

**DEVELOPMENT AND EVALUATION OF AN EQUIPMENT FOR
THRESHING AND CLEANING LEGUME CROPS**

**ADEWUMI, Babatunde Adewale
AGE/98/1238**



**A THESIS IN THE DEPARTMENT OF AGRICULTURAL ENGINEERING
SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY
SUBMITTED TO THE SCHOOL OF POST GRADUATE STUDIES
FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE.**

**IN FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF
DOCTOR OF PHILOSOPHY (Ph. D) IN AGRICULTURAL ENGINEERING
(CROP STORAGE AND PROCESSING OPTION)
THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE.**

JANUARY, 2005

DEDICATION

This work is dedicated to the triune God (The Father, Son and Holy Spirit) who is the creator and source of all wisdom.

Secondly, it is dedicated to all who are toiling and working hard to ensure a break-through in post-harvest technology in Nigeria.



CERTIFICATION

This is to certify that Engr. B. A. Adewumi carried out this research work for the award of Ph.D. in Agricultural Engineering (Crop Storage and Processing Option), in the Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria.



 10/2/05

Engr (Prof) O. C. Ademosun (FNSE, FNIAE)
Professor of Agricultural Engineering (Power and Machinery)
Major Supervisor

 10/2/05

Engr (Prof) A. S. Ogunlowo (FNSE, FNIAE)
Professor of Agricultural Engineering (Power and Machinery)
Co-Supervisor

 10/2/05

Engr (Prof) A. S. Ogunlowo (FNSE, FNIAE)
Head, Department of Agricultural Engineering, Federal University of Technology,
Akure, Nigeria.

ACKNOWLEDGEMENT

This work would not have been successful and completed without the support of God, and some men and women. Foremost, I thank God for providing me with guidance and inspiration during the course of the research. I was terribly ill during one of the critical stages of the research. But, God healed me (Ps 103:1 – 5). To God be the glory.

I appreciate the immense contributions of my major supervisor (Prof. O. C. Ademosun) and my co supervisor and Head of Department (Prof. A. S. Ogunlowo). Their positive criticisms, suggestions and supervisory roles are superior. The support and encouragement given to me by all the staff of the department are acknowledged. I express my unreserved appreciation especially to the following staff of the department for their contributions to the success of the research:

- Prof. A. A Olufayo, Dr. A. E Ajayi, and Dr. P. G. Oguntunde for assisting me to acquire literatures from libraries when they travelled abroad. Dr Ajayi equally assisted during the preparation of the power point for the oral presentations.
- Mr A. Adesina for his full participation in the fabrication and assembly of the machine and his contributions during machine testing.
- Mr Davis, Mr. Gbenga Jimoh, Mr. I. D. Ifelola and Mr Akinpelu for participating at some stages during machine fabrication.
- Dr. (Pastor) M. O. Alatise, Dr (Pastor) O.J. Olukunle, Engr (Pastor) O. Odubango and Pastor Omotoyinbo for their counsel, support and prayers during the research.
- Dr L. A. S Agbetoye Dr O. J. Olukunle for assisting in proof reading this report.

I am very grateful to the Dean of the School of Engineering and Engineering Technology, Prof C. O. Adegoke, for his counsels and moral support. I am indebted to

the management of the University Teaching and Research Farm (Crop Unit) for supporting me to propagate my seeds and store the pods. I specifically thank Pastor Fagbemi (the erstwhile Farm Manager, now retired), Dr Aladesanwa (also a former Acting Farm Manager), and Mr Fadimiroye.

I sincerely thank Mr. B. J. Abiodun of the Department of Meteorology (FUTA) for providing the Metlab software used for developing the numerical aerodynamic model for particle trajectories in the cleaning chamber. I also thank Dr. Olowofeso of the Department of Mathematical Sciences (FUTA), and Mr Sumola of the University Computer Centre for assisting in the statistical analysis of my experimental data. Dr Olowofeso introduced S-Plus Harvard Professional 3.0 softwares to me. I appreciate all the efforts and assistance provided by Mr Tunde and Mr Oloro of the University Library during the experimental work to establish the particle trajectory. I am grateful to Prof Adekoya of Geology Department who provided regular encouragement and moral support.

