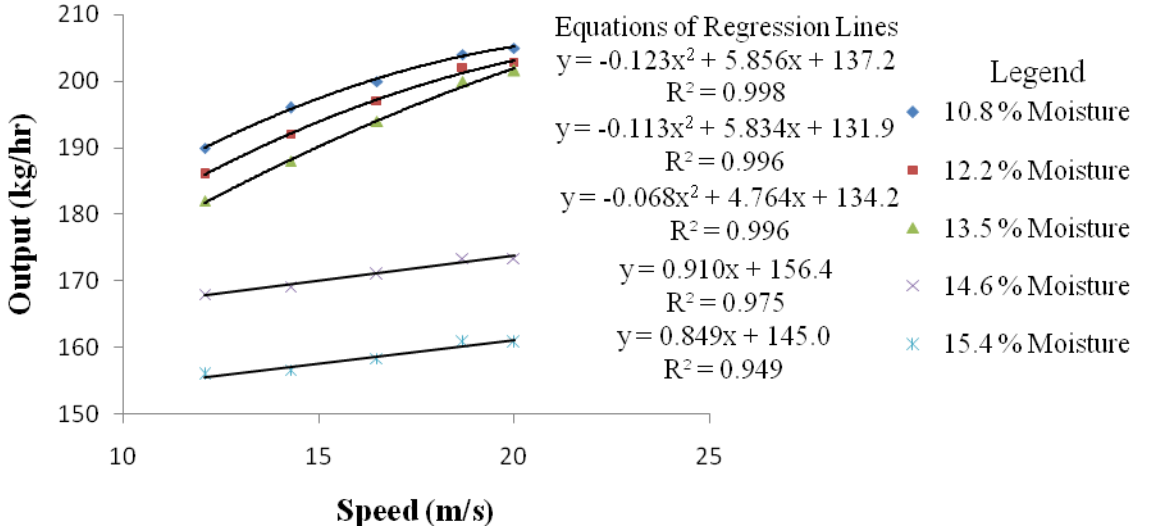


Fig. 4.10e: Variation of speed with output at various moisture content and constant feed rate of 12 kg/min for soybean crop

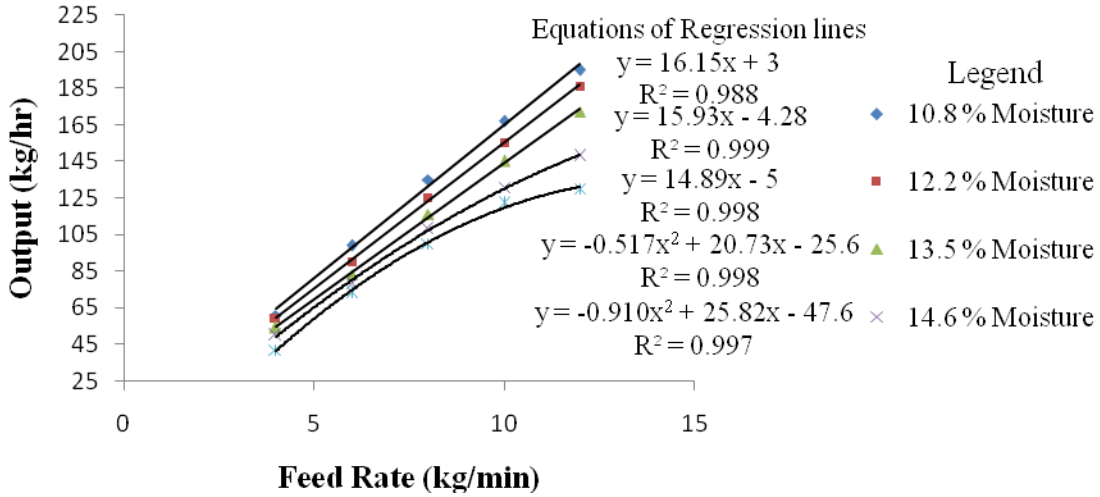


Fig. 4.11a: Variation of feed rate with output at various moisture contents and constant speed of 12.1 m/s for soybean crop

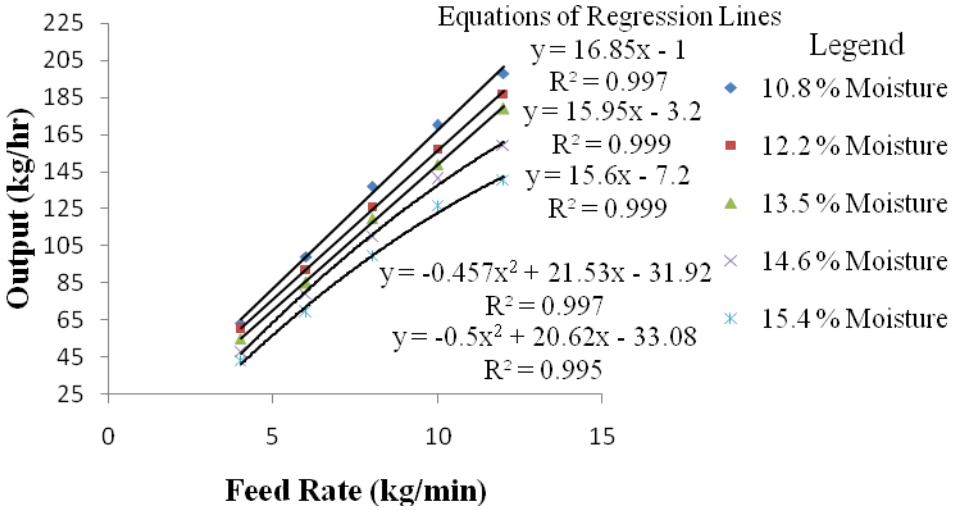


Fig. 4.11b: Variation of feed rate with output at various moisture contents and constant speed of 14.3 m/s for soybean crop

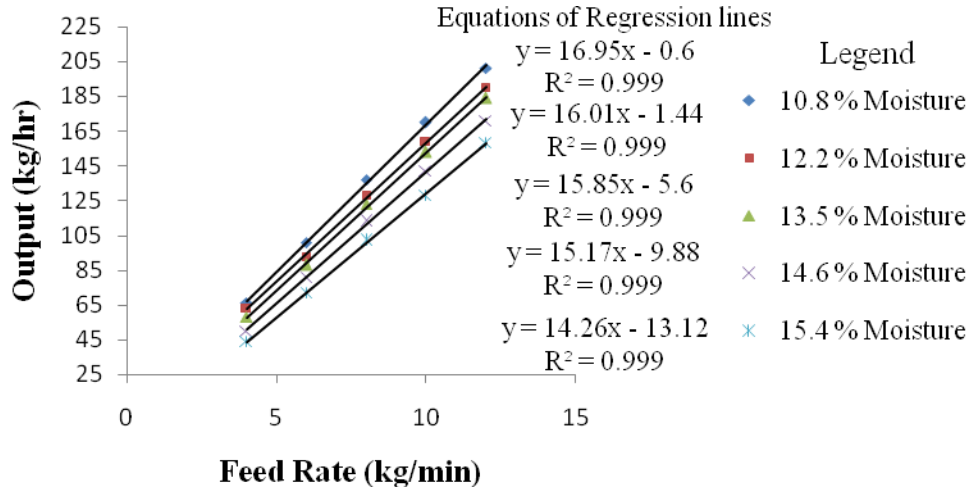


Fig. 4.11c: Variation of feed rate with output at various moisture contents and constant speed of 16.5 m/s for soybean crop

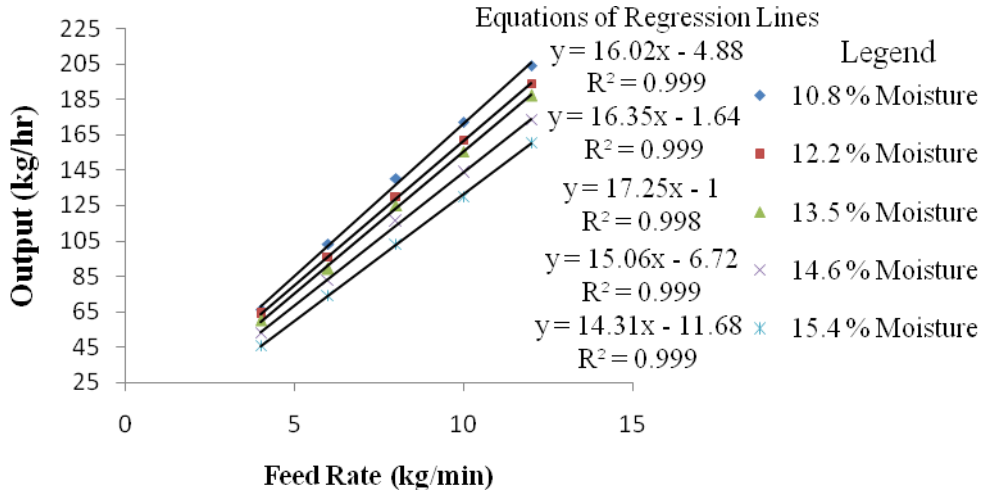


Fig. 4.11d: Variation of feed rate with output at various moisture contents and constant speed of 18.7 m/s for soybean crop

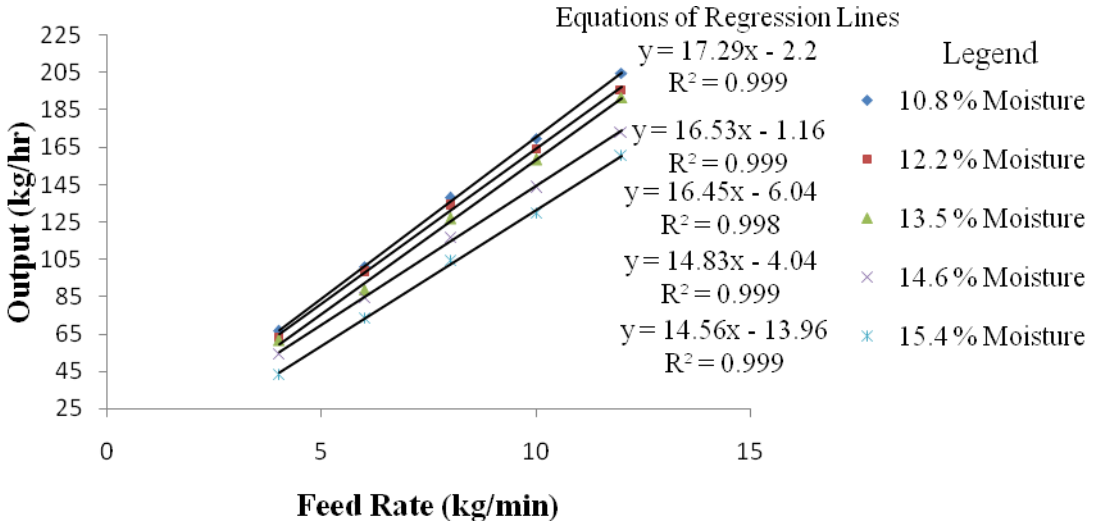


Fig. 4.11e: Variation of feed rate with output at various moisture contents and constant speed of 20 m/s for soybean crop

Table 4.10: ANOVA of output capacity for soybean crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	56413.90	14103.47	5.01E15 **
Speed (S)	4	19863.50	4965.88	1.76E15 **
Feed rate (F)	4	699203.80	174800.95	6.21E16 **
M × S	16	5490.67	343.17	1.22E14 **
M × F	16	7819.58	488.72	1.74E14 **
F × S	16	6960.51	435.03	1.54E14 **
M × S × F	64	4495.19	70.24	0.49E13 **
Error	248	0.00	0.00	
Total	374	800247.13		

** = Significant at 1 % probability level

Table 4.11a: D.M.R.T. for variation of speed with output capacity for soybean crop

Duncan Grouping	Mean Output (kg/hr)	N	Speed (m/s)
A	105.84	75	12.1
B	114.58	75	14.3
C	122.98	75	16.5
D	124.30	75	18.7
E	124.46	75	20.0

Alpha= 0.05, Error Degrees of Freedom = 248, Error Mean Square = 2.82E-12

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.11b: D.M.R.T. for variation of feed rate with output capacity for soybean crop

Duncan Grouping	Mean Output (kg/hr)	N	Feed Rate (kg/min)
A	57.19	75	4
B	83.57	75	6
C	128.50	75	8
D	144.79	75	10
E	178.10	75	12

Alpha= 0.05, Error Degrees of Freedom = 248, Error Mean Square = 2.82E-12

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.11c: D.M.R.T. for variation of crop moisture content with output capacity for soybean crop

Duncan Grouping	Mean Output (kg/hr)	N	Moisture Content (%)
A	129.12	75	10.8
B	127.85	75	12.2
C	126.38	75	13.5
D	111.19	75	14.6
E	97.61	75	15.4

Alpha= 0.05, Error Degrees of Freedom = 248, Error Mean Square = 2.82E-12

Number of Means	2	3	4	5
Critical Range	0	0	0	0

This test controls the Type I comparison wise error rate, not the experiment wise error rate. Any two means with the same letter are not significantly different at 1 % level of significance.

4.7 Threshing Efficiency for Soybean Crop

It ranges from 95.6 % to 100 % for soybean when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with threshing efficiency at various moisture contents and constant feed rates are illustrated in Fig. 4.12(a, b, c, d and e). It indicates that threshing efficiency increases as speed increase. This may be due to increase kinetic energy transfer from beater to crop causing more grains to be detarched. However at constant speed, threshing efficiency decreases as moisture content increase. The reason was the cohesive and adhesive forces that exist in crop with high moisture content that keeps the grains in place resulting to reduction in threshing efficiency.

The variation of feed rate with threshing efficiency at various crop moisture contents and constant speed are illustrated in Fig. 4.13(a, b, c, d and e). It indicates that threshing efficiency decreases as feed rate increase. This was because of reduction in speed as the load intensity on the beaters increase as more crops are fed. However at a constant feed rate, threshing efficiency decreases as moisture content increase. This was as a result of cohesive and adhesive forces that exist in crop with high moisture content that keeps the grains in place resulting to reduction in threshing efficiency. These results were similar to those of Sinha *et al.* (2009); Osueke (2013) and Saeidirad *et al.* (2013). Therefore threshing efficiency is directly proportional to speed but inversely proportional to feed rate and crop moisture contents. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of threshing efficiency for soybean crop is shown in Table 4.12. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.13(a, b and c). The result shows that in the variation of speed, feed rate and moisture content with threshing efficiency there were significant differences between the means at 1 % level of significance. This implies as speed

increase to another level threshing efficiency increase significantly (Table 4.13a); as feed rate increase to another level threshing efficiency decrease significantly (Table 4.13b); as moisture content decrease to another level threshing efficiency increase significantly (Table 4.13c). Appendix G represents measured values of threshing efficiency at five levels of cylinder speed, feed rate and crop moisture content for soybean crop.

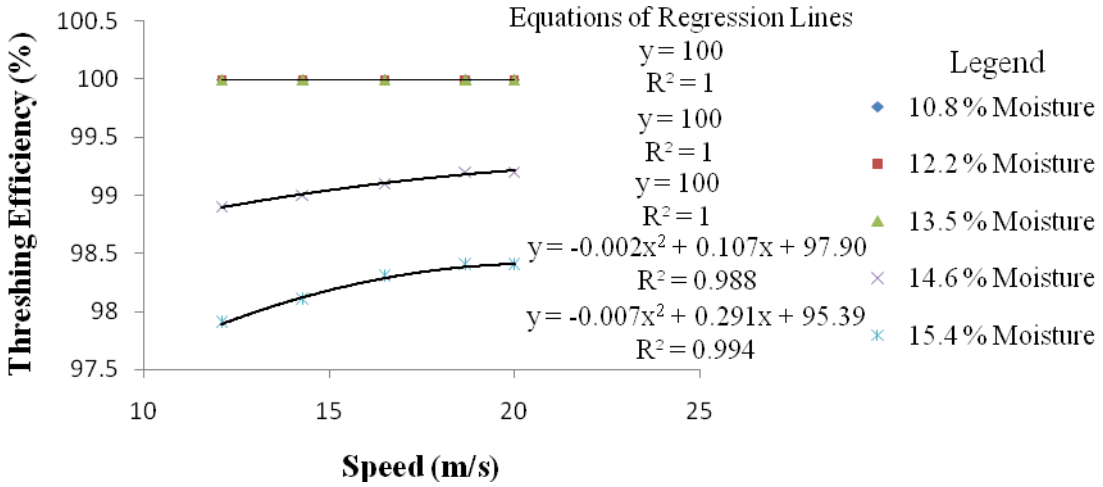


Fig. 4.12a: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 4 kg/min for soybean crop

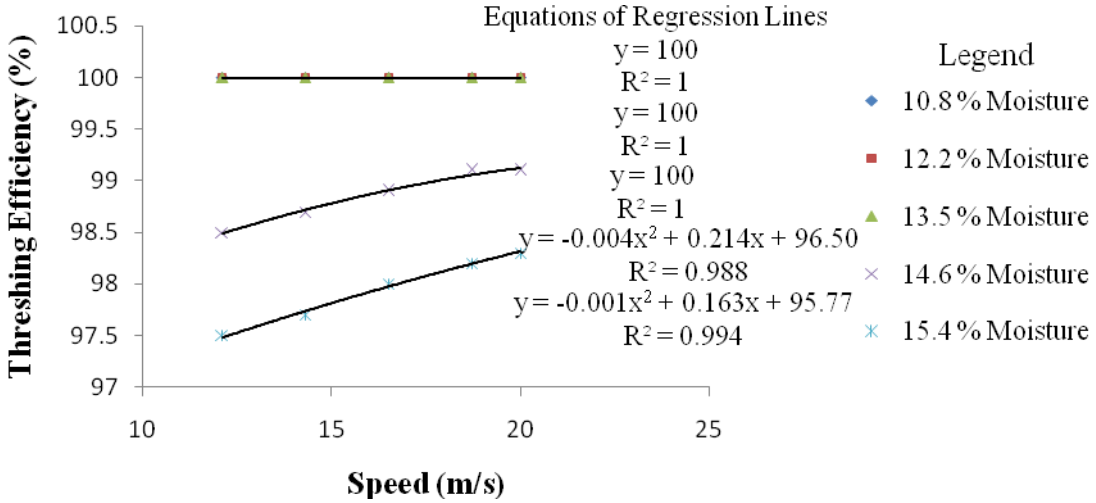


Fig. 4.12b: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 6 kg/min for soybean crop

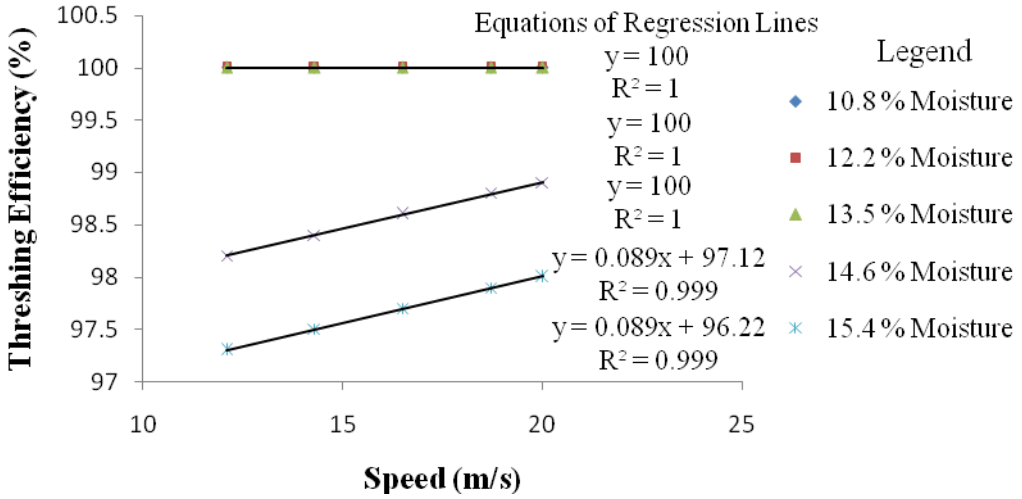


Fig. 4.12c: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 8 kg/min for soybean crop

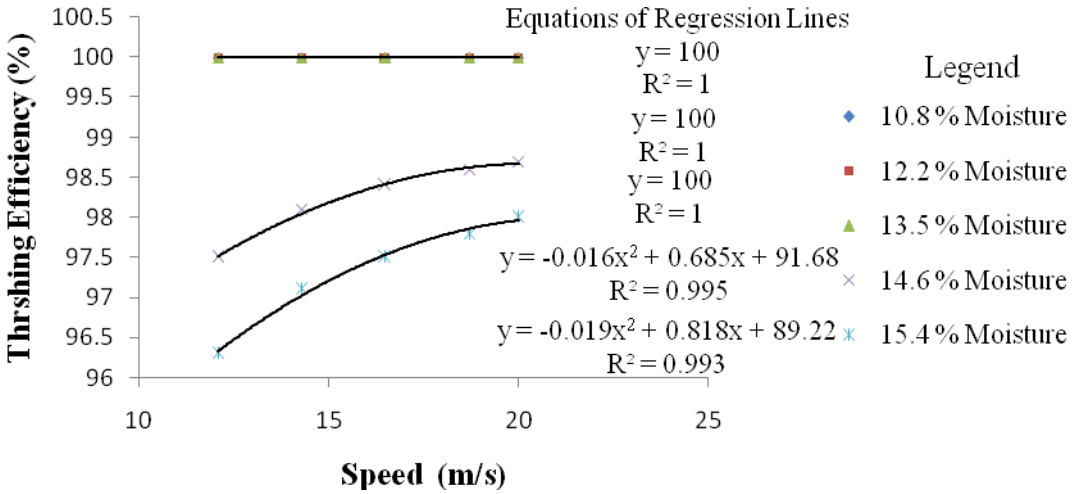


Fig. 4.12d: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 10 kg/min for soybean crop

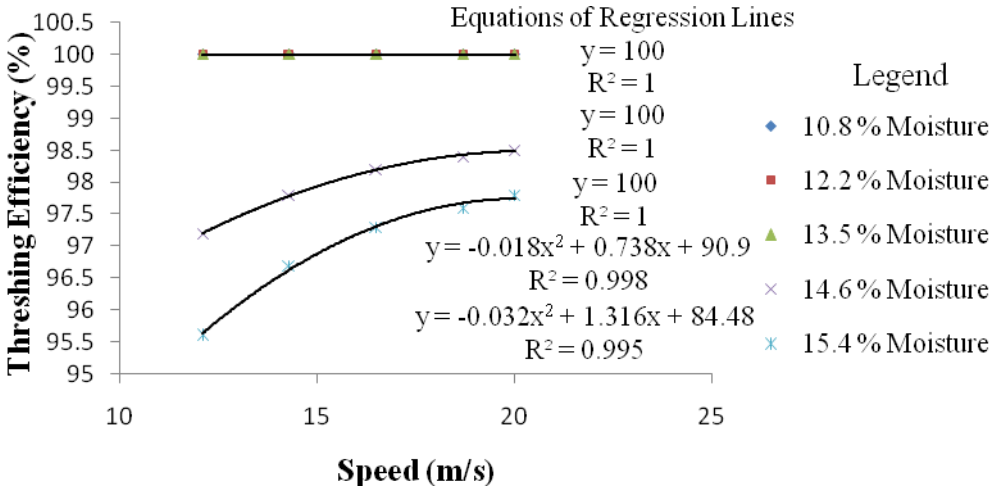


Fig. 4.12e: Variation of speed with threshing efficiency at various moisture content and constant feed rate of 12 kg/min for soybean crop

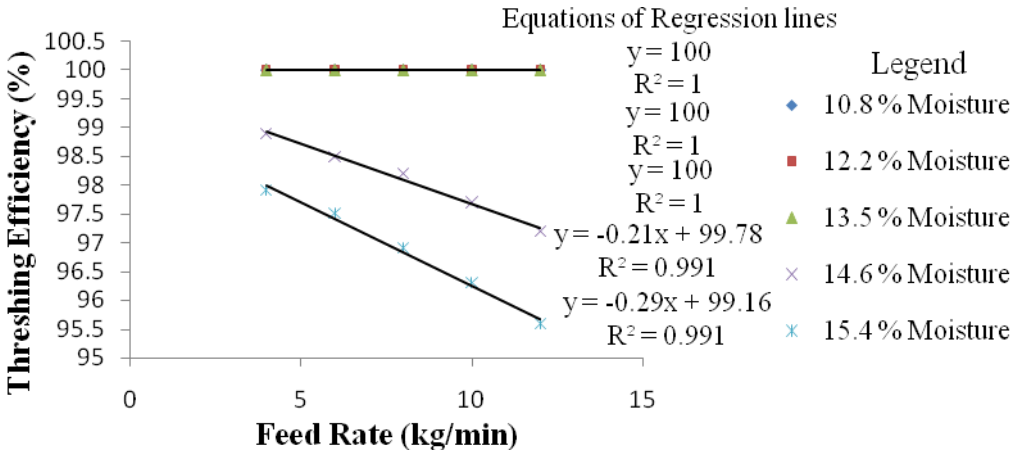


Fig. 4.13a: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 12.1 m/s for soybean crop

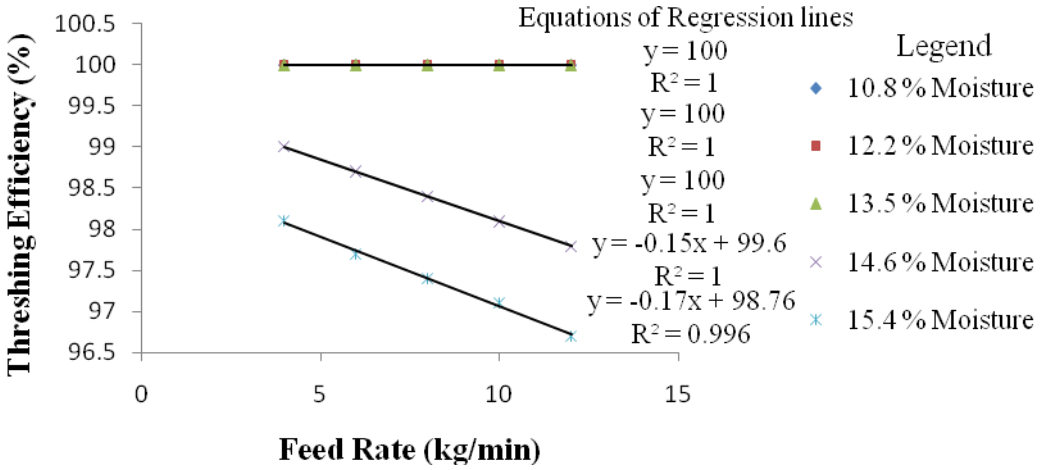


Fig. 4.13b: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 14.3 m/s for soybean crop

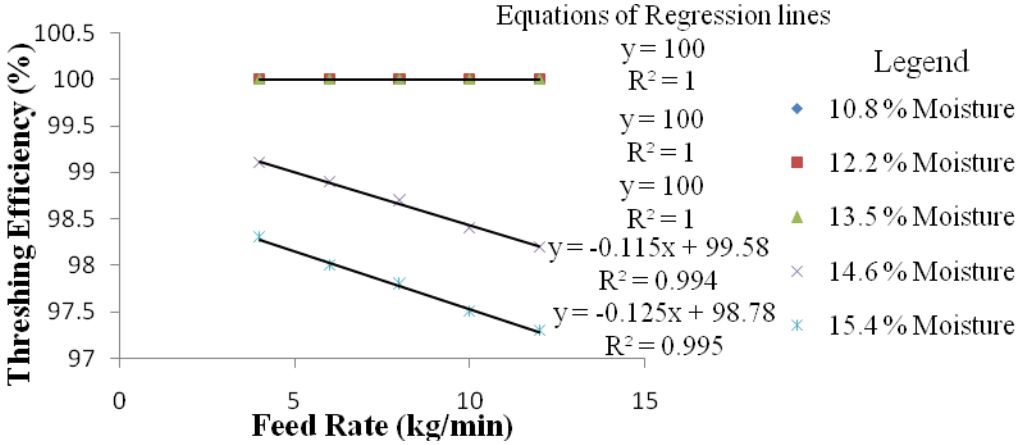


Fig. 4.13c: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 16.5 m/s for soybean crop