I acknowledge Engr. Kolawole and Engr. Abimbola of the International Institute of Tropical Agriculture (I.I.T.A) for assisting me to acquire literatures and the seeds propagated for the preliminary experimental study. I thank Prof. K. Oje. of the Agricultural Engineering Department (University of Ilorin) for giving useful suggestions that assisted in the research. Mr Kalejaiye of the Meteorology Department, FUTA, is appreciated for providing me with wind meter.

I sincerely appreciate the spiritual counsel and prayers of Pastor S. O. Adejumo (now in Cote de I'Voire), Pastor Dayisi Akinyelu (now in Siera-Leone) and Pastor F. K. Oguntuyi (the current Ondo State Overseer), all of the Deeper Christian Life Ministry. I appreciate the members of the prayer group (FUTA) namely Dr J. A. Ajayi, Prof . L. Lajide, Dr S. O. Akindele, Dr Z. O Adeyewa, Dr Okunlola, Dr Babatola and Prof. A. A. Olufayo who always provide warmth and prayer support.

I sincerely acknowledge the motivation and selfless assistance rendered to me by the Head of Quantity Survey Department, Dr Ogunsemi, and his office staff during the editing of the final manuscript. I equally thank Sister Kemi Akeju, Mrs Olubunmi Musa Mrs Moyinoluwa Adekunle, Mrs Ediale, Sister Ruth, Miss Donatus and Sister Yemi who participated in the typing of the thesis. I acknowledge my cousins, Bisoye Aderibigbe and Dapomola Adekoya who assisted me during the experimental stage and the period I was editing the final write up respectively. I thank my brother Adesegun Adewumi, and my students namely: Odunbaku, and Hazzan for assisting me during the experimental stage. I strongly appreciate Dr. and Mrs. Ojo (Medical Director, Ayo Specialist Hospital, Akure) and Dr and Mrs. Odetola (Medical Director, St. David Hospital, Akure) for the moral support and medical attentions, and the prayers they have always offered. They remain my bosom family friends.

Finally, I am very grateful to my darling wife Olajumoke Olusola, and my two lovely children, Adebayo and Adeife for giving all the encouragement and support I ever needed to be a successful man.

Engr. B. A. Adewumi



ABSTRACT

The threshing of legume grains is particularly important because the output from the thresher will, to a great extent, affect the subsequent processes and the final quality of the product. A number of equipment developed for cereal threshing which are adapted for legume threshing in African countries are mostly imported. A lot of such machines have not performed well because of poor adaptation. Therefore an equipment for threshing and cleaning soft-coated legumes (such as cowpea, pigeon pea, and soybean), incorporating a cross flow air stream, was designed and fabricated. It is made up of the conveyor, threshing and cleaning units. Power transmission is achieved with belt-pulley arrangements. The conveyor, threshing unit, transmission system and the centrifugal fan were designed using the conventional design analysis but the aerodynamic theory of separation proposed by Gorial and O'Callaghan (1991 a and b) was modified and utilized for the design of the separation chamber.

A theoretical aerodynamic model for predicting particle trajectory in a horizontal airflow was developed during the study using the 'matlab' software. The trajectory model was used for the determination of the dimensions of the cleaning chamber, hence, a design guide. The model incorporates the effect of air velocity, air direction and the terminal velocity of particle on particle trajectory.

Preliminary experiments were conducted to determine the physical properties of three varieties of cowpea (IT 812 – 994, IT 810 – 994 and Ife Bimpe) and one variety of soybean (TGX 448 – 2E). The data obtained were reported in the write-up and used for the design of the equipment. From the design analysis, the conveyor unit with a capacity of 350 kg h^{-1} could move product through a height of 2.20 m and has a maximum power rating of 650 W. The threshing drum has a diameter of 460 mm and length of 995 mm and requires a maximum power of 1.25 kW to achieve threshing. The

centrifugal fan requires a maximum drag force of 72.5 N and power rating of 787 W to clean threshed product discharged at 3.69 kgs^{-1} . It also requires fan pressure and airflow rate of 843.30 Nm^{-2} and $3.25 \text{ m}^3\text{s}^{-1}$ respectively. The cleaning chamber has a maximum of 1.30 m vertical and 0.99 m horizontal dimensions.