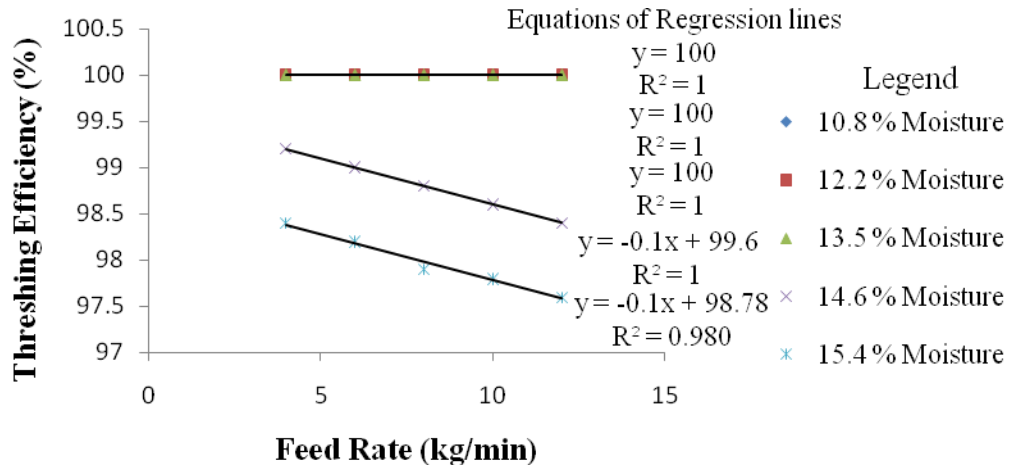


Fig. 4.13d: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 18.7 m/s for soybean crop

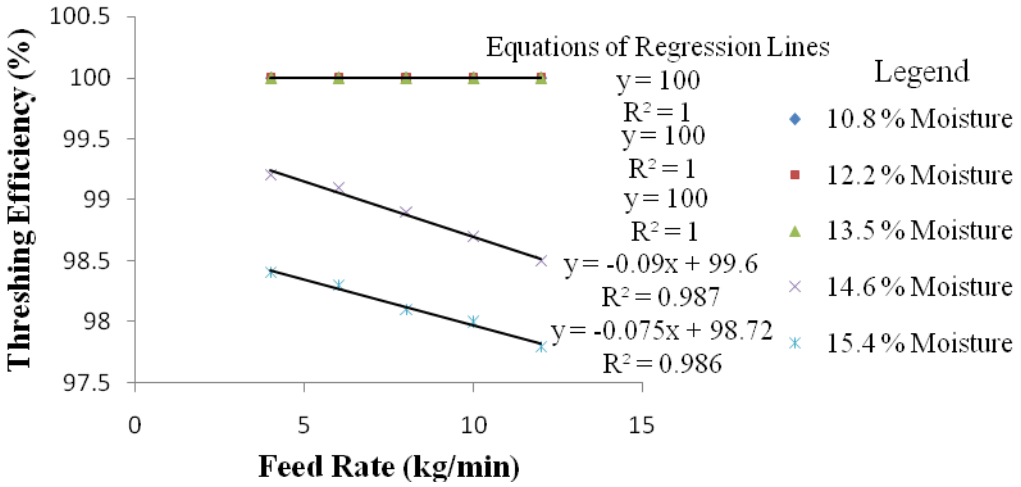


Fig. 4.13e: Variation of feed rate with threshing efficiency at various moisture contents and constant speed of 20 m/s for soybean crop

Table 4.12: ANOVA of threshing efficiency for soybean crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture(M)	4	329.45	82.363	1671.73**
Speed (S)	4	5.13	1.283	2191.62**
Feed rate (F)	4	4.68	1.171	511.83**
M × S	16	7.84	0.490	473.51**
M × F	16	7.03	0.440	783.23**
F × S	16	0.03	0.002	91.74**
M × S × F	64	0.12	0.002	56.63**
Error	248	0.00	0.000	
Total	374	354.29		

** = Significant at 1 % probability level

Table 4.13 a: D. M. R.T. for variation of speed with threshing efficiency for soybean crop

Duncan Grouping	Mean Threshing Efficiency (%)	N	Speed (m/s)
A	99.10	75	12.1
B	99.19	75	14.3
C	99.26	75	16.5
D	99.36	75	18.7
E	99.42	75	20.0

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.13 b: D. M. R.T. for variation of feed rate with threshing efficiency for soybean crop

Duncan Grouping	Mean Threshing Efficiency (%)	N	Feed Rate (kg/min)
A	99.43	75	4
B	99.34	75	6
C	99.27	75	8
D	99.18	75	10
E	99.11	75	12

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.13 c: D. M. R.T. for variation of crop moisture content with threshing efficiency for soybean crop

Duncan Grouping	Mean Threshing Efficiency (%)	N	Moisture Content (%)
A	100.0	75	10.8
B	100.0	75	12.2
C	100.0	75	13.5
D	98.6	75	14.6
E	97.8	75	15.4

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

This test controls the Type I comparison wise error rate, not the experiment wise error rate. Any two means with the same letter are not significantly different at 1 % level of significance.

4.8 Cleaning Efficiency for Soybean Crop

It ranges from 72.34 % to 97.26 % for soybean when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with cleaning efficiency at various moisture contents and constant feed rates are illustrated in Fig. 4.14(a, b, c, d and e). It indicates that cleaning efficiency increases as speed increase. This may be due to increase in air flow rate of the blower as speed increases. However at constant speed, cleaning efficiency decreases as moisture content increase. The reason was the existence of cohesive / adhesive forces and small mass difference between grains and chaff with high moisture content resulting to grains being blown away with chaff hence reduction in cleaning efficiency.

The variation of feed rate with cleaning efficiency at various moisture contents and constant speed are illustrated in Fig. 4.15(a, b, c, d and e). It indicates that cleaning efficiency decreases as feed rate increase. This was because of increasing load intensity on the sieves as multiple particles act as obstruction to grain flow resultilg to more grains blown away with chaff. Also at a constant feed rate, cleaning efficiency decreases as moisture content increase. These results were similar to those of Simonyan and Yiljep (2008); Osueke (2013). Therefore cleaning efficiency is directly proportional to speed but inversely proportional to feed rate and crop moisture content. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of cleaning efficiency for soybean crop is shown in Table 4.14. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.15(a, b and c). The result shows that in the variation of speed, feed rate and moisture content with cleaning efficiency there were significant differences between the means at 1 % level of significance. This implies as speed

increase to another level cleaning efficiency increase significantly (Table 4.15a); as feed rate increase to another level cleaning efficiency decrease significantly (Table 4.15b); as moisture content decrease to another level cleaning efficiency increase significantly (Table 4.15c). Appendix I represents measured values of cleaning efficiency at five levels of cylinder speed, feed rate and crop moisture content for soybean crop.

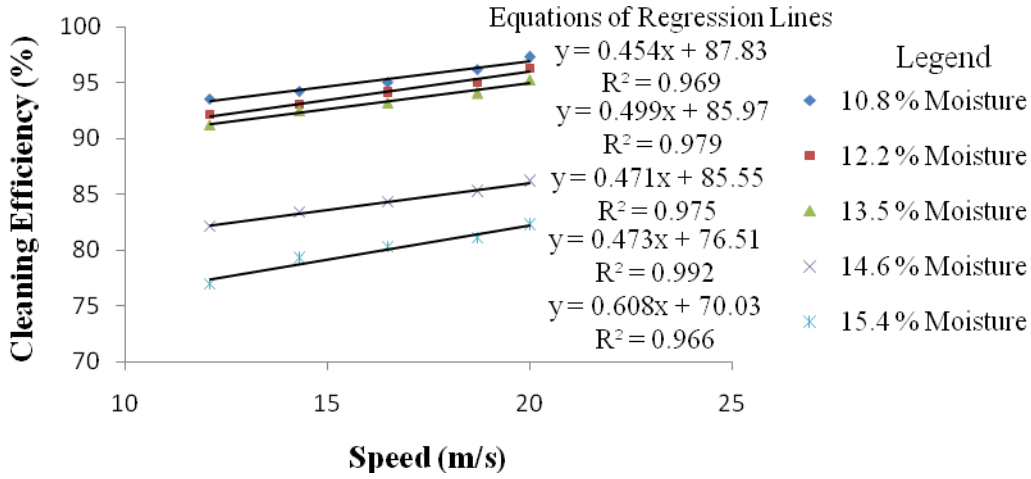


Fig. 4.14a: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 4 kg/min for soybean crop

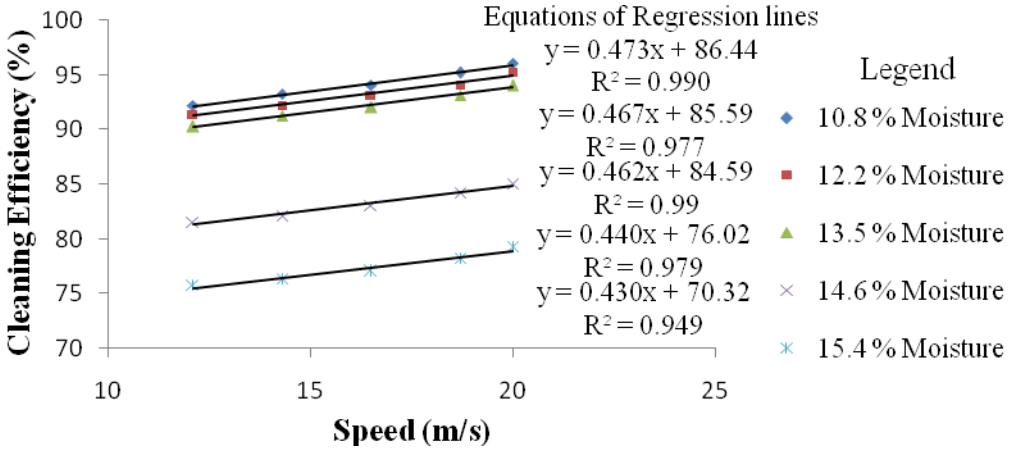


Fig. 4.14b: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 6 kg/min for soybean crop

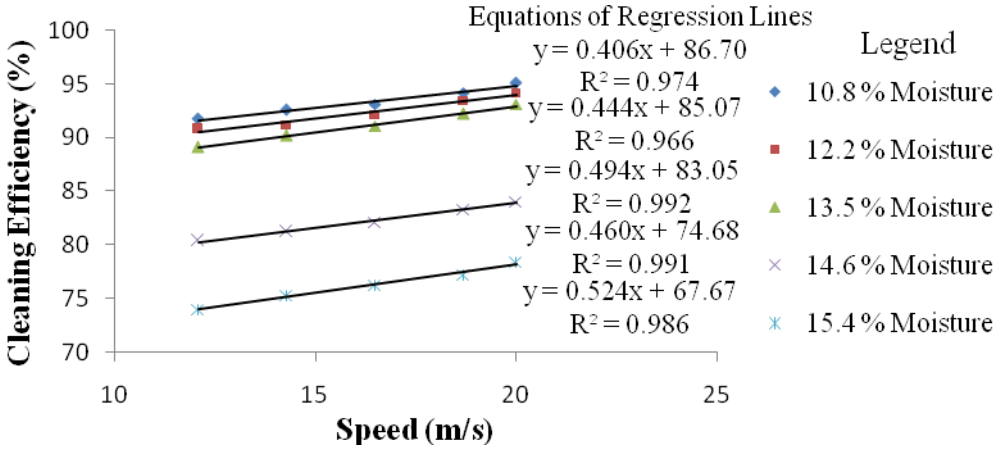


Fig. 4.14c: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 8 kg/min for soybean crop

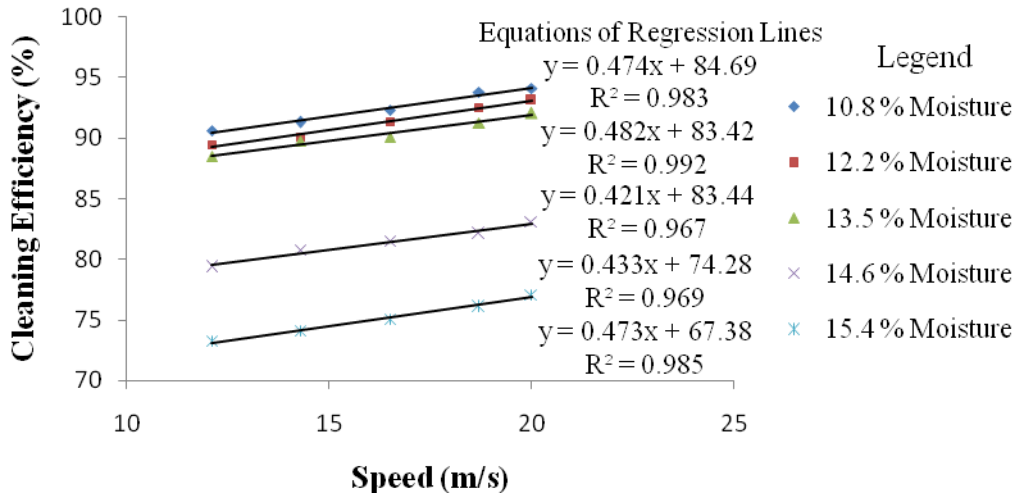


Fig. 4.14d: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 10 kg/min for soybean crop

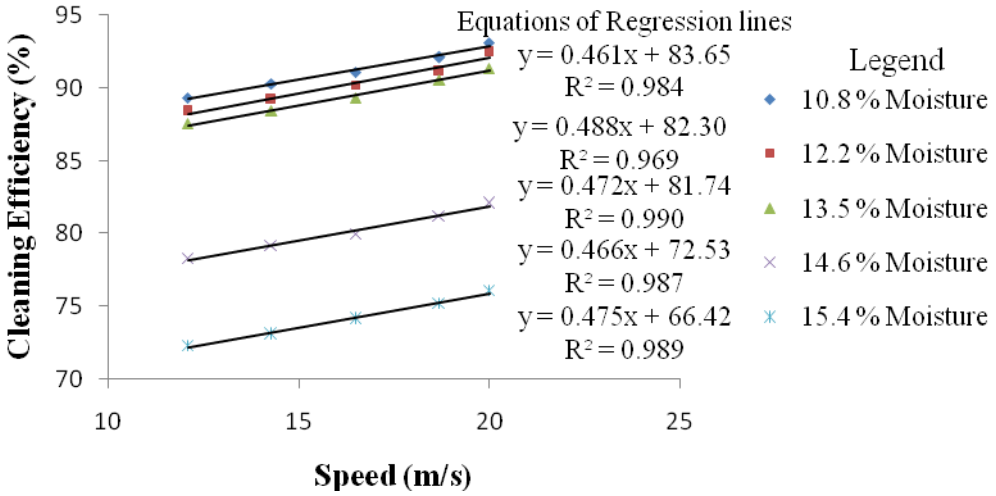


Fig. 4.14e: Variation of speed with cleaning efficiency at various moisture content and constant feed rate of 12 kg/min for soybean crop

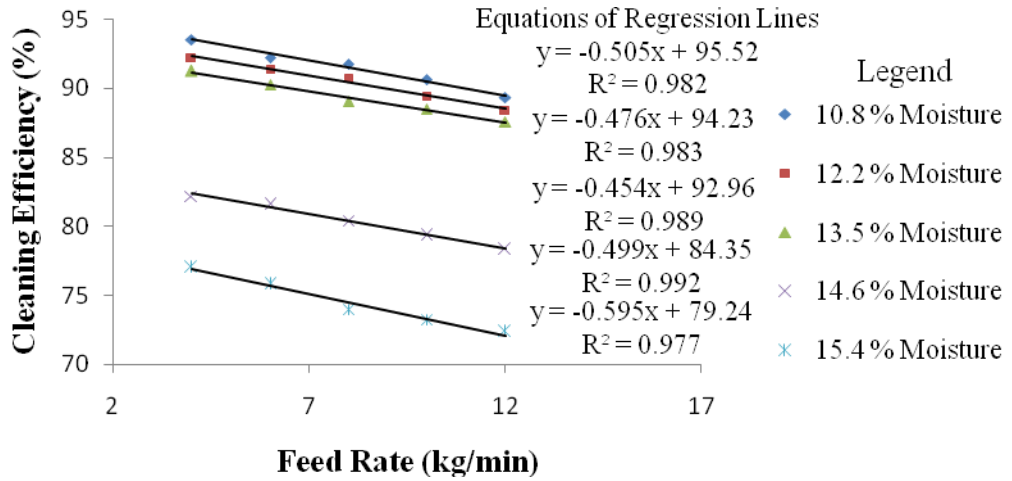


Fig. 4.15a: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 12.1 m/s for soybean crop

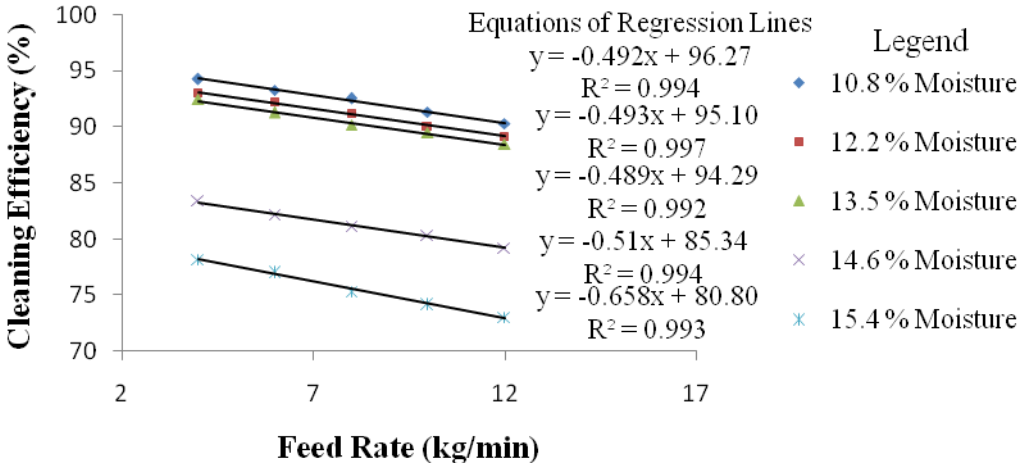


Fig. 4.15b: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 14.3 m/s for soybean crop

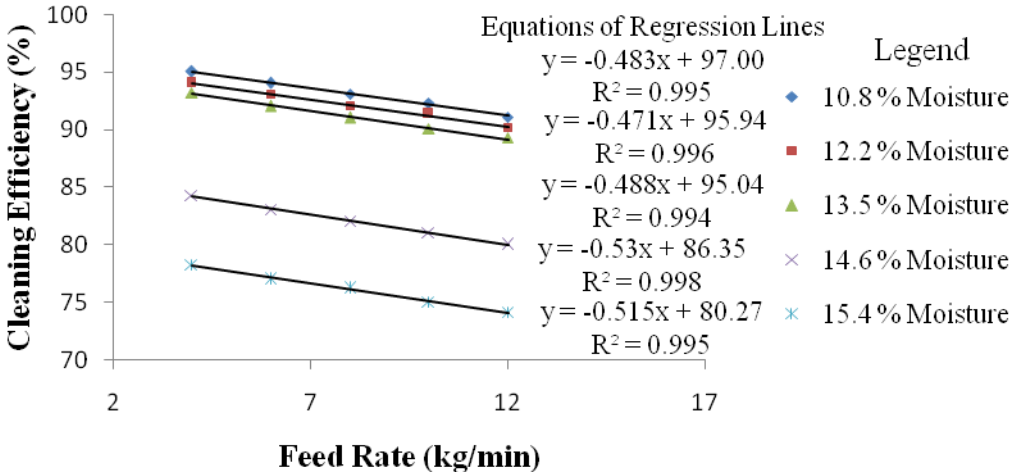


Fig. 4.15c: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 16.5 m/s for soybean crop

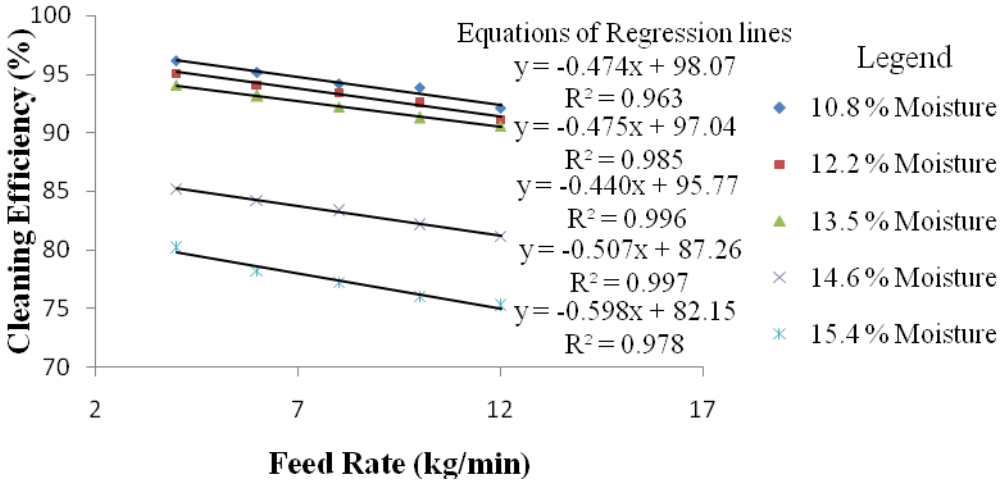


Fig. 4.15d: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 18.7 m/s for soybean crop

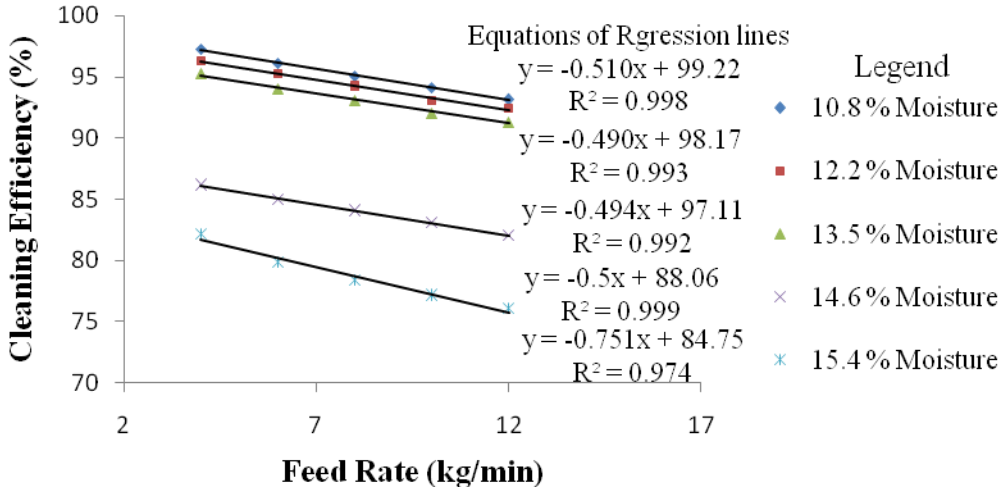


Fig. 4.15e: Variation of feed rate with cleaning efficiency at various moisture contents and constant speed of 20 m/s for soybean crop

Table 4.14: ANOVA of cleaning efficiency for soybean crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	22614.16	5653.54	872.64**
Speed (S)	4	3273.21	818.30	5830.20**
Feed rate (F)	4	1847.22	461.81	280.60**
M × S	16	2235.87	139.74	981.60**
M × F	16	557.34	34.83	837.60**
F × S	16	876.44	54.78	708.60**
M × S × F	64	1497.11	23.39	97.60**
Error	248	0.00	0.00	
Total	374	32901.35		

** = Significant at 1 % probability level

Table 4.15a: D. M. R. T. for variation of speed with cleaning efficiency for soybean crop

Duncan Grouping	Mean Cleaning Efficiency (%)	N	Speed (m/s)
A	80.60	75	12.1
B	86.18	75	14.3
C	87.04	75	16.5
D	88.11	75	18.7
E	89.01	75	20.0

Alpha= 0.05, Error Degrees of Freedom = 248, Error Mean Square= 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.15b: D. M. R. T. for variation of feed rate with cleaning efficiency for soybean crop

Duncan Grouping	Mean Cleaning Efficiency (%)	N	Feed Rate (kg/min)
A	89.34	75	4
B	88.02	75	6
C	85.70	75	8
D	84.66	75	10
E	83.22	75	12

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.15c: D. M. R.T. for variation of crop moisture content with cleaning efficiency for soybean crop

Duncan Grouping	Mean Cleaning Efficiency (%)	N	Moisture Content (%)
A	93.28	75	10.8
B	92.21	75	12.2
C	91.17	75	13.5
D	80.79	75	14.6
E	73.49	75	15.4

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0	0	0	0

This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Any two means with the same letter are not significantly different at 1 % level of significance.

4.9 Scattered Grain Loss for Soybean Crop

It ranges from 1.54 % to 7.25 % for soybean when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with scattered grain loss at various moisture contents and constant feed rates are illustrated in Fig. 4.16(a. b, c, d and e). It indicates that scattered grain loss increases as speed increase. This may be due to increase in machine vibration and air flow rate of the blower above optimum. However at constant speed, scattered grain loss decreases as moisture content increase. This may be due to cohesive and adhesive forces that exist in crops with high moisture content that keeps the grains and chaff together resulting to reduction in grain loss.

The variation of feed rate with scattered grain loss at various moisture contents and constant speeds are illustrated in Fig. 4.17(a, b, c, d and e). It indicates that scattered grain loss decreases as feed rate increase. This may be due to increase load intensity on the beaters causing the machine rotation, vibration and air flow rate to be low. Also at a constant feed rate, scattered grain loss decreases as moisture content increase. These results were similar to those of Simonyan and Yiljep (2008). Therefore scattered grain loss is directly proportional to speed but inversely proportional to feed rate and moisture content. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of scattered grain loss for soybean crop is shown in Table 4.16. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.17(a, b and c). The result shows that in the variation of speed, feed rate and moisture content with scattered grain loss there were significant differences between the means at 1 % level of significance. This implies as speed increase to another level scattered grain loss increase significantly (Table 4.17a); as feed rate increase to another level scattered grain loss decrease significantly (Table 4.17b); as moisture

content decrease to another level scattered grain loss increase significantly (Table 4.17c). Appendix K represents measured values of scattered grain loss at five levels of cylinder speed, feed rate and crop moisture content for soybean crop.

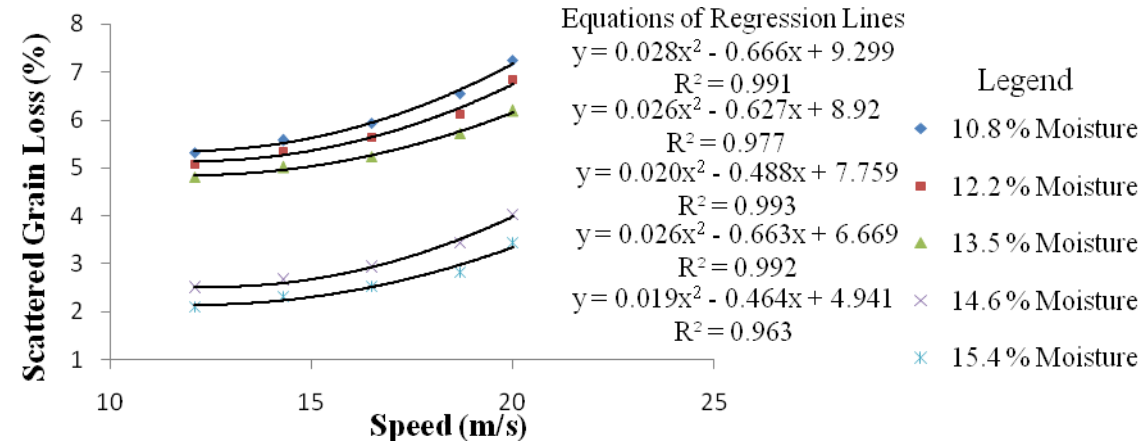


Fig. 4.16a: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 4 kg/min for soybean crop

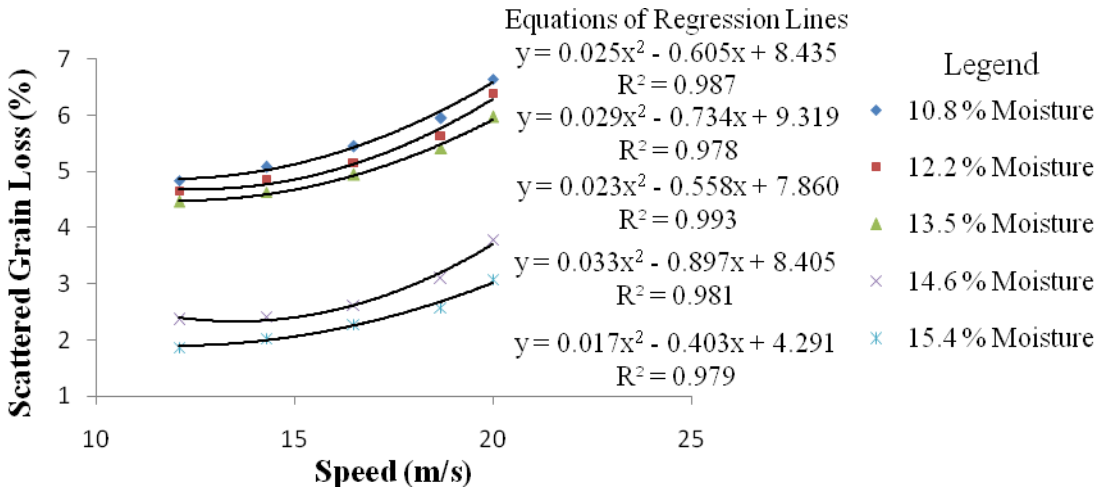


Fig. 4.16b: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 6 kg/min for soybean crop

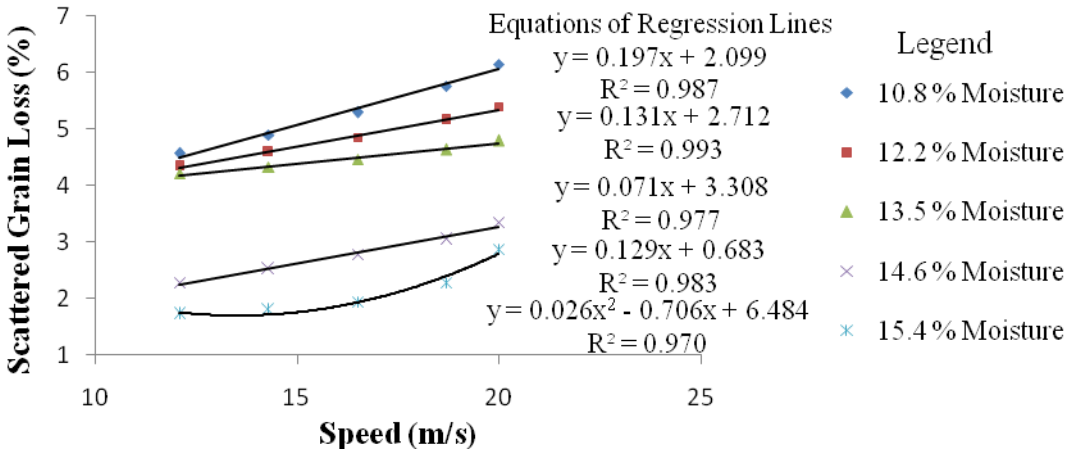


Fig. 4.16c: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 8 kg/min for soybean crop

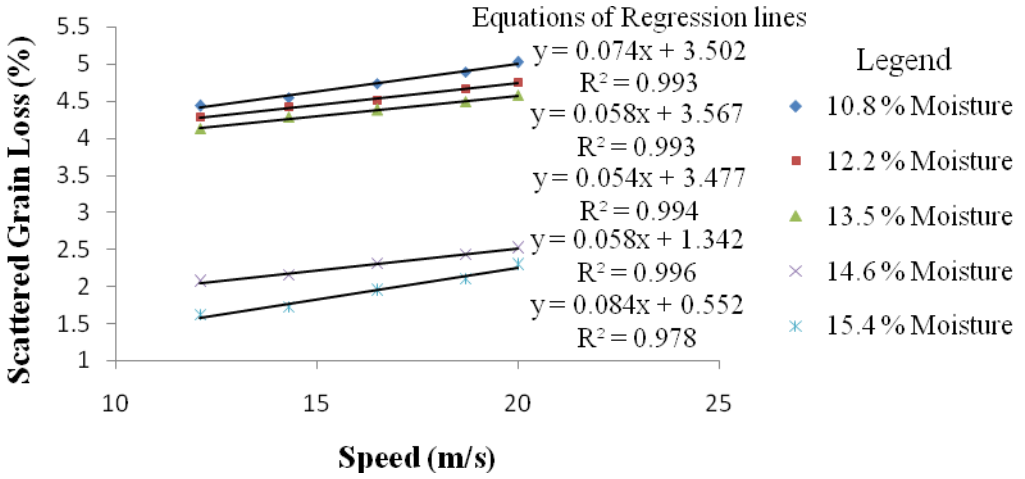


Fig. 4.16d: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 10 kg/min for soybean crop

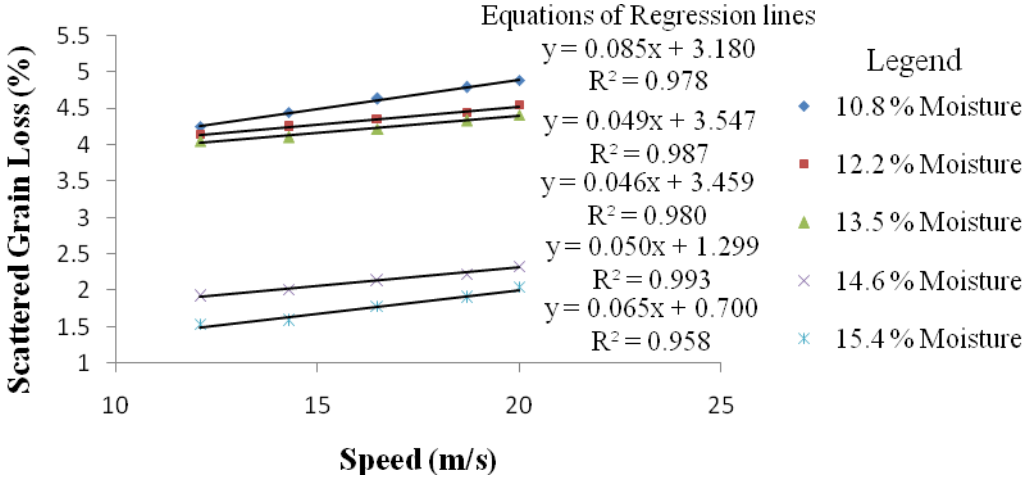


Fig. 4.16e: Variation of speed with scattered grain loss at various moisture content and constant feed rate of 12 kg/min for soybean crop

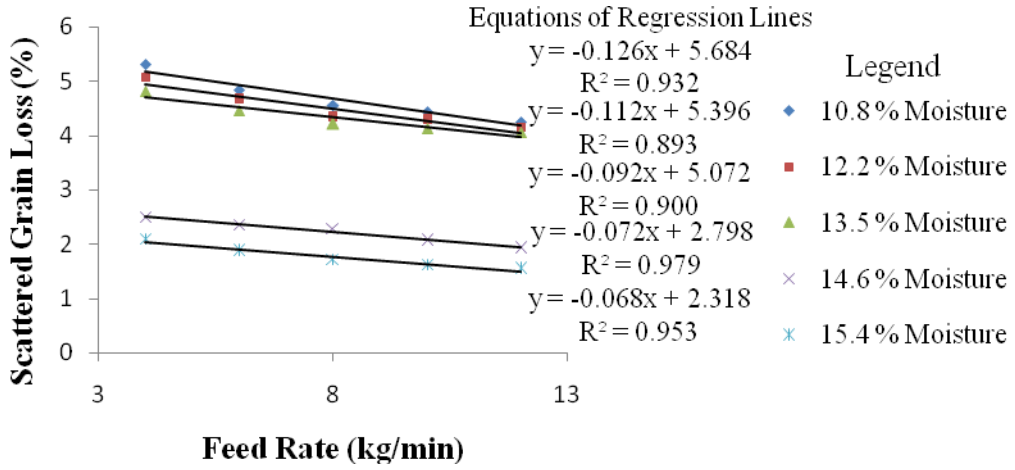


Fig. 4.17a: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 12.1 m/s for soybean crop

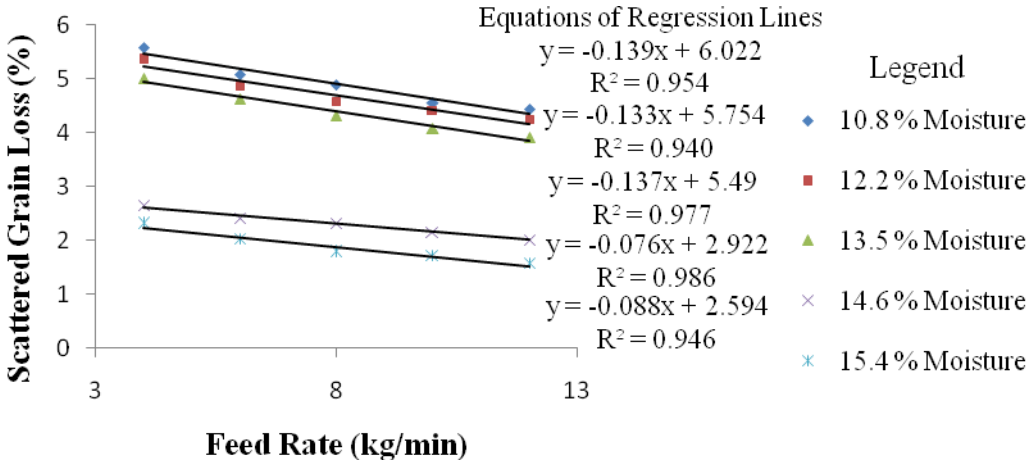


Fig. 4.17b: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 14.3 m/s for soybean crop

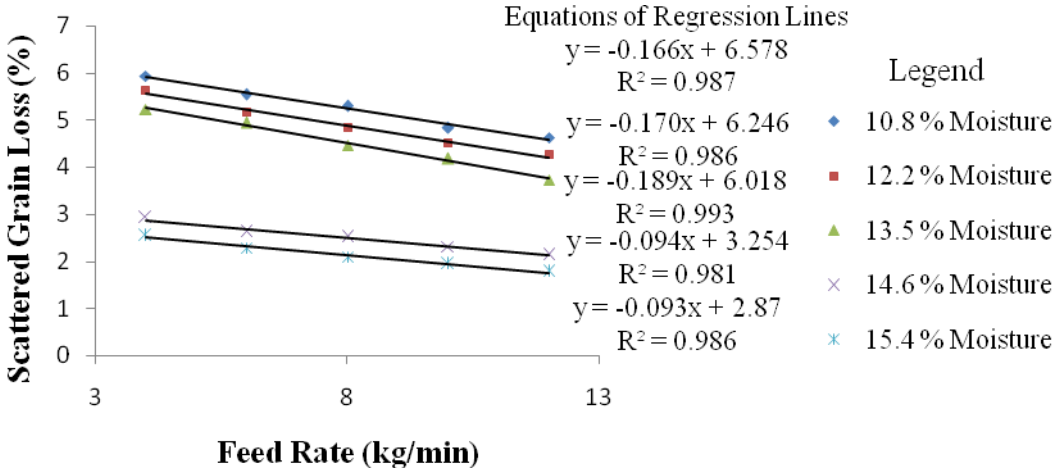


Fig. 4.17c: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 16.5 m/s for soybean crop

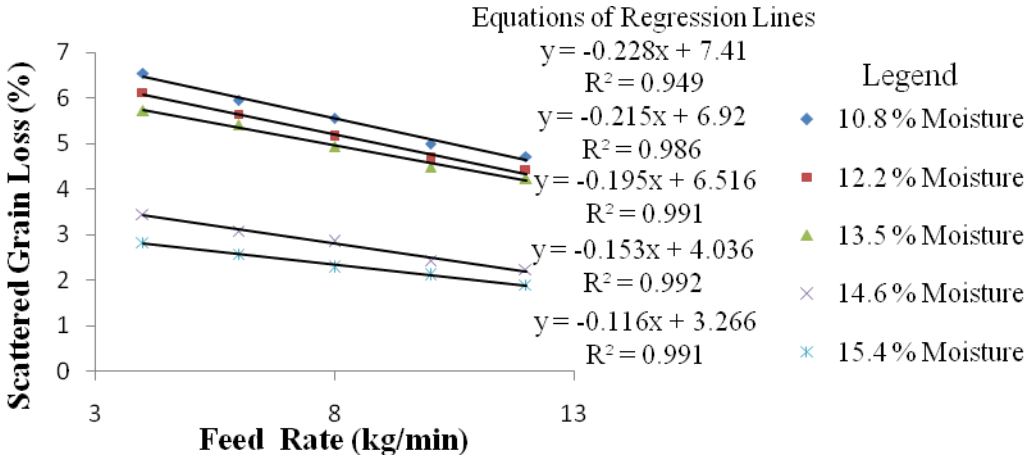


Fig. 4.17d: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 18.7 m/s for soybean crop

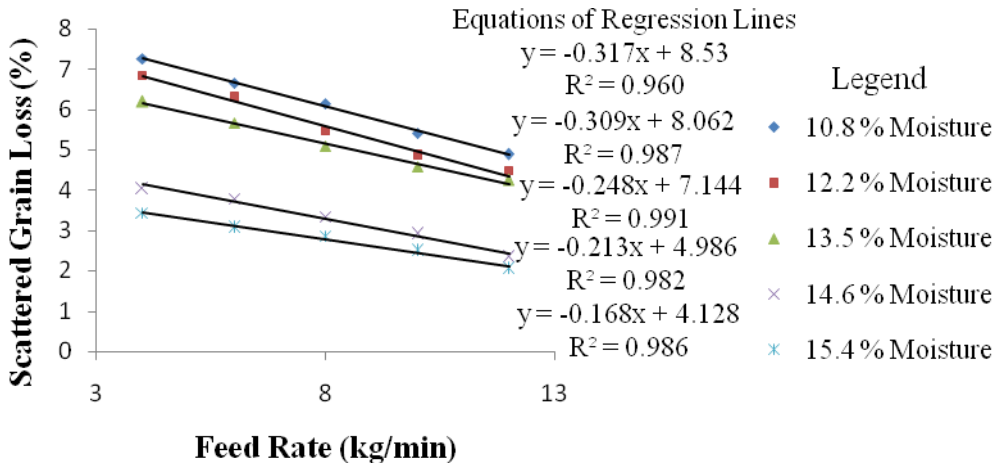


Fig. 4.17e: Variation of feed rate with scattered grain loss at various moisture contents and constant speed of 20 m/s for soybean crop

Table 4.16: ANOVA of scattered grain loss for soybean crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	641.10	160.27	2068243**
Speed (S)	4	85.82	21.45	276857**
Feed rate (F)	4	47.12	11.78	152000**
M × S	16	2.66	0.17	2141.42 **
M × F	16	2.24	0.14	1807.92 **
F × S	16	1.39	0.09	1124.97 **
M × S × F	64	1.25	0.02	252.39 **
Error	248	0.02	0.00	
Total	374	781.59		

** = Significant at 1 % probability level

Table 4.17a: D. M. R.T. for variation of speed with scattered grain loss for soybean crop

Duncan Grouping	Mean Grain Loss (%)	N	Speed (m/s)
A	3.50	75	12.1
B	3.66	75	14.3
C	3.85	75	16.5
D	4.28	75	18.7
E	4.85	75	20.0

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0.0028	0.0030	0.0031	0.0032

Table 4.17b: D.M.R.T. for variation of feed rate with scattered grain loss for soybean crop

Duncan Grouping	Mean Grain Loss (%)	N	Feed Rate (kg/min)
A	4.54	75	4
B	4.18	75	6
C	3.92	75	8
D	3.70	75	10
E	3.54	75	12

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0.0028	0.0030	0.0031	0.0032

Table 4.17c: D. M. R.T. for variation of crop moisture content with scattered grain loss for soybean crop

Duncan Grouping	Mean Grain Loss (%)	N	Moisture Content (%)
A	5.29	75	10.8
B	5.02	75	12.2
C	4.79	75	13.5
D	2.60	75	14.6
E	2.19	75	15.4

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 0

Number of Means	2	3	4	5
Critical Range	0.0028	0.0030	0.0031	0.0032

This test controls the type I comparison wise error rate, not the experiment wise error rate.

Any two means with the same letter are not significantly different at 1 % level of significance.

4.10 Grain Damage for Soybean Crop

It ranges from 0.001 % to 6 % for soybean when threshing was done at different levels of cylinder speed, feed rate and crop moisture content. The variation of speed with grain damage at various moisture contents and constant feed rates are illustrated in Fig. 4.18(a. b, c, d and e). It indicates that grain damage increase as speed increases. This may be due to increase in collision rate between grains and beaters. However at constant speed, grain damage decreases as moisture content increase from 10.8 % to 13.5 % for soybean; then increase constantly as moisture content increase above 13.5 %.

The variation of feed rate with grain damage at various moisture contents and constant speeds are illustrated in Fig. 4.19(a. b, c, d and e). It indicates that grain damage decrease as feed rate increases. This may be due to increase in cushion phenomenon as more crops are fed hence reducing the intensity of collision on the grains. Also at a constant feed rate, grain damage decrease greatly as moisture content decreases from 15.8 % to 13.5 %, and then increase gently as moisture content decreases from 13.5 % to 10.8 % for soybean. These results were similar to those of Saeidirad *et al.* (2013) and Osueke (2013). Therefore grain damage is directly proportional to speed but inversely proportional to feed rate. The reason for this behaviour was because as moisture content decreases from 15.8 % to 13.5 %, softer grains that were breaking easily with increase in speed became elastic and grain damage reduces drastically. However as moisture content decreases from 13.5 % to 10.6 %, grains that were elastic became brittle and grain damage increases a little. The equations of the regression lines are listed alongside the lines with their coefficient of determination (R^2).

The analysis of variance (ANOVA) of grain damage for soybean crop is shown in Table 4.18. The ANOVA indicates that the effect of all the factors evaluated and their interactions were significant at 1 % probability level. Further analysis of the results using Duncan's Multiple Range Test (DMRT) are shown in Tables 4.19(a, b and c). The result shows that in the variation

of speed, feed rate and moisture content with grain damage there were significant differences between the means at 1 % level of significance. This implies as speed increase to another level grain damage increase significantly (Table 4.19a); as feed rate increase to another level grain damage decrease significantly (Table 4.19b); as moisture content decrease from 15.8 % to 13.5 % grain damage decrease significantly (Table 4.19c); as moisture content decrease further from 13.5 % to 10.6 % grain damage increase significantly (Table 4.19c). Appendix M represents measured values of grain damage at five levels of cylinder speed, feed rate and crop moisture content for soybean crop.

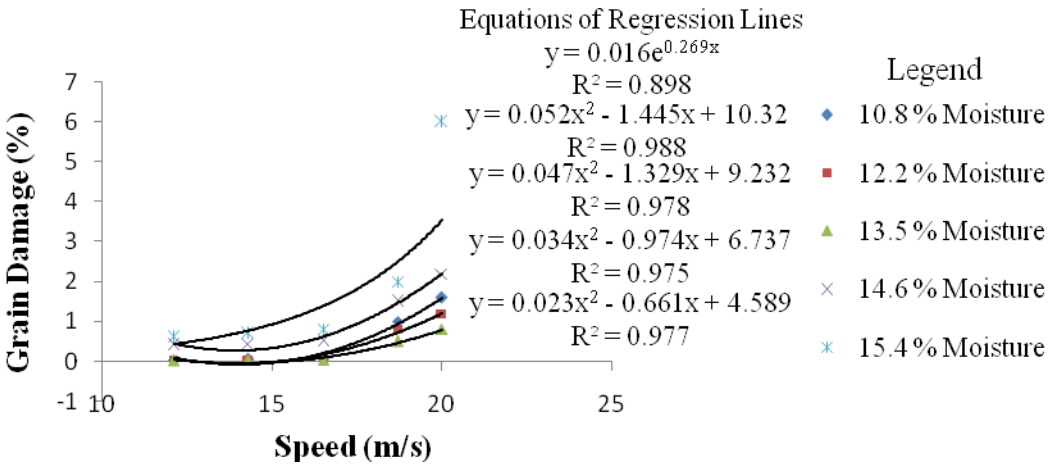


Fig. 4.18a: Variation of speed with grain damage at various moisture content and constant feed rate of 4 kg/min for soybean crop

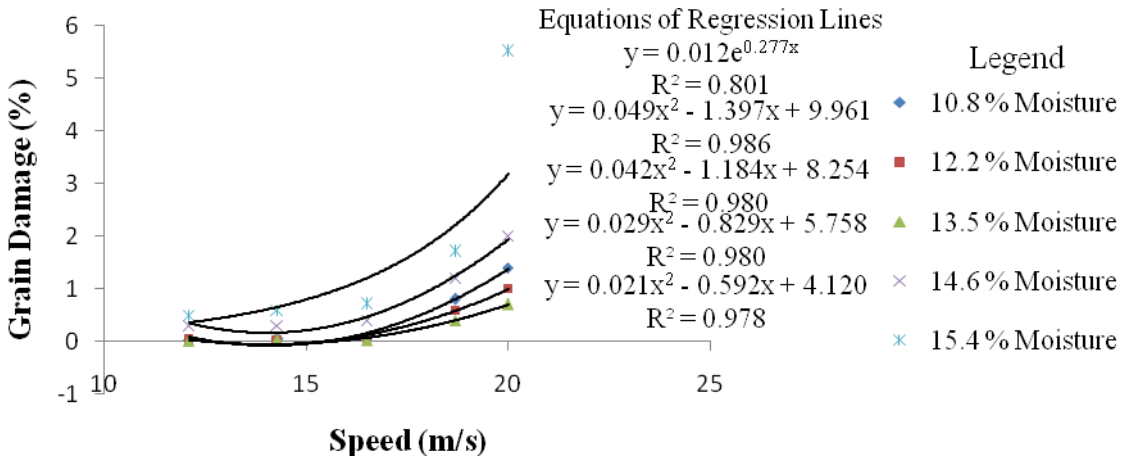


Fig. 4.18b: Variation of speed with grain damage at various moisture content and constant feed rate of 6 kg/min for soybean crop

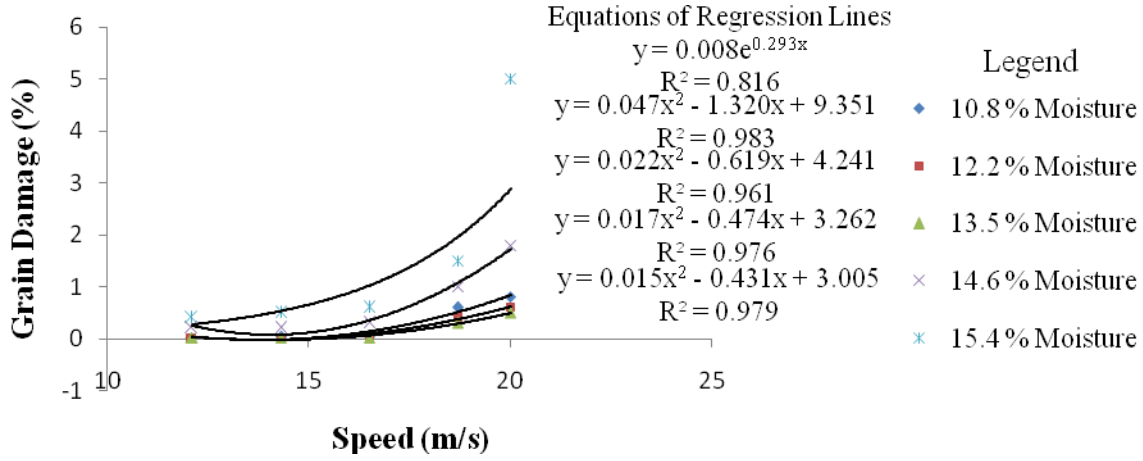


Fig. 4.18c: Variation of speed with grain damage at various moisture content and constant feed rate of 8 kg/min for soybean crop

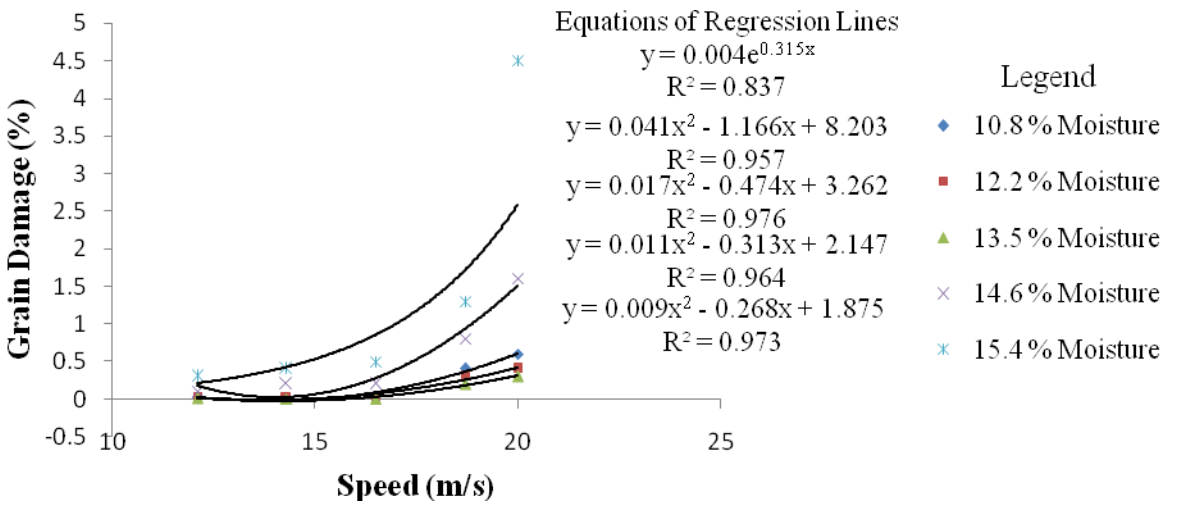


Fig. 4.18d: Variation of speed with grain damage at various moisture content and constant feed rate of 10 kg/min for soybean crop

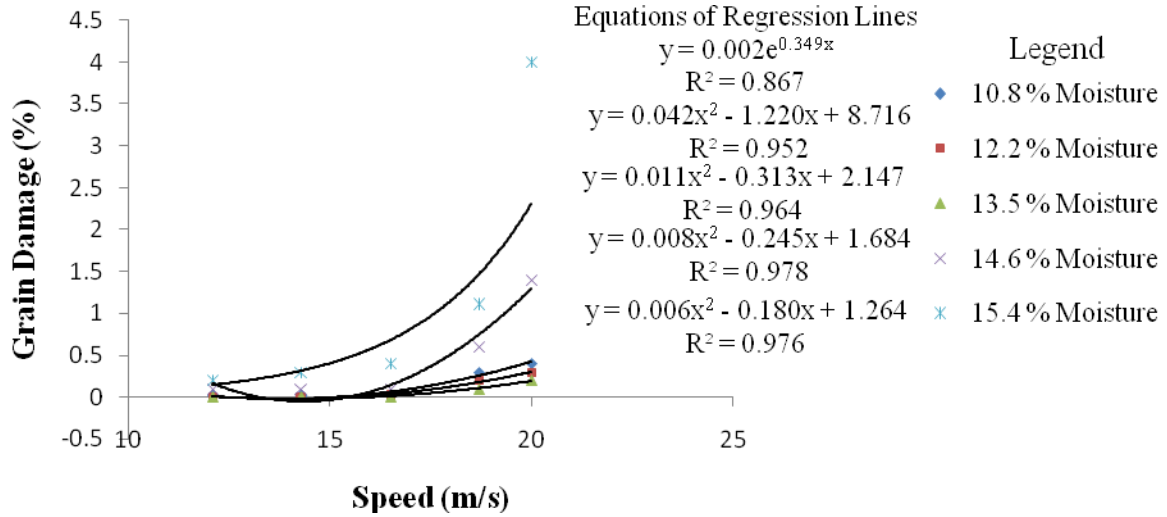


Fig. 4.18d: Variation of speed with grain damage at various moisture content and constant feed rate of 12 kg/min for soybean crop