Cowpea (Ife bimpe variety) was used for the performance evaluation of the equipment at a conveyor speed of 400 rpm, threshing speed of 600 rpm, fan speeds of 900 and 1,500 rpm, fan angles of inclination of 90, 105 and 120° , concave clearance of 20 mm, pod moisture contents (PMC) of 14.0, 18.0 and 22.0% (wet basis) and corresponding grain moisture content (GMC) of 15.3, 17.2, and 18.8% (wet basis). A wire loop threshing mechanism were also used for the evaluation. A particle dynamics study was conducted using a high speed video camera to verify the feasibility of classifying cowpea grains into size grades. The materials deposited on the trays of the cleaning chamber were collected and the spread patterns of the materials were analysed and evaluated by plotting the percentage frequency distribution curve using the S-Plus and Harvard Professional 3.0 soft wares. The characteristics (axial dimensions and percentage composition) of the materials loaded into the various units of the equipment were determined.

The whole seeds had a mean dimension of 7.64, 6.35 and 4.35 mm for big, medium and small size respectively. The pod content of the cowpea loaded into the conveyor and threshing units ranged between 60 and 72% for the three pod moisture contents. The whole seed content ranged between 20 and 22% , while the damaged seeds ranged between 8 and 19% for the three levels of PMC. The damaged done to the seeds before threshing was due to insect infestations, deliberately allowed to ensure a wide range of variety of seed weight and terminal velocity.

The conveyor efficiency of the equipment ranged between 56.9% to 74.0%, 53.2% to 73.9% and 60.1% to 79.1% for PMC of 14.0%, 18.0%, and 22.0%

respectively with mean values of 64.6% 66.2%, and 70.3%. The threshing efficiency of the equipment also ranged from 67.5% to 97.7%, 71.1% to 94.4%, and 83.1% to 97.0% for same PMC. There is significant difference in the conveyor efficiency and threshing efficiency of the equipment at the various PMC for 95% and 99% levels of confidence. This is as a result of the adsorption nature of moisture change from 14.0% to 22.0%. It was inferred from the spread pattern that the cleaning unit is most effective for GMC of 15.3%, fan speed of 900 rpm and fan angle of inclination of 90° and 105°

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The following symbols are used in text:

1 Latin Alphabets

a = major diameter (mm)

a = acceleration (ms^{-2})

A_p = projected area (m^2)

b = minor diameter (mm)

c = thickness (mm)

C_n = apparent weight correction Cn/Mt

C_D or C_d = drag coefficient

C_G = weight term

C_H = pressure head coefficient

C_P = power coefficient

C_R = coefficient of resistance

D = diameter (m)

d = geometric mean diameter (m)

D_d = duct diameter (m)

d_e = equivalent diameter (m)

D_p = average diameter of particle (m)

dt = change in time (s)

dV_p = change in particle velocity (ms^{-1})

F = Force (N)

F_{cy} , F_{cx} = Collusion forces in y and x directions respectively

F_d = drag force (N)

F_f = Frictional Force (N)

f_f = friction coefficient between the particle and wall of coefficient of friction resistance

$F_{f\omega}$ = frictional force (N)

F_g = gravitational force (N)

F_L = lift force (N)

F_p = friction factor of fluid

f_p = particle friction coefficient

F_p = pressure gradient force (N)

g = acceleration due to gravity (ms^{-2})