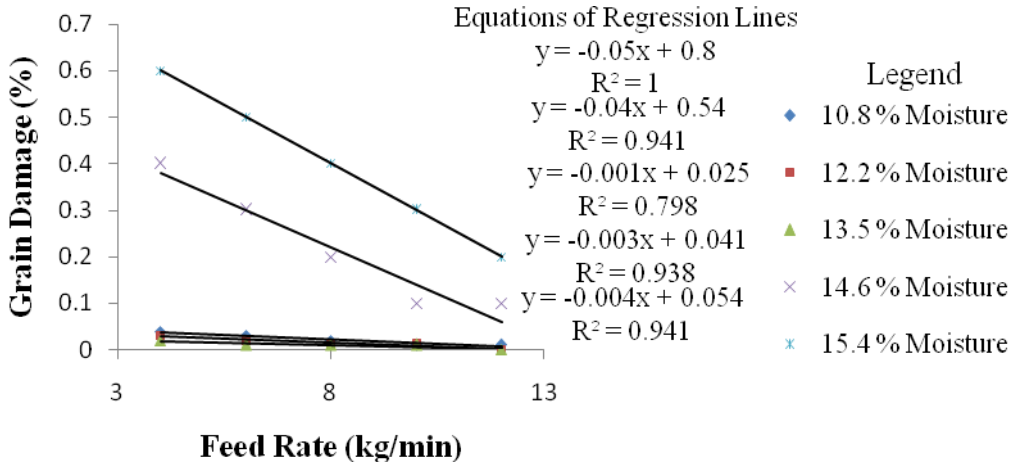


Fig. 4.19a: Variation of feed rate with grain damage at various moisture contents and constant speed of 12.1 m/s for soybean crop

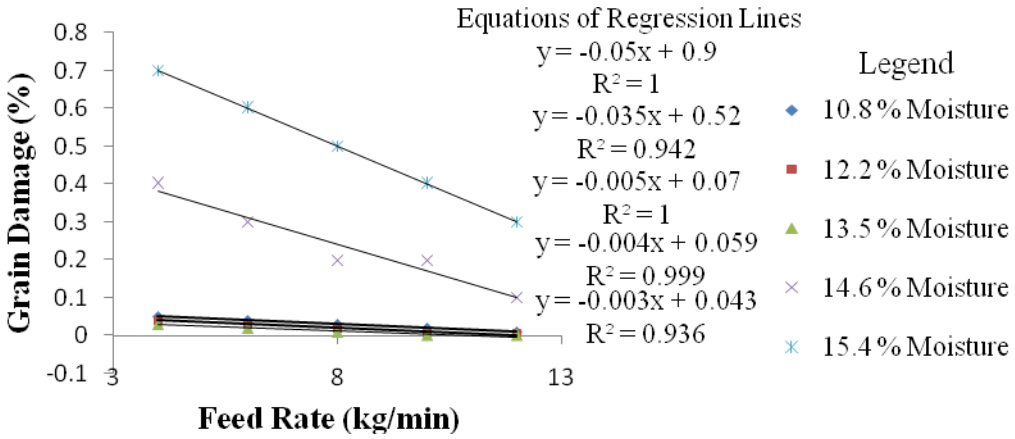


Fig. 4.19b: Variation of feed rate with grain damage at various moisture contents and constant speed of 14.3 m/s for soybean crop

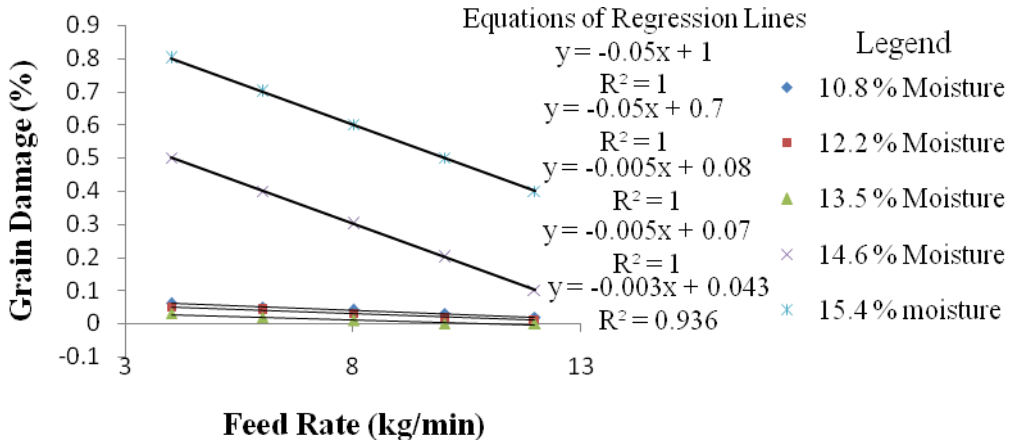


Fig. 4.19c: Variation of feed rate with grain damage at various moisture contents and constant speed of 16.5 m/s for soybean crop

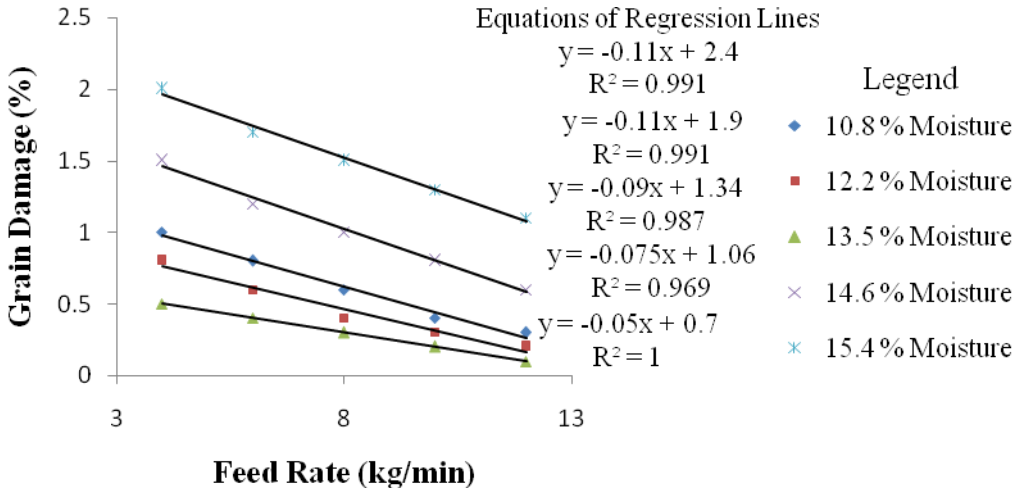


Fig. 4.19d: Variation of feed rate with grain damage at various moisture contents and constant speed of 18.7 m/s for soybean crop

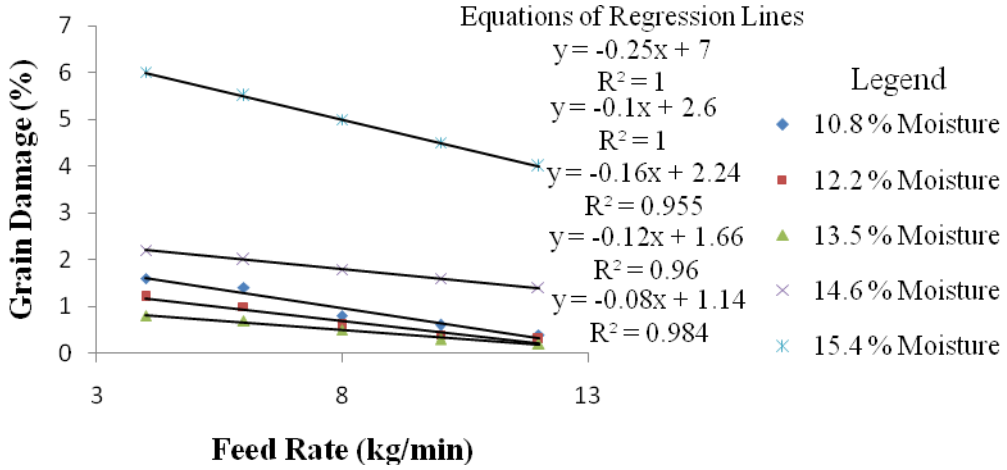


Fig. 4.19e: Variation of feed rate with grain damage at various moisture contents and constant speed of 20 m/s for soybean crop

Table 4.18: ANOVA of grain damage for soybean crop

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	107.62	26.91	5.87E16**
Speed (S)	4	143.70	35.92	7.84E16 **
Feed rate (F)	4	8.98	2.25	4.90E15 **
M × S	16	129.83	8.11	1.77E16 **
M × F	16	2.21	0.14	3.01E14 **
F × S	16	5.61	0.35	7.65E14 **
M × S × F	64	1.35	0.02	4.59E13 **
Error	248	0.00	0.00	
Total	374	399.30		

** = Significant at 1 % probability level

Table 4.19 a: D. M. R.T. for variation of speed with grain damage for soybean crop

Duncan Grouping	Mean Grain Damage (%)	N	Speed (m/s)
A	0.134	75	12.1
B	0.161	75	14.3
C	0.197	75	16.5
D	0.784	75	18.7
E	1.744	75	20.0

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 4.58E-16

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.19 b: D M. R.T. for variation of feed rate with grain damage for soybean crop

Duncan Grouping	Mean Grain Damage (%)	N	Feed Rate (kg/min)
A	0.83	75	4
B	0.71	75	6
C	0.60	75	8
D	0.49	75	10
E	0.39	75	12

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 4.58E-16

Number of Means	2	3	4	5
Critical Range	0	0	0	0

Table 4.19 c: D. M. R.T. for variation of crop moisture content with grain damage for soybean crop

Duncan Grouping	Mean Grain Damage (%)	N	Moisture Content (%)
A	0.30	75	10.8
B	0.23	75	12.2
C	0.17	75	13.5
D	0.72	75	14.6
E	1.60	75	15.4

Alpha = 0.05, Error Degrees of Freedom = 248, Error Mean Square = 4.58E-16

Number of Means	2	3	4	5
Critical Range	0	0	0	0

This test controls the type I comparison wise error rate, not the experiment wise error rate.

Any two means with the same letter are not significantly different at 1 % level of significance.

4.11 Model Validation Results

A good linear relationship was achieved between the measured and predicted data with the coefficient of determination (r^2), slope and intercept found to be 0.73, 1.3 and -27.3 respectively (Fig. 4.20). A paired t-test was conducted and the result revealed that the calculated t-value (0.101) was less than the tabular value (1.96) at 1 % level of significance. This shows that there was no significant difference between the predicted and measured threshing efficiency values. A Standard Error of 0.13, Mean Squared Deviation (MSD) of 0.92, Bias (mean deviation) of 0.74 and Root Mean Square Error (RMSE) of 0.96 were obtained for the predicted and measured values. These small values for Standard Error, Mean Squared Deviation (MSD), Bias and Root Mean Square Error (< 1 %) for a threshing efficiency range of 0 to100 % indicate that the model is accurate. A high Coefficient of Determination (r^2 = 0.73) and Coefficient of Efficiency (E = 0.53) is also an indication that the model is accurate. The developed threshing efficiency model is given in equation (3.54). Appendix N represents measured and predicted threshing efficiencies of the machine for SOSAT C88 millet variety at five levels of cylinder speed, feed rate and crop moisture content. Fig. 4.20 represents plot of measured versus predicted threshing efficiency of the machine.

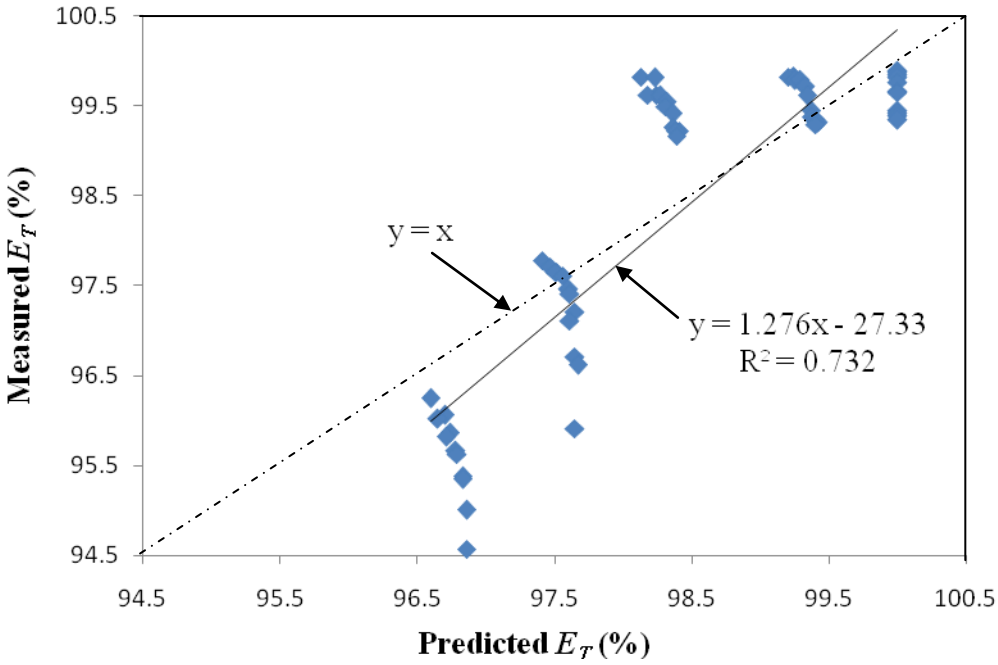


Fig. 4.20: Plot of measured versus predicted threshing efficiency of the machine

4.12 Optimization Results

An optimum speed of 18.7 m/s was determined for millet and soybean. An optimum feed rates of 12 kg/min and 10 kg/min were determined for millet and soybean respectively. Optimum moisture contents of 11.9 % and 12.2 % were determined for millet and soybean respectively.

i. Optimum threshing efficiency of 99.7 % and 100 % were determined for millet and soybean respectively.

ii. Optimum cleaning efficiency of 97.4 % and 92.5 % were determined for millet and soybean respectively.

iii. Optimum Scatter loss of 11.2 % and 4.7 % were determined for millet and soybean respectively.

iv. Optimum grain damage of 0.02 % and 0.3 % were determined for millet and soybean respectively.

v. Optimum output capacity of 420 kg/hr and 163 kg/hr were determined for millet and soybean respectively.

Tables 4.20(a, b and c) are Maximum, Optimum and Minimum performance respectively of the multicrop thresher for SOSAT C88 millet variety and Samsoy-2 soybean variety.

Table 4.20a: Maximum performance of the multicrop thresher for SOSAT C88 millet variety and Samsoy-2 soybean variety

Crop Type	Max Speed (m/s)	Max Feed Rate (kg/min)	Max Moisture Content (%)	Output Capacity (kg/hr)	Threshing Efficiency (%)	Cleaning Efficiency (%)	Grain Loss (%)	Grain Damage (%)
Millet	20	14	15.8	520.6	99.98	99.71	12.18	0.62
Soybean	20	12	15.4	205	100	97.26	7.25	6

Table 4.20b: Optimum performance of the multicrop thresher for SOSAT C88 millet variety and Samsoy-2 soybean variety

Crop Type	Opt. Speed (m/s)	Opt. Feed Rate (kg/min)	Opt. Moisture Content (%)	Output Capacity (kg/hr)	Threshing Efficiency (%)	Cleaning Efficiency (%)	Grain Loss (%)	Grain Damage (%)
Millet	18.7	12	11.9	420	99.7	97.4	11.2	0.02
Soybean	18.7	10	12.2	163	100	92.5	4.7	0.3

Table 4.20c: Minimum performance of the multicrop thresher for SOSAT C88 millet variety and Samsoy-2 soybean variety

Crop Type	Min Speed (m/s)	Min Feed Rate (kg/min)	Min Moisture Content (%)	Output Capacity (kg/hr)	Threshing Efficiency (%)	Cleaning Efficiency (%)	Grain Loss (%)	Grain Damage (%)
Millet	12.1	6	10.6	166.6	94.02	84.27	5.77	0.001
Soybean	12.1	4	10.8	42	95.6	72.34	1.54	0.001

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The IAR multicrop thresher was modified and reconstructed at the Department of Agricultural Engineering, Ahmadu Bello University; to increase its threshing performance for Millet and Soybean crops. The performance of the machine was evaluated, mathematical models for predicting its threshing efficiency, threshing loss and output capacity were developed and the machine was optimized for both crops. Based on the result of this study the following conclusions were made:

i. The materials used for construction of the machine components were durable and resilient as the stress imposed by the stems of bulky crops on the threshing cylinder of the existing IAR Soybean/Multicrop threshers causing it to slow down or even stop was not noticed in the modified machine during performance testing.

ii. The performance test conducted on the modified machine gave a feed rate, threshing efficiency, cleaning efficiency, scatter loss, grain damage and output capacity of 14 kg/min, 99.98 %, 99.71 %, 12.18 %, 0.62 %, and 520.6 kg/hr respectively with SOSAT C88 millet variety, as against 3 kg/min, 92 %, 80 %, 2.4 %, 3.5 %, and 81 kg/hr respectively for the existing IAR multicrop thresher when both machines were operated at 20 m/s. With Samsoy-2 Soybean variety the modified machine gave 12 kg/min, 100 %, 97.26 %, 7.25 %, 6 %, and 205 kg/hr respectively, as against 1.7 kg/min, 80 %, 70 %, 2 %, 1.94 %, and 23 kg/hr respectively for the existing IAR soybean thresher when both machines were operated at 20 m/s.

iii. The above result indicates that the modifications made on the hopper, threshing cylinder, top sieve, shaker and blower of the existing IAR multicrop thresher has greatly increase feed rate for millet from 3 kg/min to 14 kg/min and output capacity from 81 kg/hr to 520

kg/hr, feed rate for soybean from 1.7 kg/min to 12 kg/min and output capacity from 23 kg/hr to 205 kg/hr when the machine was operated at a speed of 20 m/s. Also, threshing and cleaning efficiencies of the machine for both crops were increased.

iv. The model developed was accurate and valid for predicting the threshing efficiency of the machine. This was confirmed by low values for Standard Error, Mean Squared Deviation (MSD), Bias and Root Mean Square Error (< 1 %); and high values for coefficient of determination ($r^2 = 0.73$) and coefficient of efficiency (E = 0.53).

v. The optimum threshing efficiency, cleaning efficiency, scatter loss, grain damage and output capacity obtained was 99.7 %, 97.4 %, 11.2 %, 0.02 %, and 420 kg/hr respectively with SOSAT C88 millet variety at a cylinder speed, feed rate and moisture content of 18.7 m/s (850 rpm), 12 kg/min and 11.9 % respectively; and 100 %, 92.5 %, 4.7 %, 0.3 %, and 163 kg/hr respectively with Samsoy-2 Soybean variety at a cylinder speed, feed rate and moisture content of 18.7 m/s (850 rpm), 10 kg/min and 12.2 % respectively.

vi. Developing this multicrop thresher has cut down the cost of purchasing separate machine for each crop. As its cost of production is closer to the cost of producing several single crop threshers. It has also solved the problem of threshing bulky crops such as soybean and millet manually by farmers.

5.2 Recommendations

i. Even though soybean and millet was the only test crops used for this study, the machine was design to thresh many other cereal crops such as sorghum, rice, wheat and maize. So researchers are encouraged to continue testing this machine with different cereal crops so that its full potential can be exploited.

ii. Farmers are encouraged to purchase this multicrop thresher as it will greatly cut down cost of purchasing separate machine for each crop.

iii. To achieve the best threshing result, the sieve hole diameter of the top and bottom sieves should always match the crop to be threshed. Hence users are advised to always change the top and bottom sieves to match the crop size and also adjust the air entering the blower by shifting the side cover up or down for perfect cleaning.

iv. The design of other spike tooth threshers can be improved by using the mathematical models for predicting threshing efficiency, threshing loss and output capacity of this machine. Hence researcher should test and adopt these models on their machines.

v. The models should be used in optimizing the threshing performance of spike tooth threshers in different parts of the world. Hence, providing useful methods for understanding how these machines can be operated in different crop situations and different threshing conditions

vi. The cleaning efficiency and grain damage models for this machine were yet to be developed, so other researcher are encouraged to develop them.

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APPENDIX A

Design Calculations

The following calculations were conducted in the design of the machine.

Determination of blower casing diameter

The diameter of blower casing was determined using the expression in equation (3.3) as follows:

$$\gamma = \gamma_o(1 + \kappa\theta)$$

Where,

γ_o= initial radius of casing (mm).

k = constant (0.0020 to 0.0023).

θ = angular displacement in degrees.

γ = radius of casing at θ shift from initial radius of casing (mm).

γ_o = radius of blade + clearance = 176 mm + 14 mm = 190 mm

k = 0.0023

θ = 15° (assume a displacement of 15° from initial position)

γ = 190 (1+ 0.0023×15) = 196.555 mm

Thus, a radius of 197 mm was determined.

Therefore the diameter of the blower casing was chosen to be 394 mm.

Determination of threshing cylinder diameter

The threshing cylinder diameter was carefully selected. The cylinder was design to have two different diameters along its length. A section on the cylinder was chosen to have a diameter of 210 mm. This forms the larger diameter section of the threshing cylinder which lay directly below the feed hopper so that crops such as soybean with cultivars ranging from 450mm to 1200mm will not entangle easily on the cylinder. Another section on the cylinder was chosen to

have a diameter of 160 mm. This forms the smaller diameter section of the threshing cylinder with a larger threshing volume to accommodate much threshing material at a time. Both diameters were carefully selected to solve the problem of bulky crops such as soybean and millet entangling the cylinder causing it to slow down or stop as was observed on the existing IAR multicrop thresher.

Determination of sieves hole diameter

The diameter of sieve hole was determined using the expression in equation (3.7) as follows:

$$D_e = \left[6V_g / \pi\right]^{\frac{1}{3}}$$

Where,

D_e= equivalent diameter (mm)

\V_g= grain volume (mm^3)

The grain volume of Ex Borno millet seed at 20 % moisture content V_g= 16.1728 mm^3

Hence, $D_e = \left[6(16.1728)/\pi\right]^{\frac{1}{3}}$

D_e= 3.14 mm

The grain volume of SOSAT C88 millet seed at 20 % moisture content V_g = 37.9496 mm^3

Hence, $D_e = \left[6(37.9496)/\pi\right]^{\frac{1}{3}}$

D_e= 4.17 mm

For easy discharge of grains the chosen diameter was made 20 % larger than the calculated equivalent diameter of the millet seed.

Thus, the chosen diameter $= 0.2D_e + D_e$

$= 0.2(4.17) + 4.17$

$= 5$ mm

Therefore the sieve hole diameter for millet threshing was determined to be 5 mm.

The grain volume of Samsoy-2soybean seed at 15 % moisture content V_g =158.24 mm^3

Hence, $D_e = \left[6(158.24)/\pi\right]^{\frac{1}{3}}$

D_e = 6.71 mm

The grain volume of TGX 1485-IDsoybean seed at 15 % moisture content V_g =163.36 mm^3

Hence, $D_e = \left[6(163.36)/\pi\right]^{\frac{1}{3}}$

D_e=6.78 mm

For easy discharge of grains the chosen diameter was made 25 % larger than the calculated equivalent diameter of the soybean seed.

Thus, the chosen diameter = $0.25D_e + D_e$

= 0.25(6.78) + 6.78

= 8.5 mm

Therefore the sieve hole diameter for soybean threshing was determined to be 8.5 mm.

Determination of the concave sieve radius

The radius of the concave sieves was determined using the expression in equation (3.6) as follows:

$$r_c = r_d + h_p + c_c$$

Where,

r_d = radius of threshing cylinder (mm)

h_p = height of peg (mm)

c_c = concave clearance (mm)

r_c = radius of concave sieve (mm)

With r_d = 80, h_p = 130, c_c = 20 for soybean and c_c = 10 for millet

Thus, r_c = 80 + 130 + 20 = 230 mm

The soybean concave sieve radius was determined to be 230 mm

And r_c = 80 + 130 + 10 = 220 mm

The millet concave sieve radius was determined to be 220 mm

Determination of fan speed required for cleaning

The fan speed required for cleaning was determined using the expression in equation (3.11) as follows:

$$V = \frac{2\pi rN}{60}$$

Where,

V = terminal velocity of crop or air velocity required for cleaning (m/s)

N = fan speed required for cleaning (rpm)

r = distance between the center of the shaft and the apex of the fan blade (m)

The velocity of air required for cleaning a particular type of grain is less than or equal to the terminal velocity of the grain since chaff and threshed heads which constitute a larger portion of the total mass of material has terminal velocities substantially less than that of the grain. Ojediran *et al.* (2006) determined the terminal velocity of millet at 20 % moisture content as 5.13 m/s. Therefore, for millet threshing, the fan speed to achieve this terminal velocity was obtained as follows:

V = 5.13 m/s, r = 176 mm= 0.176 m

Hence, $5.13 = \frac{2 \times \pi \times 0.176 \times N}{60}$

$$N = \frac{5.13 \times 60}{2 \times \pi \times 0.176} = 278.1 \text{ rpm}$$

Therefore the fan speed required for cleaning millet was determined to be 278.1 rpm

Refik *et al.* (2006) determined the terminal velocity of soybean at 15.3 % moisture content as 9.24 m/s. Therefore, for soybean threshing, the fan speed to achieve this terminal velocity was obtained as follows:

V = 9.24 m/s, r = 176 mm = 0.176 m

Hence,

$$9.24 = \frac{2 \times \pi \times 0.176 \times N}{60}$$

$$N = \frac{9.24 \times 60}{2 \times \pi \times 0.176} = 501.1 \text{ rpm}$$

Therefore the fan speed required for cleaning soybean was determined to be 501.1 rpm

Determination of air discharge by the blower

The air discharge by the blower (Q) was determined using the expression in equation (3.12) as follows:

Air flow rate (Q) = AV

Where,

Q = air flow rate (m^3/s)

A = area of inlet duct of the blower (m^2)

V = terminal velocity of the threshed grain (air velocity required for cleaning) (m/s)

But the area of inlet duct of the blower $(A) = LW$

Where:

L = length of inlet duct of the blower (m) = 510 mm = 0.510m

W = width of inlet duct of the blower (m) = 126 mm = 0.126m

Therefore, A = 0.510 x 0.126 = 0.06426 m^2

Considering the terminal velocity of the heavier grain V = 9.24 m/s

Therefore, Air flow rate Q = 0.06426 x 9.24 = 0.5938 (m^3/s)

Since the efficiency of a blower is 30 %, (Hem, 1981) the actual air flow rate was given as:

Q_a = 0.3 x 0.5938 = 0.1781 (m^3/s)

Therefore, the actual air flow rate of the blower was determined to be 0.1781 (m^3/s)

Determination of the number of blades required

The number of blades required was determined using the expression in equation (3.13) as follows:

The volume of air displaced per blade per second (V) was given as:

Volume of air displaced = Area of blade x Distance covered by blade per second

$$V = (l \times w) \times (\pi \times D)$$

Where,

l = length of blade (m) = 430 mm = 0.43 m

w = width of blade (m) = 130 mm = 0.13 m

D = diameter of circle inscribed by tip of blade (m) = 260 mm = 0.26 m

Therefore, $V = (0.43 \times 0.13) \times (\pi \times 0.26) = 0.04566$ (m^3/s)

Thus,

The number of blades (N_b) required = Actual air flow rate / Volume of air displaced per blade (V)

$$N_b = \frac{Q_a}{V}$$

Where,

Q_a= air flow rate (m^3/s)

V = volume of air displaced per blade per second (m^3/s)

N_b = number of blades required

$$N_b = \frac{Q_a}{V} = \frac{0.1781}{0.04566} = 3.9$$

$N_b = 3.9 \approx 4$

Therefore, the number of blades required by the machine was determined to be four.

Determination of weight of the blower

The weight of the blower (W_b) was determined using the expression in equation (3.10) as follows:

$$W_b = \delta g v$$

Where,

W_b = weight of blower (N)

δ = density of blower galvanized steel blade (kg/m^3)

g = acceleration due to gravity (m/s^2)

v = volume of the blades (length x width x thickness) (m^3)

The weight of blower blade (W_1) was determined as follows:

With δ = 7850 (kg/m^3)

g = 9.81 (m/s^2)

v = (0.43 x 0.13 x 0.002) = 1.118 x 10^{-4} (m^3)

Hence, W_1= 7850 x 9.81 x 1.118 x 10^{-4} = 8.6 N. Thus, all four blower blades weighed 34.4 N

The weight of blower shaft (W_2) was determined as follows:

With δ = 7850 (kg/m^3)

g = 9.81 (m/s^2)

$v = (\pi D_1^2/4) L = (\pi 0.02^2/4) 0.78$ = 2.45 x 10^{-4} (m^3)

Where,

D_1 = diameter of shaft (m)

L = length of shaft (m)

Hence, W_2 = 7850 x 9.81 x 2.45 x 10^{-4} = 18.9 N. Thus, the blower shaft weighed 18.9 N

The weight of blower pulley (W_3) was determined as follows:

With δ = 7850 (kg/m^3)

g = 9.81 (m/s^2)

$v = (\pi (D_2\text{-}D_1)^2/4)\ t = (\pi (0.14 - 0.02)^2/4)\ 0.015 = 1.7 \times 10^{-4}\ (m^3)$

Where,

D_2 = external diameter of pulley (m)

t = thickness of pulley (m)

Hence, $W_3 = 7850 \times 9.81 \times 1.7 \times 10^{-4} = 21.8$ N. Thus, the blower pulley weighed 13.1 N

Therefore, $W_b = 4W_1 + W_2 + W_3 = 34.4 + 18.9 + 13.1 = 66.4$ N

Thus, the weight of the blower **(**W_b) was determined to be 66.4 N; so the mass was 6.64 kg

Determination of pulley diameters

The pulley diameters were determined using the expression in equation (3.14) as follows:

$$N_1 D_1 = N_2 D_2$$

Where,

N_1 = speed of drive pulley (petrol engine pulley) (rpm)

N_2= speed of driven cylinder pulley (rpm)

D_1 = diameter of drive pulley (petrol engine pulley) (mm)

D_2 = diameter of driven cylinder pulley (mm)

The driven cylinder pulley

The diameter of the driven cylinder pulley (D_2) was determined as shown below:

N_1 = 1300 rpm

D_1 = 100 mm

N_2= 650 rpm

Thus, $D_2 = \dfrac{N_1 D_1}{N_2} = \dfrac{1300x100}{650} = 200$ mm

Therefore, the diameter of the driven cylinder pulley D_2 was chosen to be 200 mm.

The shaker pulley

The diameter of the shaker pulley (D_4) was determined as shown below:

N_3 = speed of threshing cylinder smaller pulley = 650 rpm

D_3 = diameter of threshing cylinder smaller pulley = 90 mm

N_4= speed of shaker pulley = 189 rpm

Thus, $D_4 = \frac{N_3 D_3}{N_4} = \frac{650 \times 90}{189} = 309.5 \approx 310$ mm

Therefore, the diameter of the shaker pulley D_4 was chosen to be 310 mm.

The blower pulley

The diameter of the blower pulley (D_5) was determined as shown below:

N_4 = speed of thresher pulley = 650 rpm

D_4 = diameter of threshing cylinder larger pulley = 200 mm

N_5 = speed of blower pulley = 929 rpm

Thus, $D_5 = \frac{N_4 D_4}{N_5} = \frac{650 \times 200}{929} = 140$ mm

Therefore, the diameter of the blower pulley D_5 was chosen to be 140 mm.

Determination of belt lengths

The length of each belt (L) was determined using the expression in equation (3.15) as follows:

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

Where,

L = effective length of belt (cm)

c = center distance from drive to driven pulley (cm)

d = outside diameter of drive pulley (cm)

D = diameter of driven pulley (cm)

The cylinder belt length

The cylinder belt length (L_1) was determined as shown below:

c =107 cm

d =10 cm

D =20 cm

Thus, $L_1 = \frac{\pi}{2}(20+10) + 2(107) + \frac{(20-10)^2}{4(107)}$ = 261.4 cm OR $\frac{261.4}{2.5} = 104.5 \approx 105$ inches

Therefore, the cylinder belt length (L_1) was chosen to be A105.

The shaker belt length

The shaker belt length (L_2) was determined as shown below:

c = 42 cm

d = 9 cm

D = 31 cm

Thus, $L_2 = \frac{\pi}{2}(31+9) + 2(42) + \frac{(31-9)^2}{4(42)}$ = 149.7 cm OR $\frac{149.7}{2.5} = 59.9 \approx 60$ inches

Therefore, the shaker belt length (L_2) was chosen to be A60.

The blower belt length

The blower belt length (L_3) was determined as shown below:

c = 64 cm

d = 20 cm

D = 14 cm

Thus, $L_3 = \frac{\pi}{2}(14+20) + 2(64) + \frac{(14-20)^2}{4(64)}$ = 181.5 cm OR $\frac{181.5}{2.5} = 72.6 \approx 73$ inches

Therefore, the blower belt length (L_3) was chosen to be A73

Determination of belt speeds

The speed of each belt (V) was determined using the expression in equation (3.16) as follows:

$$V = \frac{\pi DN}{60}$$

Where,

N = drive speed (rpm)

D = diameter of drive pulley (m)

V = belt speed (m/s)

The cylinder belt speed

When the prime mover was set at 909 rpm, the cylinder belt speed was determined as shown below:

N = 909 (rpm)

D = 100mm = 0.1 (m)

Thus,

$$V_1 = \frac{\pi \times 0.1 \times 909}{60} = 4.76 \text{ m/s}$$

Therefore, when the prime mover's revolution was 909 rpm, the cylinder was driven at a belt speed (V_1) of 4.76 m/s.

The shaker belt speed

When the prime mover was set at 909 rpm, the shaker belt speed was determined as shown below:

$N_1D_1 = N_2D_2$

N_1 = 909 rpm, D_1 = 100 mm, D_2 = 200 mm

$$\therefore N_2 = \frac{909 \times 100}{200} = 454.5 \text{ rpm}$$

N_2 = 454.5 (rpm)

D_3 = 90mm = 0.09 (m)

$$V_2 = \frac{\pi \times 0.09 \times 454.5}{60} = 2.14 \text{ m/s}$$

Therefore, when the prime mover's pulley revolution was 909 rpm, the cylinder pulley revolution was 454.5 rpm and the shaker was driven at a belt speed (V_2) of 2.14 m/s.

The blower belt speed

When the prime mover was set at 909 rpm, the blower belt speed was determined as shown below:

N_2 = 454.5 (rpm)

D_2 = 200mm = 0.2 (m)

$$V_3 = \frac{\pi \times 0.2 \times 454.5}{60} = 4.76 \text{ m/s}$$

Therefore, when the prime mover's pulley revolution was 909 rpm, the cylinder pulley revolution was 454.5 rpm and the blower was driven at a belt speed (V_3) of 4.76 m/s

Determination of angles of lap (contact) of belts

The angle of lap (contact) of V-belt on a pulley was determined using the expression in equations (3.20) and (3.21) as follows:

$$\theta_1 = 180 - 2\sin^{-1}\left(\frac{R-r}{C}\right)$$

$$\theta_2 = 180 + 2\sin^{-1}\left(\frac{R-r}{C}\right)$$

Where,

R = radius of larger pulley (mm)

r = radius of smaller pulley (mm)

C = center distance between driven and driving pulleys (mm)

θ_1 =angle of lap for smaller pulley (^{o})

θ_2 =angle of lap for larger pulley (^{o})

Belt lap angles between prime mover and cylinder pulleys

The belt lap angles between prime mover and cylinder pulleys were determined as shown below:

R = 100 mm

r = 50 mm

C = 1160 mm

$$\theta_1 = 180 - 2\sin^{-1}\left(\frac{100-50}{1160}\right) = 175.1^o$$

$$\theta_2 = 180 + 2\sin^{-1}\left(\frac{100-50}{1160}\right) = 184.9^o$$

Therefore, the lap angle on the prime mover pulley was 175.1 ^{o} and that on the cylinder pulley was 184.9 ^{o}.

Belt lap angles between cylinder and shaker pulleys

The belt lap angles between cylinder and shaker pulleys were determined as shown below:

R = 155 mm

r = 45 mm

C = 420 mm

$$\theta_1 = 180 - 2\sin^{-1}\left(\frac{155-45}{420}\right) = 149.6^o$$

$$\theta_2 = 180 + 2\sin^{-1}\left(\frac{155-45}{420}\right) = 210.4^o$$

Therefore, the belt lap angle on the cylinder pulley was 149.6 ^{o} and that on the shaker pulley was 210.4 ^{o}.

Belt lap angles between cylinder and blower pulleys

The belt lap angles between cylinder and blower pulleys were determined as shown below:

R = 100 mm

r= 70 mm

C = 640 mm

$$\theta_1 = 180 - 2\sin^{-1}\left(\frac{100-70}{640}\right) = 174.6^{o}$$

$$\theta_2 = 180 + 2\sin^{-1}\left(\frac{100-70}{640}\right) = 185.4^{o}$$

Therefore, the belt lap angle on the cylinder pulley was 185.4 ^{o} and that on the blower pulley was174.6 ^{o}.

Determination of power required to oscillate sieve

The power required to oscillate sieve was determined using the expression in equations (3.8) and (3.9) as shown below:

$$kW_1 = \frac{w_s \times N \times 2 \times y}{4500}$$

$$kW_2 = \frac{w_s \times N \times \mu \times 2 \times x}{4500}$$

Where:

kW_1= the power required for vertical movement (kW)

kW_2 = the power required for horizontal movement (kW)

w_s= weight of reciprocating unit along with the material on it (kg)

N = eccentric speed (rpm)

y = the vertical displacement of the reciprocating system in meter per stroke

x = the horizontal displacement of reciprocating system in meter per stroke.

μ = the kinetic coefficient of friction at hinge points.

With w_s = 15 kg, N = 900 rpm, x = 4 cm, y = 4 cm, μ=0.08

Power required for vertical movement was obtained as:

$$kW_1 = \frac{w_s \times N \times 2 \times y}{4500} = \frac{15 \times 900 \times 2 \times 0.04}{4500} = 0.24 \text{ kW}$$

Power required for horizontal movement was obtained as:

$$kW_2 = \frac{w_s \times N \times \mu \times 2 \times x}{4500} = \frac{15 \times 900 \times 0.08 \times 2 \times 0.04}{4500} = 0.02 \text{ kW}$$

Total power required $P = kW_1 + kW_2$

P = 0.24 + 0.02 = 0.26 kW

Therefore the power required to oscillate sieve was 0.26 kW

Determination of power required by the blower

The power required by the blower was determined using the expression in equation (3.23).

$$P = P_d Q$$

$$P_d = \frac{1}{2}\rho V^2$$

Where:

P = power required by the blower (W)

P_d = dynamic pressure (N/m^2)

Q = volume flow rate (m^3/s)

ρ = density of air (kg/m^3)

V = velocity of air (m/s)

With ρ =1.165 kg/m^3at 30 ^oC, V = 9.24 m/s, Q = 0.5938m^3/s

$$P_d = \frac{1}{2} \times 1.165(9.24)^2 = 49.73 \text{ N/m}^2$$

$P = 49.73 \times 0.5938 = 29.53$ W = 0.03 kW

Therefore the power required by the blower was 0.03 kW

Determination of power required by the engine

The power required by the engine for threshing soybean or millet was determined using the expression in equations (3.22)

$P_E = P_T + P_C$

Where,

P_E = engine power (kW)

P_T = power required for threshing (kW)

P_C = power required for cleaning (kW)

But,

$P_E = T_E W_E$

$P_T = T_T W_T$

$P_C = T_C W_C$

Where,

T_E = engine torque (Nm)

W_E = Angular velocity of the engine (rads/sec)

T_T = torque required for threshing (Nm)

W_T = Angular velocity required for threshing (rads/sec)

T_C = torque required for cleaning (Nm)

W_C = Angular velocity required for cleaning (rads/sec)

The power required for cleaning (P_C) equals the power required by the shaker and the power required by the blower.

The power required by the shaker was determined previously as 0.26 kW and that required by the blower was also dertermined to be 0.03 kW.

Hence, P_C = 0.26 + 0.03 = 0.29 kW

The power required to thresh crop equals the total torque on the shaft multiplied by the total angular velocity. Thus,

$$P_T = T_T W_T$$

Robertson *et al.* (1977) reported that about 3 N force was required per beater to detach grains of maize. Assuming 3 N force was also required per beater for detaching grains of soybean or millet, this force will exert a torque on the shaft given by:

$$T = Fr$$

Where,

T = torque required to thresh crop (Nm)

F = force required to detach grain (N)

r = peripheral cylinder radius (m)

thus,

F= 3 N

r = 210 mm = 0.21 m

T = 3 x 0.21 = 0.63 Nm

Therefore the effective torque (T_E) exerted by the 38 beaters was obtained as:

T_E = 0.63 x 38 = 23.94 Nm

Also, assuming a 3 N force was required for chopping the soybean and millet stem into pieces before threshing, this force will exert a torque on the shaft given by:

$$T = Fr$$

Where,

T = torque required to chop crop stem (Nm)

F = force required to chop crop stem (N)

r = peripheral cylinder radius (m)

thus,

F = 3 N

r = 210 mm = 0.21 m

T = 3 x 0.21 = 0.63 Nm

Therefore the effective torque (T_E) exerted by the 12 beaters below the feed area for cutting was obtained as:

T_E = 0.63 x 12 = 7.56 Nm

Therefore, the total torque on the shaft equals the effective torque on the beaters required for threshing plus that required for cutting. Hence,

T_T = 23.94 +7.56 = 31.5 Nm

The threshing speed of the IAR thresher for soybean and millet was determined during preliminary test to be (20 m/s). From Appendix O3 the diameter of the peripheral cylinder is 420 mm or 0.42m. Hence, the required threshing speed of the cylinder was determined as follows:

$$V = \frac{\pi DN}{60}$$

$$20 = \frac{\pi \times 420 \times N}{60}$$

$$N = \frac{60 \times 20}{\pi \times 0.42} = 909 rpm$$

Hence, for the developed thresher 20 m/s equals to 909 rpm.

But, $W = \frac{2\pi N}{60}$

Where:

W = angular velocity (rads/sec)

N = speed of threshing cylinder (rpm)

Thus,

$$W_T = \frac{2\pi N}{60} = \frac{2\pi 909}{60} = 95.19 \text{rads / sec}$$

And $P_T = T_T W_T$

$$P_T = 31.5 \times 95.19 = 2998.49 \text{ W} = 3 \text{ kW}$$

Therefore the power required for threshing soybean or millet was 3 kW.

The engine power required for threshing soybean or millet was determined thus:

$P_E = P_T + P_C$

$P_E = 3 + 0.29 = 3.29$ kW

$P_E = 3.29$ kW

The engine power required for threshing and cleaning soybean or millet was determined to be 3.29 kW.

Determination of belt tensions ratio

The tension on each belt (T) was determined using the expressions in equations (3.17), (318) and (3.19) as shown below:

Belt tensions driving the cylinder pulley

The belt tensions driving the cylinder pulley were determined with the following relationships:

$$m_t = \frac{P}{w}, \text{ and } w = \frac{2\pi N}{60}$$

Hence, $m_t = \frac{P \times 60}{2\pi N}$

Where,

m_t = torsional moment (Nm)

P = rated engine power required for threshing and cleaning (kW) = 3.2724 kW

w = angular velocity (rads/sec)

N = maximum engine speed for threshing and cleaning (rpm) = 909 rpm

Thus $m_t = \frac{3.2724x60}{2x\pi x909} = 0.03133kNm = 31.33Nm$

But $m_t = (T_t - T_s)\, r$

$$T_t - T_s = \frac{m_t}{r}$$

Where,

m_t = torsional moment = 31.33Nm

r = radius of driven pulley = 100 mm = 0.1 m

T_t = tension on the tight side of belts (N)

T_s = tension on the slack side of belts (N)

Thus $T_t - T_s = \frac{31.33}{0.1} = 313.31N$

Also,

$$\frac{T_t}{T_s} = e^{\mu\theta \operatorname{cosec}(\beta)}$$

Where,

T_t = tension on the tight side of belts (N)

T_s = tension on the slack side of belts (N)

θ = angle of lap of the driving pulley (^{o}) = 175.1^o

β = one half angle of the pulley groove (^{o}) = 20^o

μ = dynamic coefficient of friction between belt (rubber) and pulley (steel) = 0.5

Hence,

$$\frac{T_t}{T_s} = e^{0.5\times175.1\operatorname{cosec}(20)}$$

$$T_t = T_s e^{0.5\times175.1/\sin(20)}$$

$$T_t = 4.45\times10^{41}T_s$$

But $T_t - T_s = 313.31N$

Thus $4.45 \times 10^{41} T_s - T_s = 313.31N$

$T_s(4.45 \times 10^{41} - 1) = 313.31N$

$T_s = \frac{313.31N}{4.45 \times 10^{41}} = 7.04\text{x}10^{-40}N$

$T_t = 313.3 + 7.04 \times 10^{-40} N$

$T_t = 313.3N$

Therefore, belt tension on the slack side driving the cylinder pulley was $7.04\text{x}10^{-40}$ *N* and that on the tight side driving the cylinder pulley was 313.3 *N*

xiv. The initial tension on the belt (T_i) was determined as shown below:

$T_i = \frac{T_t + T_s}{2}$

$T_i = \frac{313.3 + 7.77 \times 10^{-40}}{2}$

T_i = 156.65 *N*

Therefore the initial tension on the belt (T_i) was 156.65 *N*

Belt tension driving the shaker pulley

The belt tensions driving the shaker pulley were determined with the following relationships:

$m_t = \frac{P}{w}$, and $w = \frac{2\pi N}{60}$

Hence, $m_t = \frac{P \times 60}{2\pi N}$

Where,

m_t = torsional moment (*Nm*)

P = engine power required by the shaker (kW) = 0.26 kW

w = angular velocity (rads/sec)

N = cylinder speed at the time of threshing and cleaning (rpm) = 454.5 rpm

Thus $m_t = \frac{0.26x60}{2x\pi x454.5} = 0.00546kNm = 5.46Nm$

But $m_t = (T_t - T_s)\, r$

$$T_t - T_s = \frac{m_t}{r}$$

Where,

m_t = torsional moment = 5.46 Nm

r = radius of driven pulley = 155 mm = 0.155 m

T_t = tension on the tight side of belts (N)

T_s = tension on the slack side of belts (N)

Thus $T_t - T_s = \frac{5.46}{0.155} = 35.23N$

Also,

$$\frac{T_t}{T_s} = e^{\mu\theta \operatorname{cosec}(\beta)}$$

Where,

T_t = tension on the tight side of belts (N)

T_s = tension on the slack side of belts (N)

θ = angle of lap of the driving pulley (^{o}) = 149.6^o

β = one half angle of the pulley groove (^{o}) = 20^o

μ = dynamic coefficient of friction between belt (rubber) and pulley (steel) = 0.5

Hence,

$$\frac{T_t}{T_s} = e^{0.5\times149.6\operatorname{cosec}(20)}$$

$$T_t = T_s e^{0.5\times149.6/\sin(20)}$$

$$T_t = 3.83\times10^{35} T_s$$

But $T_t - T_s = 35.23N$

Thus $3.83\times10^{35} T_s - T_s = 35.23N$

$$T_s(3.83\times10^{35} - 1) = 35.23N$$

$$T_s = \frac{35.23N}{3.83\times10^{35}} = 9.2\text{x}10^{-35}N$$

$$T_t = 35.23 + 9.2\times10^{-35} N$$

$$T_t = 35.23N$$

Therefore, the belt tension on the slack side driving the shaker pulley was 9.2 x10^{-35} *N* and that on the tight side driving the shaker pulley was 35.23 *N*

xv. The initial tension on the belt (T_i) was determined as shown below:

$$T_i = \frac{T_t + T_s}{2}$$

$$T_i = \frac{35.23 + 9.2\times10^{-35}}{2}$$

T_i = 17.62 *N*

Therefore the initial tension on the shaker belt (T_i) was 17.62 *N*

Belt tensions driving the blower pulley

The belt tensions driving the blower pulley were determined with the following relationships:

$$m_t = \frac{P}{w}, \text{ and } w = \frac{2\pi N}{60}$$

Hence, $m_t = \frac{P\times60}{2\pi N}$

Where,

m_t = torsional moment (Nm)

P = engine power required by the blower (kW) = 0.03 kW

w = angular velocity (rads/sec)

N = cylinder speed at the time of threshing and cleaning (rpm) = 454.5 rpm

Thus $m_t = \frac{0.03x60}{2x\pi x454.5} = 0.00063kNm = 0.63Nm$

But $m_t = (T_t - T_s)\, r$

$$T_t - T_s = \frac{m_t}{r}$$

Where,

m_t = torsional moment = 0.63 Nm

r = radius of driven pulley = 70 mm = 0.07 m

T_t = tension on the tight side of belts (N)

T_s = tension on the slack side of belts (N)

Thus $T_t - T_s = \frac{0.63}{0.07} = 9N$

$T_t - T_s = 9\ N$

Also,

$$\frac{T_t}{T_s} = e^{\mu\theta \operatorname{cosec}(\beta)}$$

Where,

T_t = tension on the tight side of belts (N)

T_s = tension on the slack side of belts (N)

θ = angle of lap of the driving pulley (^{o}) = 185.4^o

β = one half angle of the pulley groove (^{o}) = 20^o

μ = dynamic coefficient of friction between belt (rubber) and pulley (steel) = 0.5

Hence,

$$\frac{T_t}{T_s} = e^{0.5\times185.4\,\mathrm{cosec}(20)}$$

$$T_t = T_s e^{0.5\times185.4/\sin(20)}$$

$$T_t = 1.25\times10^{44} T_s$$

But $T_t - T_s = 9N$

Thus $1.25\times10^{44} T_s - T_s = 9N$

$$T_s(1.25\times10^{44} - 1) = 9N$$

$$T_s = \frac{9N}{1.25\times10^{44}} = 7.18\text{x}10^{-44}N$$

$$T_t = 9 + 7.18\times10^{-44} N$$

$$T_t = 9N$$

Therefore, the belt tension on the slack side driving the blower pulley was $1.25\text{x}10^{-44}$ *N* and that on the tight side driving the blower pulley was 9 *N*

xvi. The initial tension on the belt (T_i) was determined as shown below:

$$T_i = \frac{T_t + T_s}{2}$$

$$T_i = \frac{9 + 1.25\times10^{-44}}{2}$$

$T_i = 4.5$ *N*

Therefore the initial tension on the belt (T_i) was 4.5 *N*

Determination of frequency of oscillation

The frequency of oscillation of the shaker tray was determined using the expression in equation (3.4) as shown below:

$$f = \left(1/2\pi\right)\left[5g\left(\frac{a^2}{b^2}-1\right)\right]^{\frac{1}{2}} \Big/ \left[b\left(\frac{a^2}{b^2}+6\right)\right]^{\frac{1}{2}}$$

Where,

f = the rocking frequency (Hz)

a = the length of the major axis (mm)

b = the length of the minor axis (mm)

g = the acceleration due to gravity (mms^2)

Frequency of the shaker

The oscillation frequency of the shaker was determined as shown below:

a = length of connecting rod = 505 mm

b = length of the slender Plate = 140 mm

g = the acceleration due to gravity = 10000 mms^2

$$f = \left(1/2\pi\right)\left[5\times10000\left(\frac{505^2}{140^2}-1\right)\right]^{\frac{1}{2}} \Big/ \left[140\left(\frac{505^2}{140^2}+6\right)\right]^{\frac{1}{2}}$$

$$f = \frac{123.34}{51.6} = 2.4\,\text{Hz}$$

The frequency of oscillation of the shaker tray was determined to be 2.4 Hz. Therefore the shaker makes 2.4 circles per second.

Determination of torsional moment

The maximum torsional moment was determined using the expression in equation (3.19) as follows:

Torsional moment required for threshing

The torsional moment required for threshing was determined using the expression in equation (3.19) as follows:

$$m_t = \frac{P}{w}, \text{ and } w = \frac{2\pi N}{60}$$

Hence, $m_t = \frac{P \times 60}{2\pi N}$

Where,

m_t = torsional moment (Nm)

P = engine power required for threshing (kW) = 2.9824 ≈ 3 kW

w = angular velocity (rads/sec)

N = maximum engine speed required for threshing and cleaning (*rpm*) = 909 *rpm*

Thus $m_t = \frac{3x60}{2x\pi x909} = 0.03152kNm = 31.52Nm$

Therefore, the torsional moment required for threshing (M_1) was 31.52 *Nm*.

Torsional moment required by shaker

The torsional moment required by shaker was determined using the expression in equation (3.19) as follows:

$$m_t = \frac{P}{w}, \text{ and } w = \frac{2\pi N}{60}$$

Hence, $m_t = \frac{P \times 60}{2\pi N}$

Where,

m_t = torsional moment (*Nm*)

P = engine power required by the shaker (kW) = 0.26 *kW*

w = angular velocity (rads/sec)

N = cylinder speed at the time of threshing and cleaning (rpm) = 454.5 *rpm*

Thus $m_t = \frac{0.26x60}{2x\pi x454.5} = 0.00546kNm = 5.46Nm$

Therefore, the torsional moment required by shaker (M_2) was 5.46 *Nm*.

Torsional moment required by the blower

The torsional moment required by the blower was determined using the expression in equation (3.19) as follows:

$$m_t = \frac{P}{w} \text{ , and } w = \frac{2\pi N}{60}$$

Hence, $m_t = \frac{P \times 60}{2\pi N}$

Where,

m_t = torsional moment (Nm)

P = engine power required by the blower (kW) = 0.03 kW

w = angular velocity (rads/sec)

N = cylinder speed at the time of threshing and cleaning (rpm) = 454.5 rpm

Thus $m_t = \frac{0.03x60}{2x\pi x454.5} = 0.00063kNm = 0.63Nm$

Therefore, the torsional moment required by the blower (M_3) was 0.63 Nm.

The maximum torsional moment of the machine was given by:

$m_t = M_1 + M_2 + M_3$

$m_t = 31.52 + 5.46 + 0.63$

$m_t = 37.61\ Nm$

Therefore, the maximum torsional moment used for threshing and cleaning was 37.61 Nm

Available torsional moment on the prime mover

At a threshing speed of 909 rpm the torsional moment on the prime mover which was not used by the machine was determined as follows:

$$m_t = \frac{P \times 60}{2\pi N}$$

Where,

m_t = engine torsional moment (Nm)

P = rate engine power 7 Hp = 7 x 0.746 = 5.22 kW

N = maximum speed required for threshing and cleaning (rpm) = 909 rpm

Thus, $m_t = \frac{5.22 \times 60}{2 \times \pi \times 909} = 54.84 Nm$

The torsional moment available for use = 54.84 – 37.61 = 17.23 Nm

Therefore, at a threshing speed of 909 rpm the torsional moment available for use was 17.23 Nm

Determination of weight of a material

The weight of a material was determined using the expression in equation (3.24).