$\dot{Q}_B$ = bulk flow rate of particles (kg s^{-1})
 GMC = grain moisture content (%)
 L_p = length of particle (m)
 M = mass of particle (kg)
 N = rotational speed (rpm or rps)
 N_c = Convey or speed (rpm)
 P_d = power required to drive the drum (W)
 P_{imp} = kinetic power as a result of the impact of peg on the crop capacity (W)
 PMC = pod moisture content (%)
 P_t = power required to thresh (W)
 R = elbow radius
 Re = Reynolds number
 S = conveyor speed (ms^{-1})
 S = cylinder speed (ms^{-1})
 T = belt tension (N)
 V_a = velocity of air (ms^{-1})
 V_i = injection velocity, m s^{-1}
 V_p = particle velocity (ms^{-1})
 V_r = relative velocity of particle, ms^{-1}
 V_{ry} = relative velocity of particle to air in y-direction ms^{-1}
 V_T = Terminal Velocity (m/s)
 W, F_w = weight (N)
 x = distance of particle travel in x-direction (m)
 y = distance of particle travel in y-direction (m)
 Z = volume shape factor

2 Greek Alphabets

ρ_a = fluid density (kg m^{-3})
 ψ = surface sphericity
 α = angle of inclination between the axis of the injection conveyor and the direction of air flow
 (n) = net resistance coefficient
 ρ_p = particle density (kg m^{-3})
 ρ_B = bulk density of particle, (kg m^{-3})

ℓ_a = air density (kg m^{-3})

ℓ_p, ℓ_s = specific densities of particle and air respectively (kgm^{-3})

μ = viscosity of fluid

CHAPTER ONE

INTRODUCTION

1.1 GRAIN THRESHING AND CLEANING

Threshing and cleaning of crops are essential processes required in order to make seeds available for planting and consumption. The efficiency of threshing and cleaning equipment will determine the quality and market value of seeds (Wang et al., 1994). Threshing machines therefore must handle the material carefully such that the level of grain damage is brought to the barest minimum.

The earliest methods of threshing involved the use of wood to beat material tied in a sack and allowing animals to trample on crops spread on a threshing floor. The threshing sledge or threshing roller drawn by animals was the earliest type of mechanical thresher developed. The development of hand and pedal operated threshers soon followed. The use of powered threshers was initiated in the eighteenth century when the combine harvester was invented (Weir, 1988).

The early types of stationary threshers were mostly made of wooden materials. They were used for paddy threshing. Those threshers mostly have wire loop mechanism, without concave and used for crops such as rice, sorghum, wheat, oat, and millet. Bunches of the straws from the crops were held against the wire loop mechanism while the grains were discharged by gravity. The early types of threshers did not incorporate a cleaning unit.

Impurities and contaminants were separated from sound grains during the cleaning process. Grain cleaning reduces the problems that occur during storage and handling. Clean grains save storage space and increase marketability. Separation and cleaning are achieved as a result of the differences in the size, density and terminal

velocity of the mixed product (Kulkarni, 1989). Cleaning of grains is mostly done using screen or pneumatic separator. Screen separation is mostly used to separate product on the basis of the differences in their sizes. Multi-screen separators are used for classifying grains to size grades. Some screen separators incorporate fan to remove light particles (Ogunlowo and Adesuyi, 1999) Screen separator include the rotary and the reciprocating types (Kulkarni, 1989; Ademosun, 1993).

Pneumatic separation occurs as a result of the differences in the aerodynamic properties of the mixed material to partition them into two major groups. Ogunlowo and Oladapo (1990) stated that air velocity (V_a) is selected such that it is between the terminal velocity of the grain (V_T) and that of the light material (V_{TL}). $V_{TL} < V_T$, $V_a < V_{TL}$ for separation to occur.

Pneumatic separators/cleaners are basically of two types namely the vertical air stream and horizontal air stream separators (Gorial and O'Callaghan, 1991a & b). In the vertical air stream separator, air stream is flowing vertically against the injected mixed product such that heavy particles (grains) drop through the air (counter current flow) while the light materials (chaff) move upward and are carried along by the air (concurrent flow). In the horizontal air stream separator, air is blown horizontally or at an inclined angle to the horizontal against mixed product injected along the vertical plane. The mixed product are displaced along the horizontal plane at various distances based on their aerodynamic properties (Gorial and O'Callaghan, 1991b).

Modern threshers incorporate cleaners or separators. The developed nations have been involved in the commercial production of powered threshers for more than fifty years ago. Countries such as Japan, China, Taiwan, India and Philippines are now producing various types of threshers on commercial level (IRRI, 2002). In Nigeria and other African countries, prototype threshers have been constructed in a

number of Research Institutions and Universities. Also, there are pockets of manufacturers producing threshers locally. Observations show that a number of the threshers produced locally still have a number of defects. This calls for more vigorous research to enhance the efforts of local manufacturers. Also, imported threshers are very expensive and beyond the reach of peasant farmers.

1.2 AIMS AND OBJECTIVES OF THE STUDY

The general objective of the study is to develop an equipment to enhancing local manufacturing of a commercial, adaptable and efficient threshing and cleaning equipment. It is also intended that the equipment could be used for particle dynamics study in cross flow air stream. The specific objectives of the study are to:

- a Develop a legume threshing equipment incorporating a cross flow air stream cleaner/separator.
- b Evaluate the performance of the equipment using cowpea.
- c Grade and classifying the seeds in a cross flow air stream using the equipment developed.
- d Identify to some extent, seeds –seeds behavior in the separator or cleaner.

1.3 JUSTIFICATION OF THE STUDY

Legume research is highly relevant to the developing countries because grain legumes or pulses are important foodstuff in the tropical and subtropical countries. They are second in importance to cereal and are ready sources of plant protein. The threshing of grain legumes is particularly important because the output from the

thresher will, to a great extent, affect the subsequent processes and the final quality of the product.

A number of equipment developed for cereal threshing which are adapted for legume threshing in African countries are mostly imported. A lot of such machines have not performed well or as expected because of poor adaptation. Also, some of the equipment developed within Africa for legume threshing need to be improved for optimum performance. Hence, the need for this study.

Air stream is commonly used for separating chaff and pod from grains but it is rarely used for grain grading. Farran and Macmillan (1979), and Gorial and O'Callaghan (1991a) concluded that it is impossible to separate grains into size grades using vertical air stream. The common and conventional method of classifying grains to size grades has always been the use of screen. There is a dearth of literature on the study of grain classification using horizontal air stream since the report of Gorial and O'Callaghan (1991a). It is therefore essential to further research into the feasibility of grain classification in horizontal air stream.

CHAPTER TWO

LITERATURE REVIEW

2.1 LEGUME THRESHING EQUIPMENT

Threshing involves the detachment of grain kernel from the panicle, straw or pods. The detachment of grains from the ear head could either be achieved by impact, rubbing, abrasion or a combination of two or all of these processes (Richart et al., 1980). It is a process common to both cereal and legume crops. Threshers could be classified based on feeding method (mode of feeding), traveling method or mode of conveyance of grains. By feeding method, threshers could be intermittent type or continuous flow type. They could be stationary type, self propelled type, tractor mounted type or tractor drawn type based on the traveling method. Threshers could also be axial flow type or spiral flow type based on the mode of conveyance of grains (Ichikawa and Sugiyama, 1991; Kradanguga et al., 1991; Artachinda et al., 1991; Saeed et al., 1995).

A number of threshers have been developed for cereals. Commonly available threshers for cereals such as wheat are developed primarily on hammer mill principle to produce chopped straw along with the threshed grains. Those threshers are not suitable for handling crops like paddy, maize, sorghum groundnut and pulse (Goel and Nanda, 1994). The energy requirements of these threshers are very high with a range of 20 to 50 kWh/ton (Singhal and Thierstein, 1987). Common cereal threshers if used for pulse threshing can result in excessive damage, in some crops as high as 40 – 50%. There is also the problem of separation and cleaning the seeds from the straw (Tandon et al., 1988).

Most cereal threshers have not performed well for legume threshing. This is because pulse crops (legumes) are quite delicate to thresh and a high percentage of broken grains is recorded with some types of threshing mechanisms (Singhal and Thierstein, 1987). Also, the basic differences in the crop parameters between the two crops may explain why cereal threshers may not perform well for legume threshing. Legumes are dicotyledonous with the grains contained in dehiscent pods while cereals are monocotyledon. The physical and mechanical properties of the two crops differ and the mode of attachment of the two crops to the stem is equally different.