$W = \delta g v$

Where,

W = weight of material (N)

δ = density of galvanized steel (kg/m^3)

g = acceleration due to gravity (m/s^2)

v = volume of the material (length x width x thickness) (m^3)

Cylinder weight

The threshing cylinder weight was determined as shown below:

δ = 7850 (kg/m^3)

g = 9.81 (m/s^2)

v = (0.66 x 0.545) 0.003 + (0.79 x 0.503) x 0.003 = 2.271 x 10^{-3} (m^3)

W_1= 7850 x 9.81 x 2.271 x 10^{-3} = 174.9 N

Beaters weight

The beaters weight was determined as shown below:

δ = 7850 (kg/m^3)

g = 9.81 (m/s^2)

L = 5270 mm = 5.27 m

D = 15 mm = 0.015 m

$v = (\pi D^2/4) L = (\pi 0.015^2/4) 5.27 = 9.31 \times 10^{-4}$ (m^3)

$W_2 = 7850 \times 9.81 \times 9.31 \times 10^{-4} = 71.7$ N

Chaff throwers weight

The chaff thrower weight was determined as shown below:

$\delta = 7850$ (kg/m^3)

$g = 9.81$ (m/s^2)

$v = ((0.05 \times 0.125) + (0.1 \times 0.1) + (0.025/2 \times 0.1)) 0.003 \times 4 = 2.1 \times 10^{-4}$($m^3$)

$W_3 = 7850 \times 9.81 \times 2.1 \times 10^{-4} = 16.2$ N

The total load $W = W_1 + W_2 + W_3$

$W = 174.9 + 71.7 + 16.2 = 262.8$ N

Therefore, the total load on the shaft due to the cylinder, beaters and chaff throwers was 262.8 N

Load on shaft due to shaker belt tension

The load on shaft due to shaker was the tension on the tight side of the shaker belt determined previously above as 35.23 N.

Load on shaft due to blower belt tension

The load on shaft due to blower was the tension on the tight side of the blower belt determined previously above as 9 N.

Load on shaft due to prime mover belt tension

The load on shaft due to prime mover was the tension on the tight side of the prime mover belt determined previously above as 313.3 N.

Since the prime mover and the blower share the same pulley on the threshing cylinder shaft their combined load exerted at that point = 313.3 + 9 = 322.3 N

The loads acting on the shaft are shown on the free body diagram (FBD) in Fig. 3a.

R_1 and R_2 are normal reaction forces acting at the bearings. They were determined as shown below:

The sum of vertical forces equals to zero

Thus, $\sum F = 0$

$R_1 + R_2 = 262.8 + 35.23 + 313.3$

$R_1 + R_2 = 611.33$

The sum of moments about a point equals to zero

Thus, $\sum M = 0$

Taking moments about point E

$1400\ R_2 = 700 \times 262.8 + 1465 \times 35.23 + 1502 \times 313.3$

$1400\ R_2 = 706148.55$

$R_2 = 706148.55 / 1400 = 504.39$ N

$R_2 = 504.39$ N

$R_1 + 504.39 = 611.33$

$R_1 = 611.33 - 504.39$

$R_1 = 106.94$ N

Determination of maximum shear force and bending moment

The shear forces and bending moments were determined as shown below:

Shear force

Considering the forces acting downward as positive while those acting upward as negative, the shear forces at each point (A, B, C, D and E) of the shaft were determined as shown below:

$SF_A = 313.3$ N

$SF_B = 313.3 + 35.23 = 348.53$ N

$SF_C = 313.3 + 35.23 - 504.39 = -155.86$ N

$SF_D = 313.3 + 35.23 – 504.39 + 262.8 = 106.94$ N

$SF_E = 313.3 + 35.23 – 504.39 + 262.8 – 106.94 = 0$ N

The maximum shear force was determined to be 348.53 N

Bending moment

Considering the bending moment (BM_A and BM_E) at the end loads as zero and considering clockwise direction as negative and anti clockwise direction as positive, the bending moments at each point (A, B, C, D and E) of the shaft were determined as shown below:

$BM_A = - 313.3 \times 0 = 0$

$BM_B = - 313.3 \times 0.037 = -11.59$ Nm

$BM_C = (-313.3 \times (0.037 + 0.065)) + (-35.23 \times 0.065) = -34.25$ Nm

$BM_D = (-313.3 \times (0.037 + 0.065 + 0.7)) + (-35.23 \times (0.065 + 0.7) + (504.39 \times 0.7) = 75.03$ Nm

$BM_E = (-313.3 \times (0.037 + 0.065 + 0.7 + 0.7)) + (-35.23 \times (0.065 + 0.7 + 0.7) +$

$(504.39 \times 0.7+ 0.7) + (-262.8 \times 0.7)$

$= (-313.3 \times 1.502) + (-35.23 \times 1.465) + (504.39 \times 1.4) + (-262.8 \times 0.7) = 0$ Nm

Therefore, the maximum bending moment was determined to be 75.03 Nm

The free body diagram (FBD), shear force diagram (SFD) and bending moment diagram (BMD) of the cylinder shaft loading are shown on figures 3a, 3b and 3c respectively.

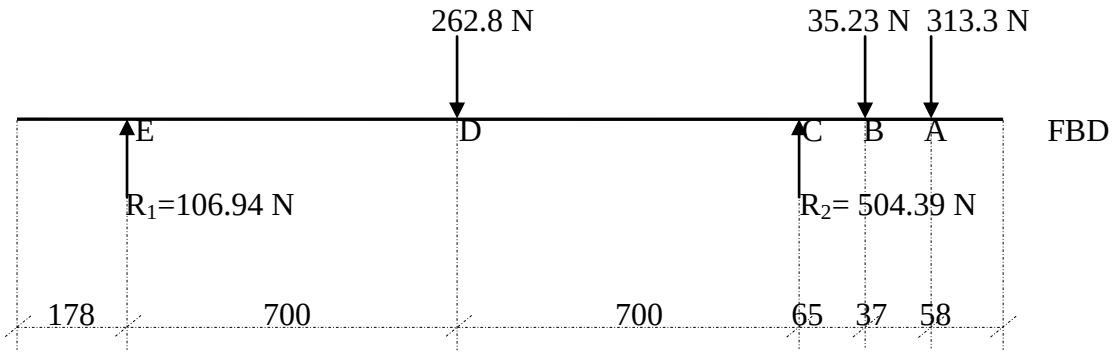


Fig. 3a: Free body diagram of the cylinder shaft. The dimensions are in millimeters

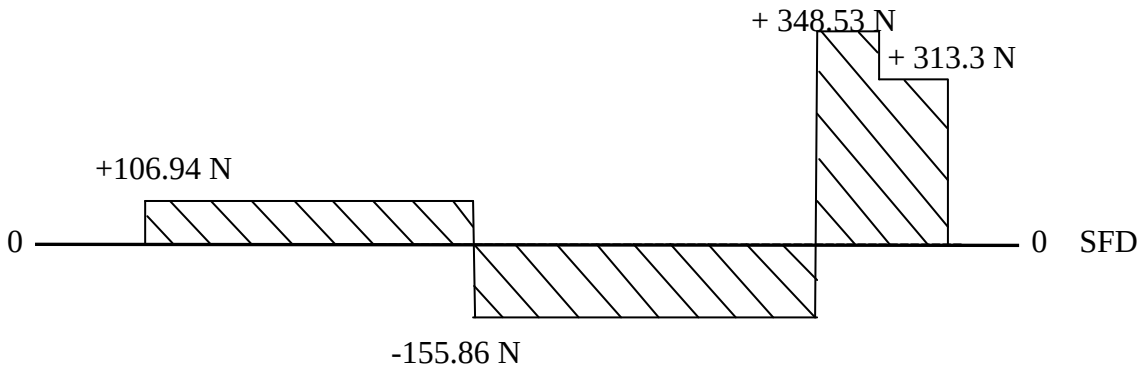


Fig. 3b: Shear force diagram of the cylinder shaft.

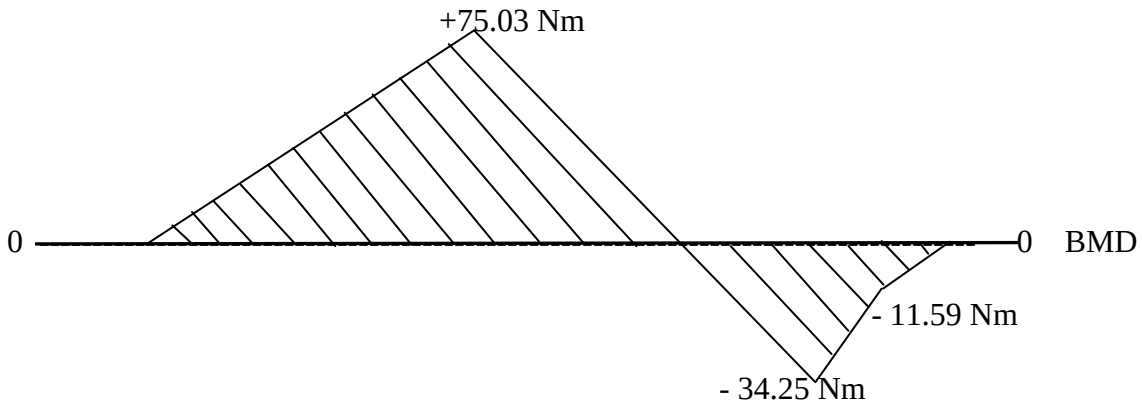


Fig. 3c: Bending moment diagrams of the cylinder shaft.

Determination of the threshing cylinder shaft diameter

To determine the diameter of the threshing cylinder shaft, the limits for the maximum allowable shear stress, bending and torsional moment of the shaft were considered. Also the weight of the pulleys, threshing cylinder, beaters and the tension exerted by each belts on the shaft were determined. Then the maximum bending moment was determined from the shaft shear force and bending moment diagram, while the maximum torsional moment was determined from the rated engine power and rated engine speed.

Thus, the shaft diameter was determined using the expression in equation (3.25) as shown below:

$$d^3 = \frac{16}{\pi S_a}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$$

Where,

d = shaft diameter (m)

S_a = allowable shear stress (N/m^2)

M_b = bending moment (Nm)

M_t = torsional moment (Nm)

K_b = combined shock and fatigue factor applied to bending moment (1.5)

K_t= combined shock and fatigue factor applied to torsional moment (1.0)

Determination of the allowable shear stress

The allowable shear stress (S_a) was determined as shown below:

Medium carbon steel rod (C1040) having the following strength properties (Yield Stress (S_y) of 568.7 MN/m^2 and Tensile Stress (S_t) of 668.8 MN/m^2) as stated by ASME, 1948 was chosen as the threshing cylinder shaft. The lower value of the allowable shear stress (S_a) (18 % ultimate tensile stress (S_t) or 30 % yield stress (S_y)) was obtained as follows:

$0.18S_t$ = 0.18 x 668.8 = 120.38 MN/m^2

$0.3S_y$ = 0.3 x 568.7 = 170.61 MN/m^2

Therefore, S_a = 120.38 MN/m^2

Since the shaft has a key way, the allowable shear stress was reduced by 25 % to take care of the stress concentration.

Hence, S_a= 120.38 x 0.75 = 90.3MN/m^2

Therefore, the allowable shear stress (S_a) was 90.3 MN/m^2

Cylinder shaft diameter

The cylinder shaft diameter (d) was determined as shown below:

$$d^3 = \frac{16}{\pi S_a}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$$

S_a = 90.3 MN/m^2, K_b = 1.5, K_t = 1.0, M_b = 75.03 Nm, M_t = 37.61 Nm

$$d^3 = \frac{16}{\pi 90.3\times 10^6}\sqrt{(1.5\times 75.03)^2 + (1\times 37.61)^2}$$

$d^3 = 6.692639$ x 10^{-6}

$$d = \sqrt[3]{6.692639\times 10^{-6}} = 0.01885m$$ = 18.85 mm

To avoid the use of an overweight shaft, a factor of safety of 1.32 was chosen to take care of deformation due to fatigue caused by cyclic loading.

Thus, d = 18.85 x 1.32 = 24.882 ≈ 25 mm

Hence for reliability and safety, a 25 mm diameter shaft was chosen for the threshing cylinder.

APPENDIX B

Analysis of variance (ANOVA) for the 5 x 5 x 5 factorial experiment in a complete randomized design

Source		DF	SS	MS	F
Replication,	R = r-1	2			
Moisture content,	M = m-1	4			
Speed,	S = s-1	4			
Feed rate,	F = f-1	4			
M * S	(m-1)(s-1)	16			
M * F	(m-1)(f-1)	16			
F * S	(f-1)(s-1)	16			
M * S * F	(m-1)(f-1)(s-1)	64			
Error	(mfs-1)(r-1)	248			
Total	(rmfs-1)	374			

APPENDIX C

A complete randomized design showing a layout of 5 x 5 x 5 factorial experiment involving 5 levels of cylinder speeds (S_1, S_2, S_3, S_4, S_5), 5 levels of Feed rates (F_1, F_2, F_3, F_4, F_5) and 5 levels of moisture contents (M_1, M_2, M_3, M_4, M_5), in three replications RI, RII, and RIII.

R I

$S_5F_2M_3$	$S_3F_1M_4$	$S_1F_5M_1$	$S_2F_2M_1$	$S_2F_2M_2$
$S_3F_5M_5$	$S_4F_1M_1$	$S_4F_1M_2$	$S_5F_5M_4$	$S_5F_5M_5$
$S_5F_1M_5$	$S_5F_2M_1$	$S_1F_2M_1$	$S_1F_2M_2$	$S_1F_2M_3$
$S_4F_2M_1$	$S_4F_2M_2$	$S_4F_2M_3$	$S_4F_4M_3$	$S_5F_1M_2$
$S_1F_4M_2$	$S_3F_5M_4$	$S_3F_2M_2$	$S_3F_4M_2$	$S_3F_4M_3$
$S_1F_1M_1$	$S_5F_2M_4$	$S_5F_2M_5$	$S_1F_1M_2$	$S_2F_3M_1$
$S_3F_3M_4$	$S_3F_3M_5$	$S_3F_4M_1$	$S_4F_4M_1$	$S_4F_4M_2$
$S_5F_4M_5$	$S_5F_5M_1$	$S_2F_4M_5$	$S_2F_5M_1$	$S_2F_5M_2$
$S_4F_2M_4$	$S_4F_2M_5$	$S_4F_3M_1$	$S_5F_5M_2$	$S_5F_5M_3$
$S_1F_4M_5$	$S_2F_2M_5$	$S_1F_2M_5$	$S_1F_3M_4$	$S_1F_3M_5$
$S_1F_5M_2$	$S_1F_5M_3$	$S_2F_1M_2$	$S_3F_4M_4$	$S_3F_4M_5$
$S_5F_2M_2$	$S_5F_3M_1$	$S_5F_3M_2$	$S_5F_3M_3$	$S_1F_4M_4$
$S_2F_5M_4$	$S_2F_5M_5$	$S_2F_3M_4$	$S_2F_3M_5$	$S_2F_4M_1$
$S_3F_2M_3$	$S_3F_3M_2$	$S_3F_1M_3$	$S_5F_1M_3$	$S_5F_1M_4$
$S_4F_3M_5$	$S_1F_1M_3$	$S_1F_1M_4$	$S_1F_1M_5$	$S_1F_4M_3$
$S_3F_2M_4$	$S_3F_2M_5$	$S_3F_3M_1$	$S_4F_4M_4$	$S_5F_1M_1$
$S_2F_3M_2$	$S_3F_1M_1$	$S_1F_5M_4$	$S_1F_5M_5$	$S_2F_1M_5$
$S_5F_4M_2$	$S_5F_4M_3$	$S_4F_3M_2$	$S_4F_3M_3$	$S_5F_4M_4$
$S_4F_5M_3$	$S_4F_5M_4$	$S_3F_1M_1$	$S_3F_1M_2$	$S_4F_1M_5$
$S_3F_1M_5$	$S_3F_2M_1$	$S_2F_1M_3$	$S_2F_1M_4$	$S_2F_1M_5$
$S_5F_3M_4$	$S_5F_3M_5$	$S_5F_4M_1$	$S_2F_3M_3$	$S_2F_4M_2$
$S_3F_5M_1$	$S_3F_5M_3$	$S_4F_1M_3$	$S_4F_1M_4$	$S_4F_1M_5$
$S_4F_3M_4$	$S_4F_4M_5$	$S_4F_5M_1$	$S_4F_5M_2$	$S_3F_5M_2$
$S_1F_2M_4$	$S_1F_4M_1$	$S_1F_3M_1$	$S_1F_3M_2$	$S_1F_4M_3$
$S_2F_2M_3$	$S_2F_2M_4$	$S_2F_4M_3$	$S_2F_5M_3$	

R II

$S_4F_1M_2$	$S_4F_1M_3$	$S_4F_1M_4$	$S_1F_3M_2$	$S_1F_4M_1$
$S_2F_5M_4$	$S_2F_5M_5$	$S_1F_1M_2$	$S_1F_1M_3$	$S_1F_1M_4$
$S_3F_5M_3$	$S_5F_1M_5$	$S_5F_2M_1$	$S_5F_2M_2$	$S_2F_2M_4$
$S_4F_4M_1$	$S_4F_4M_2$	$S_4F_4M_3$	$S_1F_5M_2$	$S_1F_5M_3$
$S_2F_3M_1$	$S_2F_3M_5$	$S_2F_4M_1$	$S_2F_4M_2$	$S_5F_5M_4$
$S_1F_3M_1$	$S_3F_5M_4$	$S_3F_5M_5$	$S_4F_1M_1$	$S_3F_4M_3$
$S_1F_4M_4$	$S_4F_5M_4$	$S_5F_1M_3$	$S_5F_1M_4$	$S_1F_1M_5$
$S_3F_2M_3$	$S_3F_2M_4$	$S_3F_2M_5$	$S_3F_5M_1$	$S_3F_5M_2$
$S_2F_1M_3$	$S_2F_1M_4$	$S_4F_5M_5$	$S_5F_1M_1$	$S_5F_1M_2$
$S_4F_2M_1$	$S_4F_2M_2$	$S_4F_3M_1$	$S_5F_4M_5$	$S_5F_5M_1$
$S_4F_3M_3$	$S_4F_3M_4$	$S_4F_3M_5$	$S_2F_1M_2$	$S_2F_1M_5$
$S_5F_2M_5$	$S_5F_4M_2$	$S_5F_4M_3$	$S_4F_5M_2$	$S_4F_5M_3$
$S_2F_4M_4$	$S_2F_4M_5$	$S_2F_5M_1$	$S_2F_5M_2$	$S_4F_5M_4$
$S_1F_4M_5$	$S_1F_5M_5$	$S_1F_5M_1$	$S_5F_3M_4$	$S_5F_4M_1$
$S_1F_3M_3$	$S_1F_3M_4$	$S_1F_3M_5$	$S_4F_5M_1$	$S_4F_5M_5$
$S_3F_3M_4$	$S_3F_4M_5$	$S_3F_5M_1$	$S_3F_5M_2$	$S_3F_5M_3$
$S_3F_1M_2$	$S_3F_1M_3$	$S_3F_1M_4$	$S_3F_4M_4$	$S_3F_4M_5$
$S_1F_5M_4$	$S_1F_5M_5$	$S_2F_1M_1$	$S_4F_4M_4$	$S_4F_4M_5$
$S_3F_3M_1$	$S_3F_3M_2$	$S_3F_4M_1$	$S_3F_5M_3$	$S_1F_2M_5$
$S_5F_5M_2$	$S_5F_4M_3$	$S_5F_4M_4$	$S_2F_1M_5$	$S_2F_2M_5$
$S_2F_3M_2$	$S_2F_3M_3$	$S_2F_3M_4$	$S_1F_2M_4$	$S_1F_2M_5$
$S_3F_1M_1$	$S_2F_2M_5$	$S_2F_2M_1$	$S_2F_2M_2$	$S_2F_2M_3$
$S_5F_3M_1$	$S_5F_3M_2$	$S_5F_3M_3$	$S_4F_1M_5$	$S_4F_3M_2$

R III

$S_5F_1M_1$	$S_5F_1M_2$	$S_5F_1M_3$	$S_2F_1M_2$	$S_1F_3M_5$
$S_2F_3M_1$	$S_3F_3M_1$	$S_3F_3M_2$	$S_3F_3M_3$	$S_5F_2M_5$
$S_4F_4M_1$	$S_4F_4M_2$	$S_4F_5M_4$	$S_3F_1M_1$	$S_3F_1M_2$
$S_3F_5M_3$	$S_4F_1M_5$	$S_4F_2M_1$	$S_1F_4M_1$	$S_2F_3M_2$
$S_2F_1M_4$	$S_2F_1M_5$	$S_3F_3M_4$	$S_3F_3M_5$	$S_1F_4M_4$
$S_3F_2M_5$	$S_4F_1M_1$	$S_3F_4M_3$	$S_1F_4M_3$	$S_1F_4M_5$
$S_4F_3M_1$	$S_4F_3M_2$	$S_5F_3M_4$	$S_5F_4M_1$	$S_3F_1M_3$
$S_5F_2M_2$	$S_5F_2M_3$	$S_2F_5M_4$	$S_2F_5M_5$	$S_4F_5M_1$
$S_2F_4M_2$	$S_2F_4M_3$	$S_1F_5M_4$	$S_1F_5M_5$	$S_2F_1M_3$
$S_5F_5M_2$	$S_1F_1M_1$	$S_1F_2M_4$	$S_2F_1M_1$	$S_5F_4M_4$
$S_1F_2M_1$	$S_1F_2M_2$	$S_1F_2M_3$	$S_3F_4M_4$	$S_5F_5M_3$
$S_5F_3M_4$	$S_1F_3M_1$	$S_2F_2M_2$	$S_2F_2M_3$	$S_4F_2M_3$
$S_3F_1M_5$	$S_3F_2M_1$	$S_5F_1M_5$	$S_5F_4M_1$	$S_5F_5M_5$
$S_4F_4M_3$	$S_4F_5M_2$	$S_4F_5M_3$	$S_5F_5M_1$	$S_2F_2M_5$
$S_3F_4M_2$	$S_3F_4M_3$	$S_1F_1M_3$	$S_1F_1M_4$	$S_4F_2M_4$
$S_1F_5M_1$	$S_1F_5M_2$	$S_3F_4M_5$	$S_4F_2M_5$	$S_5F_1M_4$
$S_4F_4M_4$	$S_4F_4M_5$	$S_4F_5M_1$	$S_3F_4M_1$	$S_3F_5M_1$
$S_5F_3M_1$	$S_5F_3M_2$	$S_5F_3M_3$	$S_1F_2M_5$	$S_1F_3M_1$
$S_1F_4M_3$	$S_5F_2M_4$	$S_3F_5M_4$	$S_4F_1M_4$	$S_4F_1M_3$
$S_2F_4M_3$	$S_2F_4M_4$	$S_2F_4M_5$	$S_2F_5M_1$	$S_1F_4M_2$
$S_1F_3M_2$	$S_1F_3M_4$	$S_3F_2M_3$	$S_3F_2M_4$	$S_3F_4M_1$

APPENDIX D

Measured values of output capacity for SOSAT C88 millet Variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Output Capacity (kg/hr)				
		10.6 % Moisture	11.9 % Moisture	13.2 % Moisture	14.3 % Moisture	15.8 % Moisture
550 rpm (12.1 m/s)	6	196.8	193.6	183.8	179.6	166.6
	8	260.6	250.8	245.8	233.2	211.2
	10	319.4	300.2	290.2	270.8	255.8
	12	388.2	377.0	355.8	326.2	276.6
	14	447.6	433.0	410.8	345.0	288.4
650 rpm (14.3 m/s)	6	200.4	198.6	190.5	185.4	175.4
	8	274.6	258.2	246.6	236.0	226.6
	10	330.6	317.8	310.4	290.4	273.6
	12	404.6	383.4	370.2	340.8	314.8
	14	468.8	443.6	419.8	384.4	358.2
750 rpm (16.5 m/s)	6	215.2	202.8	195.8	190.4	180.2
	8	287.0	265.8	254.6	241.0	227.8
	10	345.4	332.4	317.2	302.6	285.4
	12	419.4	398.2	385.8	358.8	339.0
	14	474.6	455.8	442.2	417.8	395.6
850 rpm (18.7 m/s)	6	230.8	210.8	198.4	185.2	166.6
	8	299.4	281.2	267.6	237.2	217.8
	10	360.0	347.8	331.4	320.4	296.6
	12	436.6	419.4	398.1	377.2	361.2
	14	488.6	475.2	464.6	446.8	425.2
909 rpm (20 m/s)	6	255.6	219.2	200.6	125.8	65.4
	8	317.4	291.2	274.6	230.2	187.8
	10	382.6	359.0	343.8	331.4	298.4
	12	449.8	433.0	408.4	380.8	357.2
	14	520.6	502.8	475.0	457.2	427.2

APPENDIX E

Measured values of output capacity for Samsoy-2 soybeanvariety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Output Capacity (kg/hr)				
		10.8 % Moisture	12.2 % Moisture	13.5 % Moisture	14.6 % Moisture	15.4 % Moisture
550 rpm (12.1 m/s)	4	61	59.4	54.2	50.0	42.0
	6	99	90.0	83.0	78.0	73.0
	8	135	125.0	116.2	108.0	100.0
	10	167	155.4	145.2	131.0	122.0
	12	195	186.0	172.0	148.0	130.0
650 rpm (14.3 m/s)	4	63	60.0	55.0	48.0	43.2
	6	99	92.0	85.0	79.0	69.0
	8	137	126.0	120.0	110.0	100.0
	10	170	157.0	149.0	141.0	126.6
	12	198	187.0	179.0	159.2	140.6
750 rpm (16.5 m/s)	4	65	63.0	58.0	50.0	44.0
	6	101	93.0	88.0	81.0	72.0
	8	137	128.0	123.0	113.0	102.0
	10	170	159.2	153.0	142.4	128.4
	12	201	190.0	184.0	171.0	158.4
850 rpm (18.7 m/s)	4	66	63.6	60.0	53.0	45.6
	6	103	96.0	89.0	83.0	74.4
	8	140	130.0	125.0	116.0	103.0
	10	172	162.2	155.4	143.4	130.2
	12	204	194.0	187.0	173.4	160.8
909 rpm (20 m/s)	4	66	63.6	61.8	54.4	43.4
	6	101	98.0	89.0	84.8	73.8
	8	138	133.8	127.0	117.0	104.4
	10	170	164.2	158.4	143.4	130.2
	12	205	195.8	191.6	173.4	160.8

APPENDIX F

Measured values of threshing efficiency for SOSAT C88 millet variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Threshing Efficiency (%)				
		10.6 % Moisture	11.9 % Moisture	13.2 % Moisture	14.3 % Moisture	15.8 % Moisture
550 rpm (12.1 m/s)	6	99.85	99.78	99.62	97.65	95.82
	8	99.76	99.71	99.49	97.46	95.66
	10	99.66	99.44	99.41	97.11	95.35
	12	99.39	99.35	99.16	96.71	95.01
	14	99.34	99.31	99.22	95.91	94.02
650 rpm (14.3 m/s)	6	99.87	99.82	99.62	97.71	96.02
	8	99.81	99.78	99.61	97.61	95.86
	10	99.64	99.61	99.54	97.41	95.63
	12	99.41	99.37	99.26	97.21	95.38
	14	99.44	99.29	99.22	96.62	94.57
750 rpm (16.5 m/s)	6	99.88	99.85	99.82	97.78	96.25
	8	99.84	99.83	99.81	97.65	96.06
	10	99.81	99.71	99.65	97.52	95.95
	12	99.69	99.61	99.54	97.31	95.74
	14	99.52	99.45	99.42	97.01	95.68
850 rpm (18.7 m/s)	6	99.97	99.96	99.85	97.38	95.82
	8	99.96	99.95	99.94	97.56	96.23
	10	99.91	99.86	99.82	97.63	96.39
	12	99.83	99.71	99.59	97.66	96.44
	14	99.65	99.56	99.48	97.47	96.41
909 rpm (20 m/s)	6	99.98	99.97	99.87	96.65	95.11
	8	99.97	99.96	99.96	97.35	95.99
	10	99.98	99.98	99.93	97.79	96.71
	12	99.93	99.81	99.78	97.72	96.70
	14	99.86	99.82	99.72	97.56	96.52