Existing mechanical threshers include those powered by diesel engine, petrol engine, tractor or electricity (Ghaly, 1985; Sharma et al., 1984). Mechanical threshers available in literatures include the IRRI portable thresher, axial flow thresher, stationery thresher, Alvan Blanch midget thresher, LCT thresher, general purpose thresher and rubber roll thresher. Other types of grain threshers also exist but they all operate on the basic principle as those already mentioned.

2.1.1 IRRI Portable Thresher.

This thresher was originally developed by the International Rice Research Institute (IRRI), Phillipines (Singhal and Thierstein, 1987; Gummert et al, 1992). It was designed to satisfy the need of small-scale farmers. It is low cost and could be carried into the field. The thresher (Fig. 2.1) consists of a metal frame, a peg – tooth cylinder with four straw throwing paddles on one end, semi circular cover with four spiral louvers, and a round bar lower concave. A 3 kW petrol engine operates the thresher. Dash and Das (1989) developed a similar thresher with wire loop type of threshing mechanism.

The IRRI portable thresher operates on the axial flow principle. The material is fed at one end of the cylinder and discharged through the other end. The pegs on the

threshing cylinder hit the material, separating the grain from the straw and at the same time accelerating them round the cylinder. The bulk of the grain is threshed during the first initial impact. Further threshing is effected while the material moves axially until the straw paddle at the exit end discharges the straw. The original design was suitable for threshing paddy but could not be used to thresh sorghum and millet. Also, it does not have provision for changing the threshing concave cylinder. Under the optimum threshing condition, the machine has a maximum efficiency of 82% and 76% and grain output of 280 kg/h and 186 kg/h for sorghum and millet respectively (Singhal and Theirstein, 1987).

2.1.2 Axial Flow Thresher

The axial flow thresher (Fig. 2.2) originally developed by IRRI, Philippines evolved as a result of the operational and cleaning problems encountered in the early design of the portable thresher (Joshi, 1981; Gummert et al, 1992; Singhal and Thierstein, 1987). The thresher consists of the threshing, cleaning and conveying sections. The threshing section has a peg tooth cylinder and a semi hexagonal cover to assist in the separation of the grains from the straw by interrupting its smooth circular motion. This action stirs the straw to improve separation efficiency. The concave has a semi-circular shape made from round bar and fixed in position. The cleaning system consists of upper and lower oscillating screens and twin centrifugal blower between the screens which provides air movement to clean light -weight material from the grain as it drops from the upper screen. The screens move in opposite directions at the frequency of 340 oscillations per minute and stroke length of 32 mm providing a quiet and balanced operation. The upper and lower screens are replaceable to suit various cleaning conditions and seed sizes.



Fig. 2. ZIRRI Portable Thresher

Source: Singhal and Thierstein, 1987

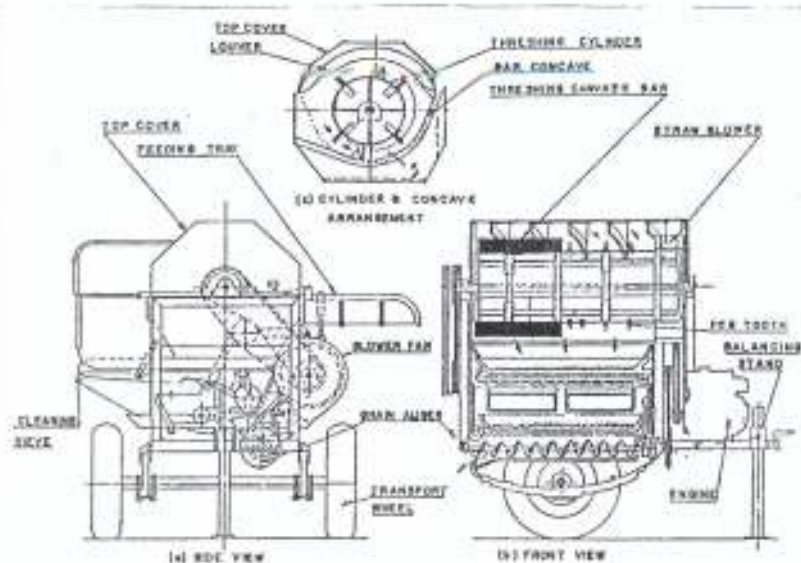


Fig. 2. Axial Flow Thresher

Source: Singhal and Thierstein, 1987

The clean grains are conveyed to the left side of the thresher by an auger mounted under the lower screen of the oscillating sieves. The thresher has no provision for changing the speed of cylinder fan and oscillating sieves. It has a power requirement of 3.7 – 5.2 kW. Three men are required to operate the machine – one to place sheaves on the feed tray, another to feed the sheaves in the feed opening and the third to collect and bag the grains.

Singhal and Thierstein (1987) modified the arrangement of the threshing cylinder – concave assembly, and the cleaning sieves of the axial flow thresher in order to improve the performance of the thresher. The modification made on the thresher enabled the machine to perform efficiently for a wide range of crops including sorghum, pearl millet, pigeon pea, chicken pea and wheat. The modified thresher was preferred over the conventional threshers due to some additional merits namely low labour requirements, ease in feeding ear head, less vibration during operation and operational safety. The modified machine has a threshing efficiency above 95% with a grain output of 500 – 800 kg/hr for most of the crops (Singhal and Thierstein, 1987).

2.1.3 Stationary Thresher

Ghaly (1985) designed and fabricated a tractor operated stationary threshing machine for wheat (Fig. 2.3). The machine consists of power unit, threshing – chopping cylinder and two concave of different design, all supported by a rectangular steel frame mounted on four wheels. A diesel engine of 30 hp mounted on the machine frame was used to operate the threshing – chopping cylinder. A clutch – gear box assembly was used to connect and disconnect the power from the diesel engine and for speed selection. Power is transmitted via a belt and pulley arrangement. Threshing is accomplished by means of 12 beaters welded into the circumference of

the drum in 4 rows (3 beaters in each row). Chopping of straw is accomplished by means of 36-toothed inclined knives bolted to 12 steel plates (3 knives on each plate). A 65 kg cast iron flywheel is mounted on one end of the shaft carrying the threshing – chopping cylinder.

A concave made of steel sheet, 6 mm diameter equally spaced wire is fitted underneath the threshing section of the cylinder, covering an axial distance of 70 cm. The machine recorded the highest feed rate of 24 ton/h at a cylinder speed of 1000 rpm and chopping concave sieve diameter of 4.5 mm.

2.1.4 Alvan Blanch Midget Thresher

This thresher has a very simple design. It consists of a 30 cm wide triangular section threshing drum with three rap bar at 120 mm spacing and a fixed bar concave (Carruther, 1985; Singhal and Thierstein, 1987). The clearance between the drum and concave is adjustable by sliding the drum shaft bearing vertically and by spacers in the bearing mounting which displaces it horizontally.

The thresher has no provision for cleaning and separation of grains from the chaff, consequently the output was mixed with chaff. A stationary straw rack was provided to separate the straw and with additional cleaning. It worked satisfactorily for paddy and sorghum threshing but was not suitable for millet, groundnut and maize. It utilizes a 2.25 kW power unit for its operation. Figure 2.4 shows the diagram of the machine.