APPENDIX G

Measured values of threshing efficiency for Samsoy-2 soybean variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Threshing Efficiency (%)				
		10.8 % Moisture	12.2 % Moisture	13.5 % Moisture	14.6 % Moisture	15.4 % Moisture
550 rpm (12.1 m/s)	4	100	100	100	98.9	97.9
	6	100	100	100	98.5	97.5
	8	100	100	100	98.2	96.9
	10	100	100	100	97.7	96.3
	12	100	100	100	97.2	95.6
650 rpm (14.3 m/s)	4	100	100	100	99.0	98.1
	6	100	100	100	98.7	97.7
	8	100	100	100	98.4	97.4
	10	100	100	100	98.1	97.1
	12	100	100	100	97.8	96.7
750 rpm (16.5 m/s)	4	100	100	100	99.1	98.3
	6	100	100	100	98.9	98.0
	8	100	100	100	98.7	97.8
	10	100	100	100	98.4	97.5
	12	100	100	100	98.2	97.3
850 rpm (18.7 m/s)	4	100	100	100	99.2	98.4
	6	100	100	100	99.0	98.2
	8	100	100	100	98.8	97.9
	10	100	100	100	98.6	97.8
	12	100	100	100	98.4	97.6
909 rpm (20 m/s)	4	100	100	100	99.2	98.4
	6	100	100	100	99.1	98.3
	8	100	100	100	98.9	98.1
	10	100	100	100	98.7	98.0
	12	100	100	100	98.5	97.8

APPENDIX H

Measured values of cleaning efficiency for SOSAT C88 millet variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Cleaning Efficiency (%)				
		10.6 % Moisture	11.9 % Moisture	13.2 % Moisture	14.3 % Moisture	15.8 % Moisture
550 rpm (12.1 m/s)	6	98.2	97.31	96.44	92.67	88.79
	8	98.04	97.15	96.05	92.44	88.35
	10	97.86	96.81	95.78	92.17	87.88
	12	96.71	95.69	94.69	91.53	86.66
	14	96.13	95.04	94.01	90.12	84.27
650 rpm (14.3 m/s)	6	98.53	97.64	96.73	93.55	88.95
	8	98.44	97.33	96.57	92.93	88.58
	10	98.39	97.18	96.30	92.35	87.85
	12	97.86	96.53	95.14	91.83	86.55
	14	97.52	96.13	94.74	90.76	84.85
750 rpm (16.5 m/s)	6	98.82	97.57	97.09	95.19	89.05
	8	98.67	97.36	96.86	94.09	88.06
	10	98.42	97.19	96.34	93.13	87.25
	12	98.04	97.15	95.75	92.08	86.52
	14	97.87	96.93	95.13	90.62	85.51
850 rpm (18.7 m/s)	6	99.70	98.20	97.14	92.31	91.20
	8	99.14	97.62	96.91	91.17	89.86
	10	98.60	97.57	96.55	90.22	88.35
	12	98.48	97.43	96.01	89.51	87.12
	14	98.16	97.08	95.35	88.53	86.12
909 rpm (20 m/s)	6	99.71	98.23	97.57	94.26	92.24
	8	99.43	98.05	97.14	93.64	91.98
	10	98.79	97.92	96.48	93.11	91.39
	12	98.62	97.57	96.16	92.53	90.57
	14	98.49	97.36	95.84	91.55	89.31

APPENDIX I

Measured values of cleaning efficiency for Samsoy-2 soybean variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Cleaning Efficiency (%)				
		10.8 % Moisture	12.2 % Moisture	13.5 % Moisture	14.6 % Moisture	15.4 % Moisture
550 rpm (12.1 m/s)	4	93.55	92.18	91.25	82.19	77.01
	6	92.23	91.39	90.25	81.58	75.81
	8	91.74	90.76	89.08	80.39	74.01
	10	90.61	89.41	88.49	79.34	73.25
	12	89.31	88.41	87.59	78.32	72.34
650 rpm (14.3 m/s)	4	94.25	93.05	92.47	83.41	78.21
	6	93.27	92.24	91.27	82.15	76.99
	8	92.55	91.21	90.19	81.19	75.32
	10	91.31	90.09	89.49	80.39	74.11
	12	90.31	89.19	88.47	79.19	73.07
750 rpm (16.5 m/s)	4	95.07	94.06	93.21	84.32	78.31
	6	94.06	93.11	92.04	83.07	77.02
	8	93.13	92.11	91.05	82.09	76.23
	10	92.34	91.38	90.07	81.09	75.06
	12	91.10	90.21	89.31	80.01	74.14
850 rpm (18.7 m/s)	4	96.15	95.07	94.06	85.19	80.11
	6	95.18	94.10	93.13	84.25	78.24
	8	94.16	93.44	92.19	83.30	77.23
	10	93.82	92.48	91.26	82.09	76.06
	12	92.09	91.13	90.59	81.20	75.22
909 rpm (20 m/s)	4	97.26	96.28	95.28	86.11	82.21
	6	96.09	95.24	94.03	85.02	79.91
	8	95.09	94.18	93.11	84.01	78.40
	10	94.14	93.09	92.05	83.10	77.11
	12	93.13	92.45	91.33	82.07	76.10

APPENDIX J

Measured values of scattered grain loss for SOSAT C88 millet variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Scattered Grain Loss (%)				
		10.6 % Moisture	11.9 % Moisture	13.2 % Moisture	14.3 % Moisture	15.8 % Moisture
550 rpm (12.1 m/s)	6	11.11	10.93	10.52	7.87	6.79
	8	11.05	10.87	10.46	7.66	6.73
	10	11.02	10.77	10.41	7.51	6.27
	12	10.88	10.67	10.32	7.19	6.09
	14	10.87	10.36	10.02	7.05	5.77
650 rpm (14.3 m/s)	6	11.21	11.06	10.66	7.97	6.86
	8	11.27	10.98	10.57	7.78	6.81
	10	11.19	10.89	10.60	7.65	6.49
	12	10.97	10.75	10.43	7.35	6.28
	14	10.93	10.55	10.33	7.22	6.04
750 rpm (16.5 m/s)	6	11.54	11.22	10.81	8.12	7.06
	8	11.51	11.22	10.71	8.01	7.09
	10	11.41	11.08	10.69	7.88	6.85
	12	11.38	11.01	10.67	7.70	6.82
	14	11.24	10.76	10.47	7.63	6.42
850 rpm (18.7 m/s)	6	11.81	11.53	11.08	8.4	7.52
	8	11.73	11.45	10.99	8.36	7.49
	10	11.68	11.34	11.13	8.25	7.23
	12	11.37	11.16	10.94	8.11	7.06
	14	11.42	11.05	10.82	7.94	6.77
909 rpm (20 m/s)	6	12.18	11.94	11.57	8.97	8.04
	8	12.03	11.89	11.45	8.76	7.91
	10	11.88	11.52	11.19	8.36	7.61
	12	11.64	11.43	11.11	8.37	7.53
	14	11.63	11.39	10.96	8.24	7.28

APPENDIX K

Measured values of scattered grain loss for Samsoy-2 soybean variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Scattered Grain Loss (%)				
		10.8 % Moisture	12.2 % Moisture	13.5 % Moisture	14.6 % Moisture	15.4 % Moisture
550 rpm (12.1 m/s)	4	5.31	5.08	4.81	2.49	2.1
	6	4.83	4.66	4.46	2.36	1.87
	8	4.56	4.33	4.21	2.28	1.72
	10	4.43	4.28	4.13	2.06	1.62
	12	4.25	4.15	4.05	1.92	1.54
650 rpm (14.3 m/s)	4	5.57	5.35	5.01	2.65	2.31
	6	5.08	4.86	4.63	2.42	2.03
	8	4.89	4.58	4.32	2.32	1.79
	10	4.55	4.42	4.08	2.16	1.72
	12	4.44	4.24	3.91	2.02	1.58
750 rpm (16.5 m/s)	4	5.94	5.64	5.23	2.92	2.54
	6	5.54	5.16	4.94	2.62	2.28
	8	5.29	4.84	4.46	2.51	2.09
	10	4.83	4.51	4.18	2.31	1.94
	12	4.63	4.26	3.72	2.13	1.78
850 rpm (18.7 m/s)	4	6.54	6.11	5.72	3.44	2.83
	6	5.95	5.63	5.41	3.09	2.57
	8	5.56	5.15	4.93	2.84	2.28
	10	4.99	4.67	4.49	2.44	2.11
	12	4.71	4.44	4.23	2.23	1.9
909 rpm (20 m/s)	4	7.25	6.85	6.19	4.03	3.44
	6	6.65	6.29	5.67	3.78	3.07
	8	6.14	5.48	5.09	3.34	2.87
	10	5.42	4.85	4.58	2.91	2.49
	12	4.89	4.48	4.25	2.33	2.05

APPENDIX L

Measured values of grain damage for SOSAT C88 millet variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Grain Damage (%)				
		10.6 % Moisture	11.9 % Moisture	13.2 % Moisture	14.3 % Moisture	15.8 % Moisture
550 rpm (12.1 m/s)	6	0.04	0.020	0.010	0.41	0.47
	8	0.03	0.020	0.010	0.40	0.45
	10	0.02	0.010	0.010	0.38	0.43
	12	0.02	0.010	0.010	0.36	0.42
	14	0.01	0.001	0.001	0.35	0.40
650 rpm (14.3 m/s)	6	0.06	0.040	0.010	0.44	0.49
	8	0.04	0.020	0.010	0.41	0.47
	10	0.02	0.010	0.010	0.39	0.46
	12	0.02	0.010	0.010	0.39	0.43
	14	0.01	0.001	0.001	0.37	0.41
750 rpm (16.5 m/s)	6	0.06	0.040	0.010	0.46	0.51
	8	0.05	0.030	0.010	0.42	0.49
	10	0.04	0.020	0.010	0.40	0.47
	12	0.03	0.010	0.010	0.40	0.46
	14	0.02	0.001	0.001	0.38	0.43
850 rpm (18.7 m/s)	6	0.11	0.080	0.020	0.51	0.58
	8	0.09	0.060	0.020	0.47	0.54
	10	0.07	0.050	0.010	0.43	0.51
	12	0.05	0.020	0.010	0.41	0.48
	14	0.04	0.010	0.001	0.39	0.45
909 rpm (20 m/s)	6	0.14	0.120	0.040	0.56	0.62
	8	0.12	0.100	0.040	0.51	0.58
	10	0.08	0.050	0.010	0.46	0.55
	12	0.07	0.030	0.010	0.42	0.51
	14	0.06	0.030	0.001	0.41	0.48

APPENDIX M

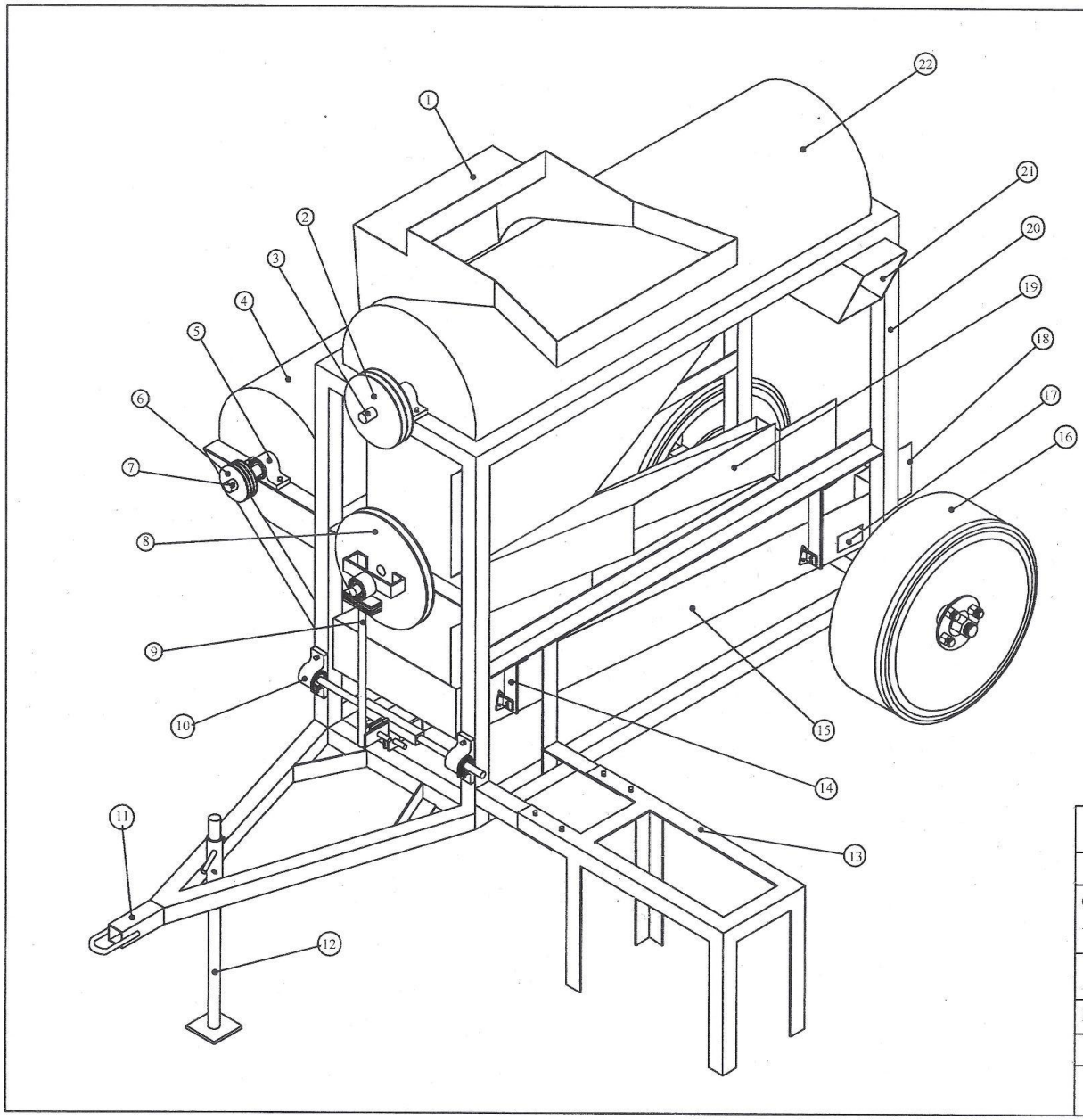
Measured values of grain damage for Samsoy-2 soybean variety at five levels of cylinder speed, feed rate and crop moisture content

Cylinder Speed (m/s)	Feed Rate (kg/min)	Grain Damage (%)				
		10.8 % Moisture	12.2 % Moisture	13.5 % Moisture	14.6 % Moisture	15.4 % Moisture
550 rpm (12.1 m/s)	4	0.04	0.030	0.020	0.4	0.6
	6	0.03	0.020	0.010	0.3	0.5
	8	0.02	0.010	0.010	0.2	0.4
	10	0.01	0.010	0.010	0.1	0.3
	12	0.01	0.001	0.001	0.1	0.2
650 rpm (14.3 m/s)	4	0.05	0.040	0.030	0.4	0.7
	6	0.04	0.030	0.020	0.3	0.6
	8	0.03	0.020	0.010	0.2	0.5
	10	0.02	0.010	0.001	0.2	0.4
	12	0.01	0.001	0.001	0.1	0.3
750 rpm (16.5 m/s)	4	0.06	0.050	0.030	0.5	0.8
	6	0.05	0.040	0.020	0.4	0.7
	8	0.04	0.030	0.010	0.3	0.6
	10	0.03	0.020	0.001	0.2	0.5
	12	0.02	0.010	0.001	0.1	0.4
850 rpm (18.7 m/s)	4	1.00	0.800	0.500	1.5	2.0
	6	0.80	0.600	0.400	1.2	1.7
	8	0.60	0.400	0.300	1.0	1.5
	10	0.40	0.300	0.200	0.8	1.3
	12	0.30	0.200	0.100	0.6	1.1
909 rpm (20 m/s)	4	1.60	1.200	0.800	2.2	6.0
	6	1.40	1.000	0.700	2.0	5.5
	8	0.80	0.600	0.500	1.8	5.0
	10	0.60	0.400	0.300	1.6	4.5
	12	0.40	0.300	0.200	1.4	4.0

APPENDIX N

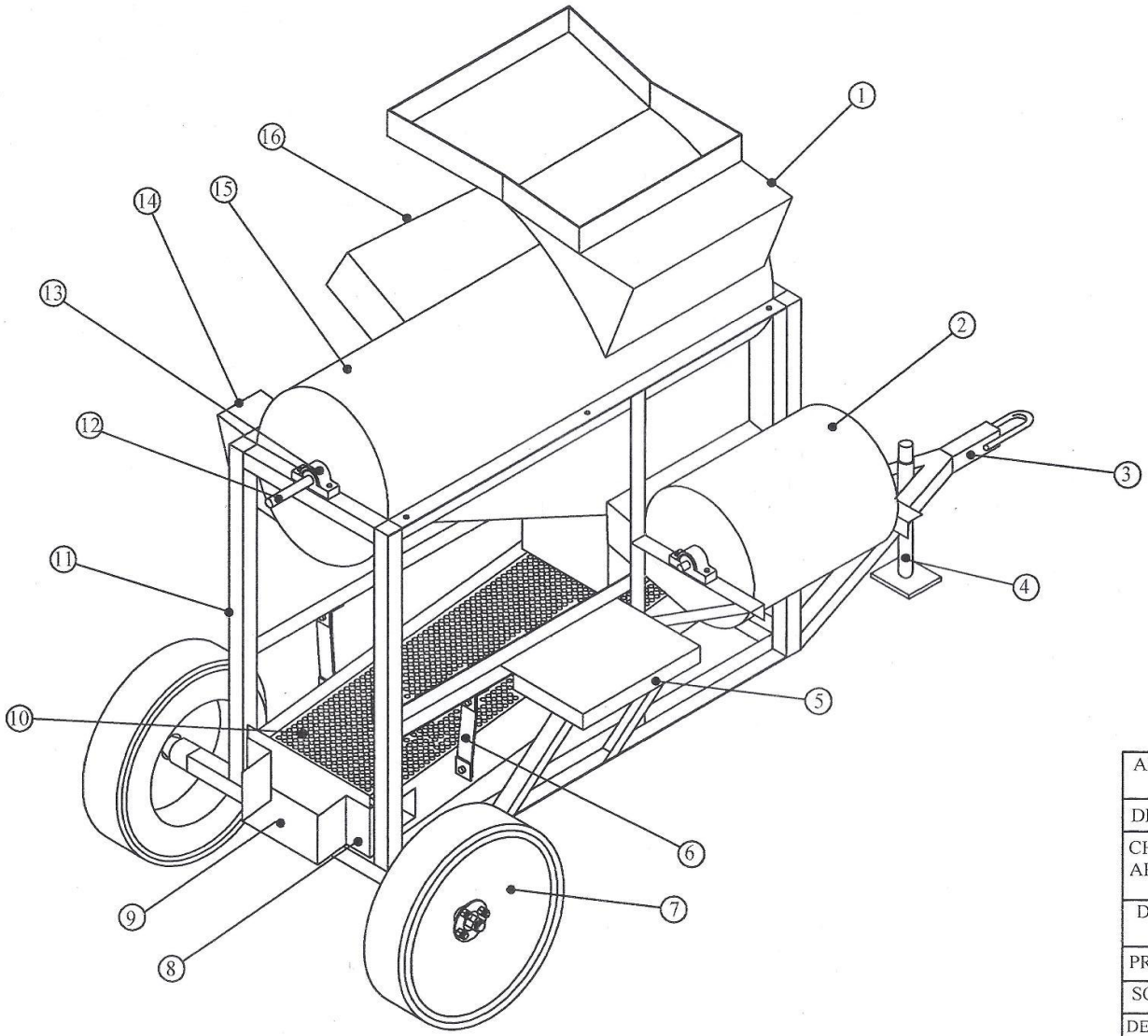
Measured and predicted threshing efficiencies of the machine

Measured E_T	Predicted E_T	Deviation	Measured E_T	Predicted E_T	Deviation
99.88	100.00	0.12	99.29	99.40	0.11
99.87	100.00	0.13	99.26	98.36	0.90
99.84	100.00	0.16	99.22	98.41	0.81
99.83	99.24	0.59	99.22	98.38	0.84
99.82	99.20	0.62	99.16	98.39	0.77
99.82	98.13	1.69	97.78	97.41	0.37
99.81	100.00	0.19	97.71	97.47	0.24
99.81	98.23	1.58	97.65	97.52	0.13
99.78	99.25	0.53	97.65	97.51	0.14
99.78	99.29	0.49	97.61	97.56	0.05
99.76	100.00	0.24	97.46	97.60	0.14
99.71	99.33	0.38	97.41	97.61	0.20
99.66	100.00	0.34	97.21	97.65	0.44
99.65	100.00	0.35	97.11	97.61	0.50
99.62	98.24	1.38	96.71	97.65	0.94
99.62	98.18	1.44	96.62	97.67	1.05
99.61	99.34	0.27	96.25	96.60	0.35
99.61	98.27	1.34	96.06	96.70	0.64
99.54	98.32	1.22	96.02	96.65	0.63
99.49	98.31	1.18	95.91	97.65	1.74
99.44	100.00	0.56	95.86	96.74	0.88
99.44	99.37	0.07	95.82	96.71	0.89
99.41	98.36	1.05	95.66	96.78	1.12
99.41	100.00	0.59	95.63	96.79	1.16
99.39	100.00	0.61	95.38	96.83	1.45
99.37	99.37	0.00	95.35	96.83	1.48
99.35	99.40	0.05	95.01	96.86	1.85
99.34	100.00	0.66	94.57	96.86	2.29
99.31	99.42	0.11	94.02	96.88	2.86



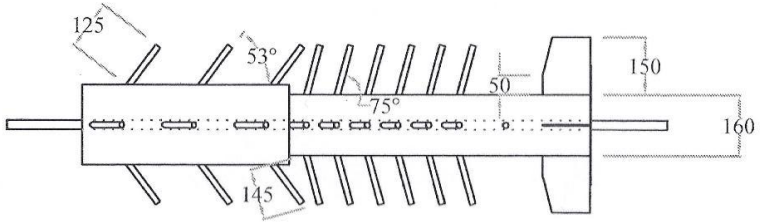
S/N	PART NAME
1	HOPPER
2	CYLINDER PULLEY
3	CYLINDER SHAFT
4	BLOWER CASING
5	BLOWER BEARING
6	BLOWER BEARING
7	BLOWER SHAFT
8	SHACKER PULLEY
9	CONNECTING ROD
10	SHAKER BEARING
11	TOW BAR
12	MACHINE STAND
13	ENGINE SEAT
14	SHAKER SUPPORT
15	SHAKER TRAY
16	REAR WHEEL
17	SHAKER CHAFF OUTLET
18	GRAIN OUTLET
19	BLOWER CHAFF OUTLET
20	MACHINE FRAME
21	TOP CHAFF OUTLET
22	THRESHING CHAMBER

APPENDIX O1	ISOMETRIC VIEW OF THE THRESHER (FRONT SIDE)
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	

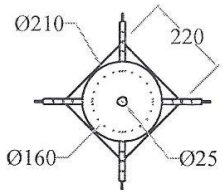


S/N	PART NAME
1	HOPPER
2	BLOWER CASING
3	TOW BAR
4	MACHINE STAND
5	OPERATOR'S STAND
6	SHACKER SUPPORT
7	REAR WHEEL
8	SHAKER TRAY
9	GRAIN OUTLET
10	BOTTOM SIEVE
11	MACHINE FRAME
12	CYLINDER SHAFT
13	CYLINDER BEARING
14	TOP CHAFF OUTLET
15	THRESHING DRUM COVER
16	BLOWER CHAFF OUTLET

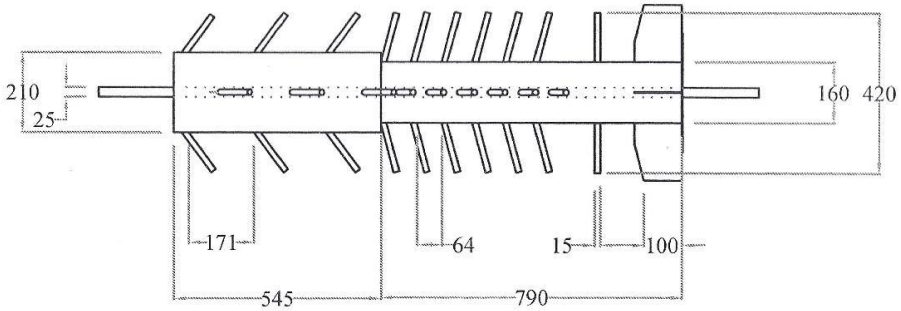
APPENDIX O2	ISOMETRIC VIEW OF THE THRESHER (REAR SIDE)
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



FRONT VIEW

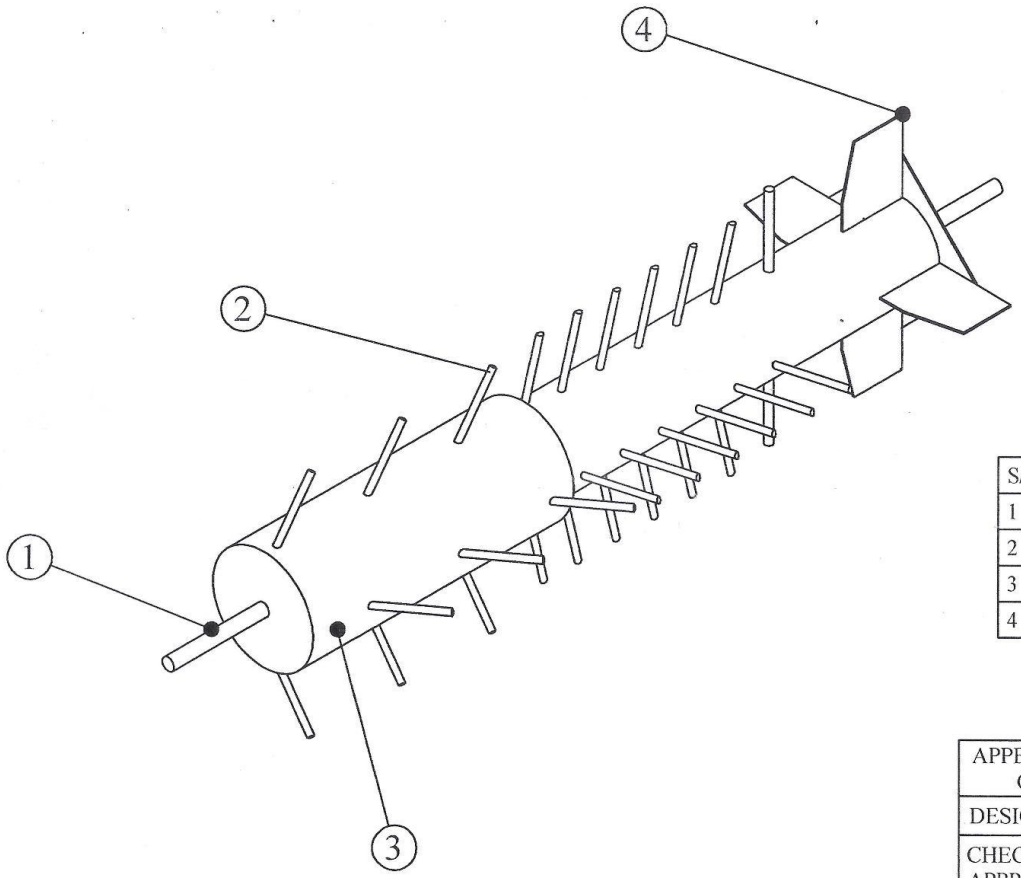


END VIEW



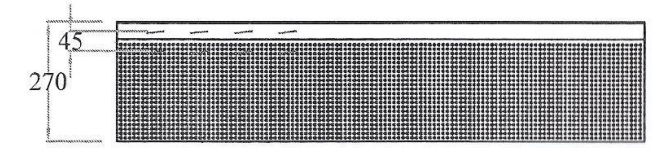
PLAN

APPENDIX O3	ORTHOGRAPHIC PROJECTION OF THE THRESHING CYLINDER
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	

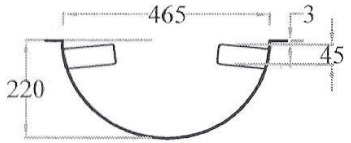


S/N	PART NAME
1	SHAFT
2	BEATER
3	THRESHING CYLINDER
4	CHAFF THROWER

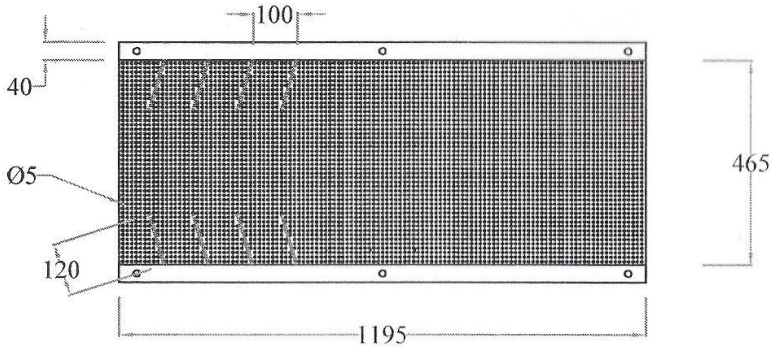
APPENDIX O4	ISOMETRIC VIEW OF THE THRESHING CYLINDER
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



FRONT VIEW

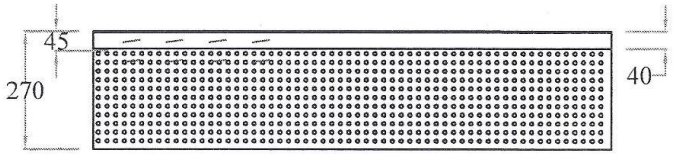


END VIEW

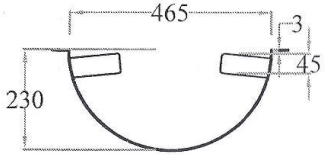


PLAN

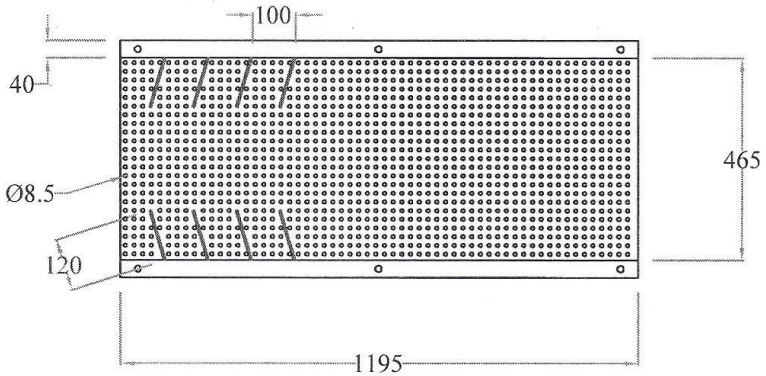
APPENDIX O5	ORTHOGRAPHIC PROJECTION OF THE MILLET TOP SIEVE
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



FRONT VIEW

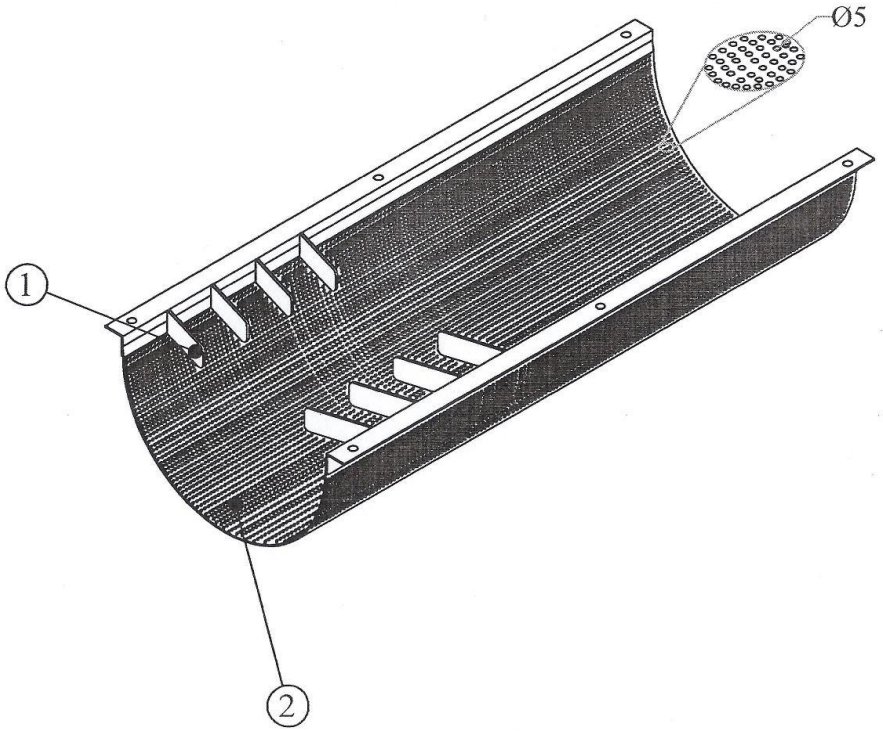


END VIEW



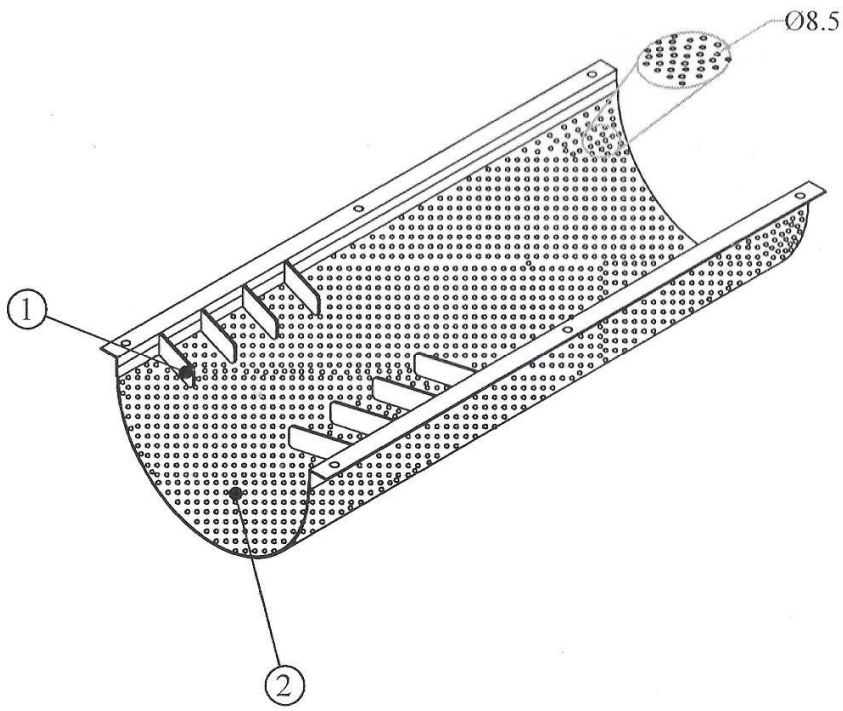
PLAN

APPENDIX O6	ORTHOGRAPHIC PROJECTION OF THE SOYBEAN TOP SIEVE
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



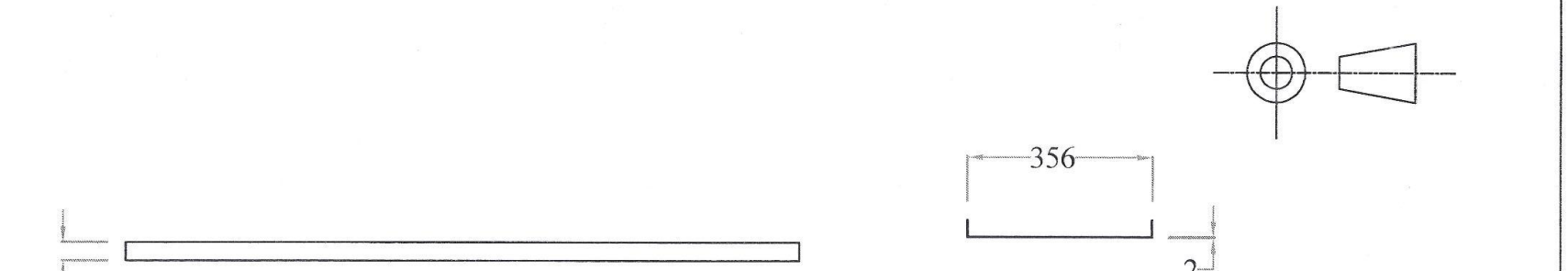
S/N	PART NAME
1	CUTTING KNIFE
2	SIEVE HOLE

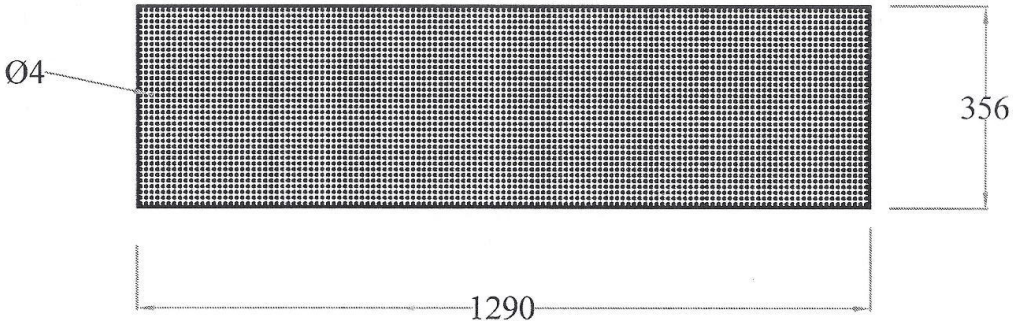
APPENDIX O7	ISOMETRIC VIEW OF THE TOP SIEVE USED FOR MILLET
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



S/N	PART NAME
1	CUTTING KNIFE
2	SIEVE HOLE

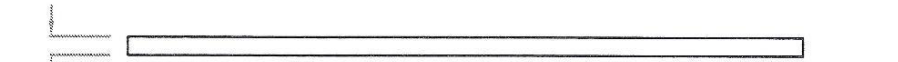
APPENDIX O8	ISOMETRIC VIEW OF THE TOP SIEVE USED FOR SOYBEAN
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



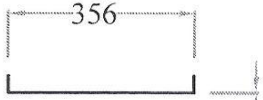


PLAN

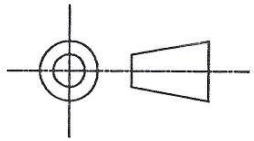
APPENDIX O9	ORTHOGRAPHIC PROJECTION OF THE BOTTOM SIEVE FOR MILLET
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	

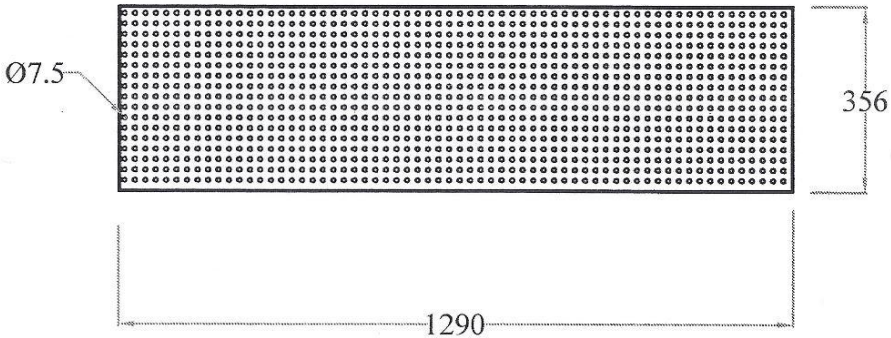


FRONT VIEW



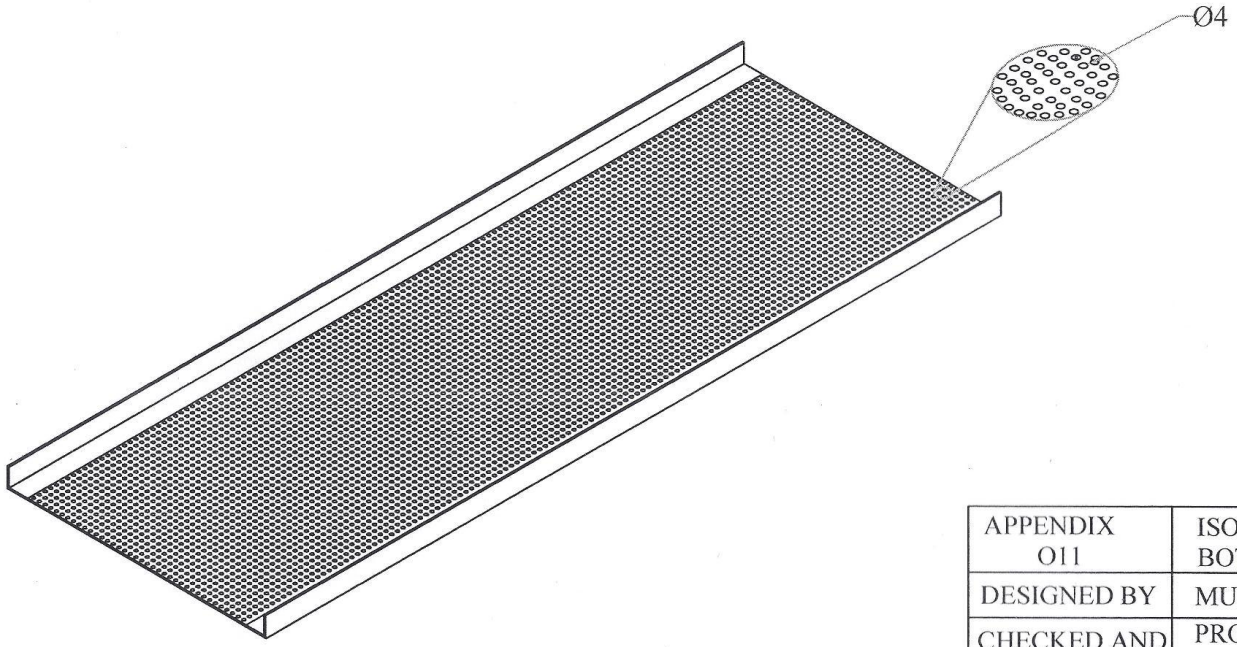
END VIEW



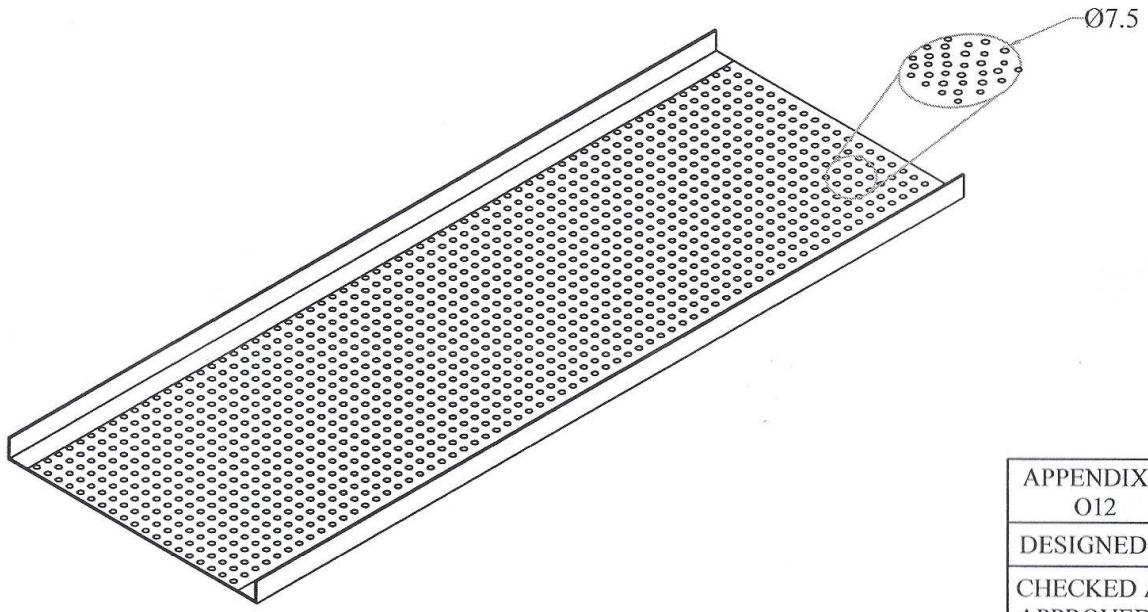


PLAN

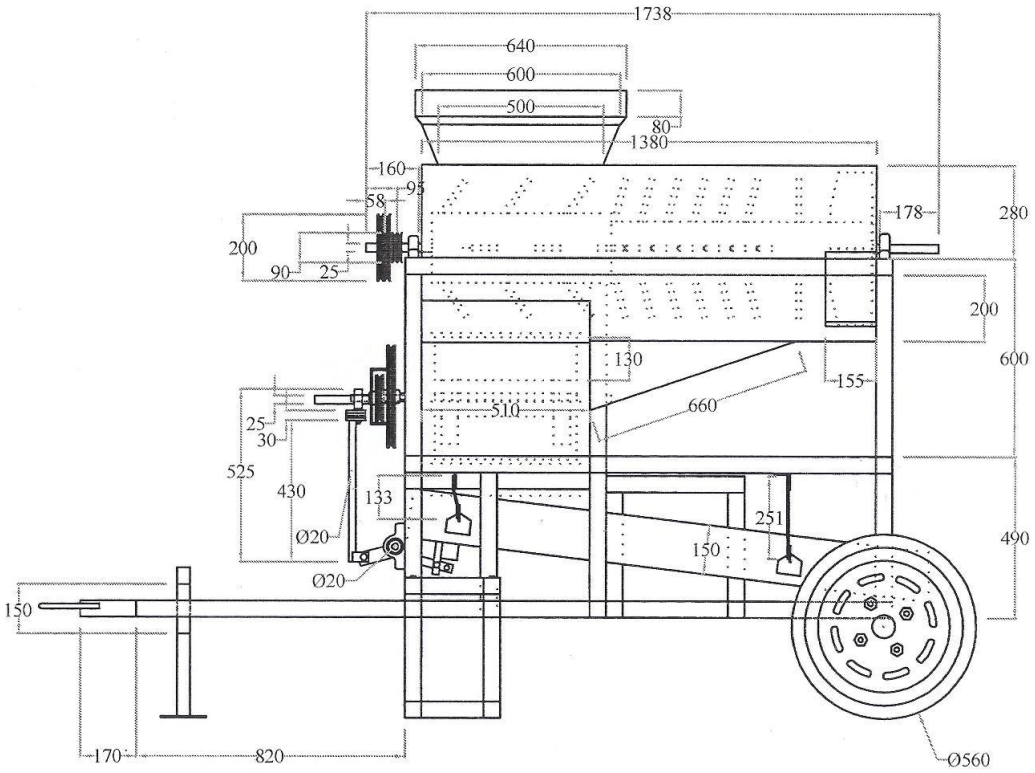
APPENDIX O10	ORTHOGRAPHIC PROJECTION OF THE SOYBEAN BOTTOM SIEVE
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



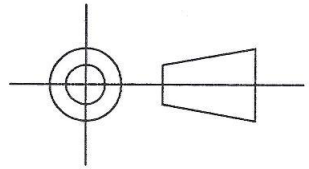
APPENDIX O11	ISOMETRIC VIEW OF THE BOTTOM SIEVE FOR MILLET
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



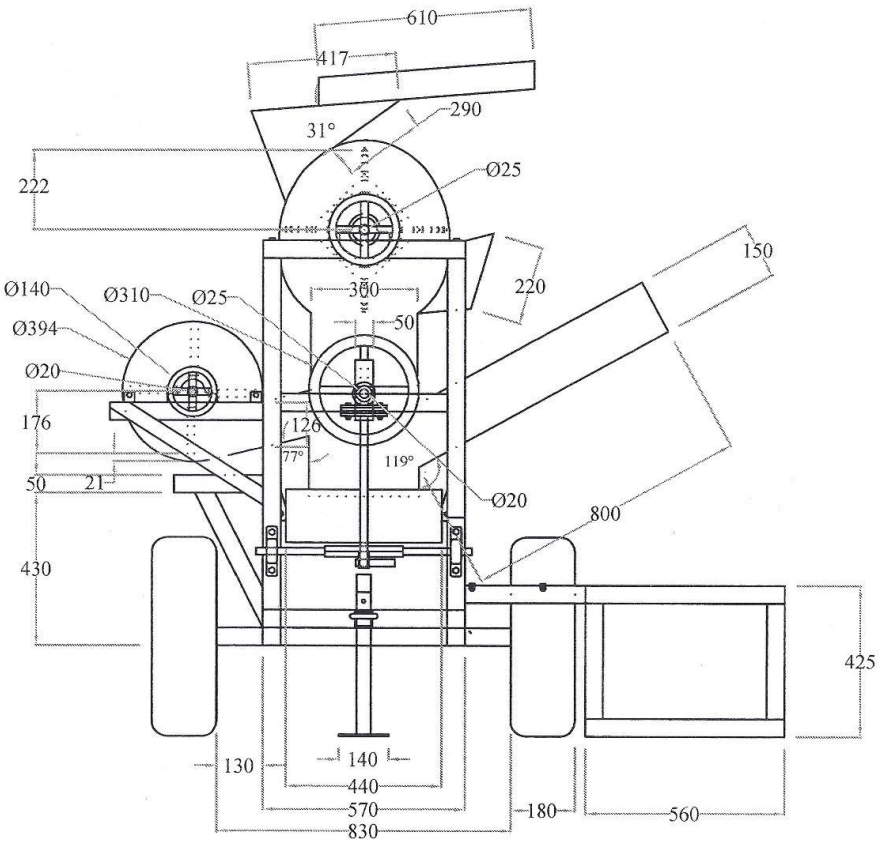
APPENDIX O12	ISOMETRIC VIEW OF THE BOTTOM SIEVE FOR SOYBEAN
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



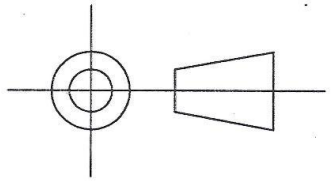
FRONT VIEW



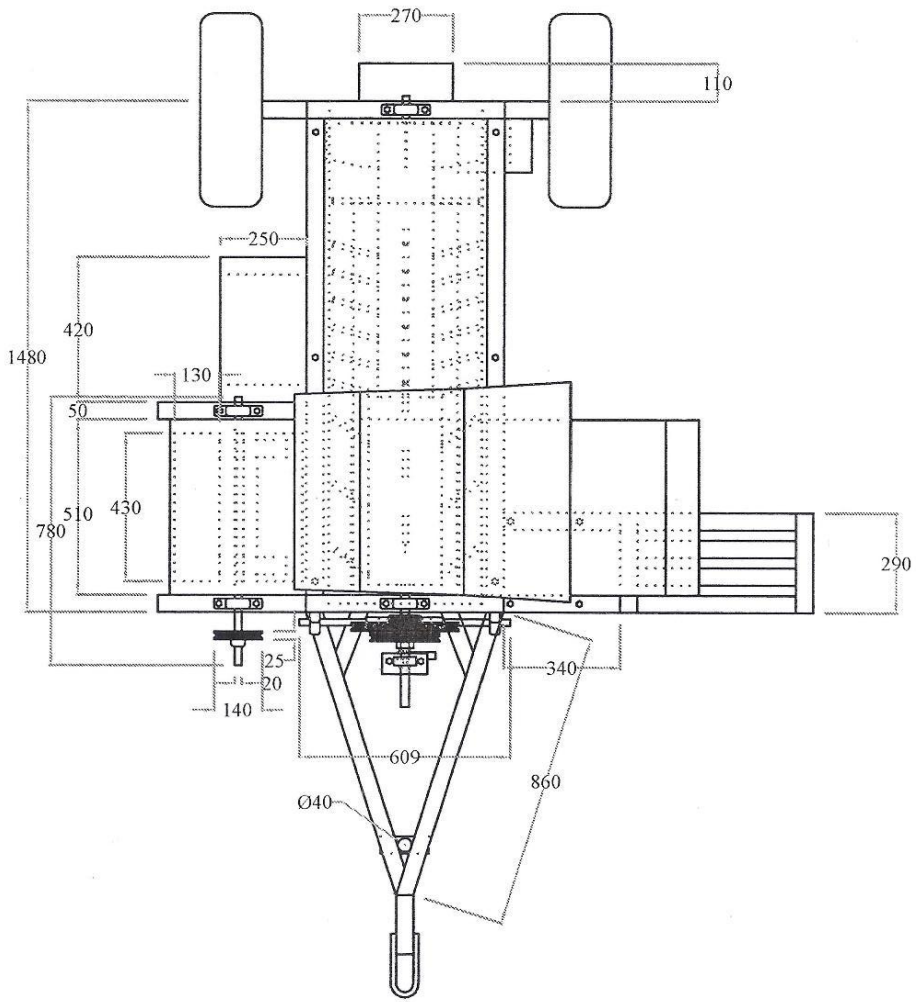
APPENDIX O13	FRONT VIEW OF THE MULTICROP THRESHER
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



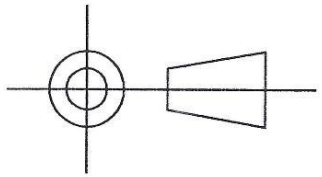
END VIEW



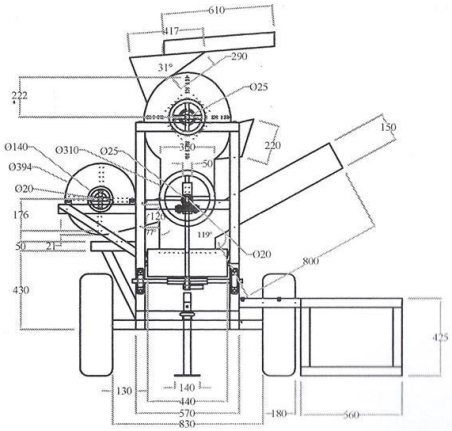
APPENDIX O14	END VIEW OF THE MULTICROP THRESHER
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



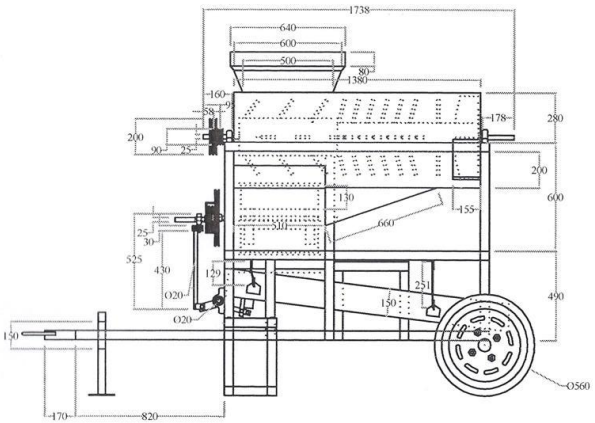
PLAN



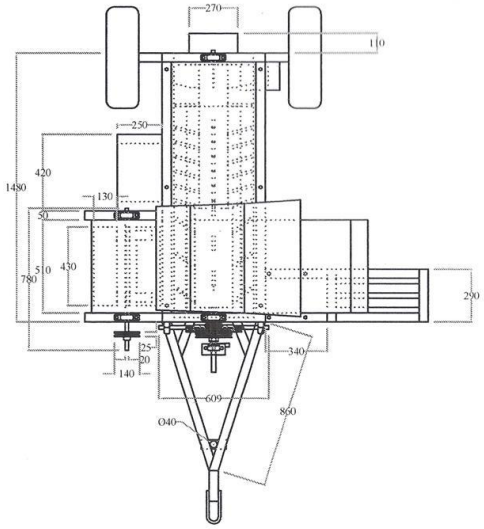
APPENDIX O15	PLAN OF THE MULTICROP THRESHER
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	



END VIEW



FRONT VIEW



PLAN

APPENDIX O16	ORTHOGRAPHIC PROJECTION OF THE MULTICROP THRESHER
DESIGNED BY	MUNA NYAMBI HUMPHRED
CHECKED AND APPROVED BY	PROF. U.S. MUHAMMED PROF. A.M.I. EL-OKENE PROF. M. ISIAKA
DEPARTMENT OF AGRICULTURAL ENGINEERING AHMADU BELLO UNIVERSITY, ZARIA	
PROJECTION	1st ANGLE
SCALE	1:10
DEVELOPMENT AND OPTIMIZATION OF THE THRESHING PERFORMANCE OF A MULTICROP THRESHER	