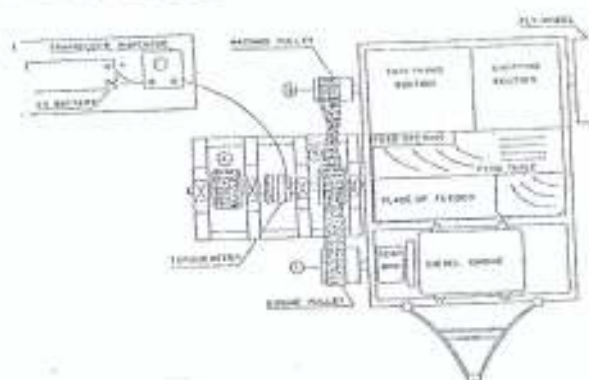


Fig 2.3: Stationary Thresher (1. feeding opening; 2. diessel engine; 3. feed table; 4. wooden platform)

Source: Ghaly, 1985

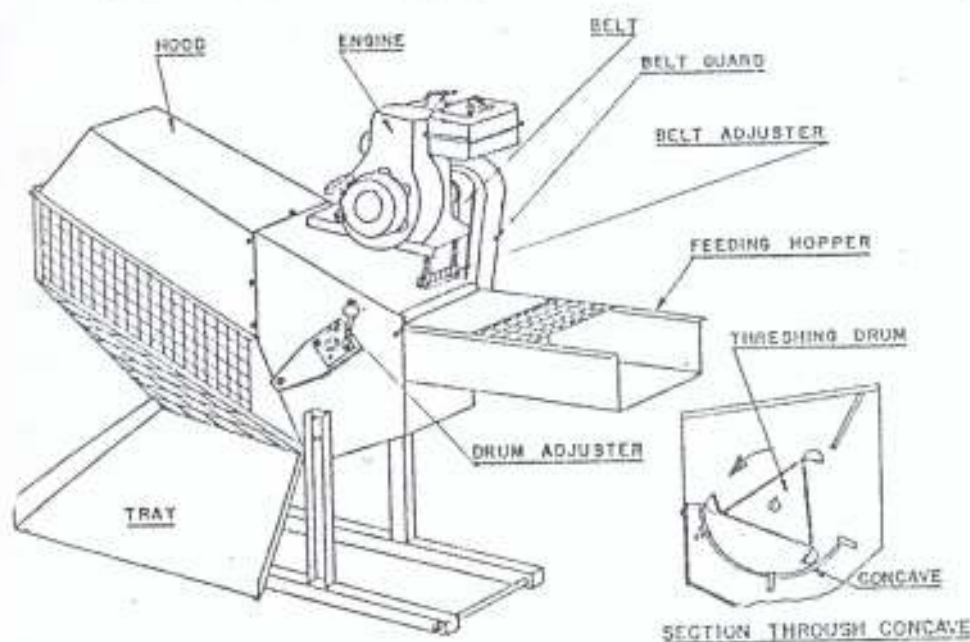


Fig. 2.4: Alvan Blanch Midget Thresher

Source: Singhal and Thierstein, 1987

The machine is safe in operation. Three persons are required to operate it – two to feed the ear heads and one to collect the threshed materials (Singhal and Thierstein 1987).

2.1.5 LCT Thresher

The LCT thresher shown in Fig. 2.5 is suitable for threshing sorghum (Carruther, 1985). It consists of the rasp bar type open cylinder and a stationary wire concave. The material, after threshing, passes to the straw walker and oscillating cleaning sieve. A 15 kW petrol engine is required to operate the thresher for cleaning operation. The machine has 98% threshing efficiency, 96% cleaning efficiency, 5.5% broken grain and 1000 kg/h capacity for sorghum threshing (Singhal and Thierstein, 1987).

2.1.6 General Purpose Thresher

This is a multi-crop thresher which could satisfactorily thresh crops such as wheat, barley, peas, sorghum, jowar, bajra and mustard. A 5 hp electric motor or 7.5 hp engine could operate it. The cylinder is the spike tooth or rasp bar type rotating against a stationary concave. The space between the cylinder and concave is adjustable and could be set for each type of crop under consideration. The threshed grains are collected in a pass at the grain outlet.

2.1.7 Rubber Roll Thresher

Rubber rolls used in modern rice mills for dehusking and shelling paddy are sometimes used for threshing podded crops like beans (Singhal and Thierstein, 1987; Omar and Yamashita, 1987; Jayasena and Ilangantileke, 1986). The rolls are mounted on two horizontal shafts driven in opposite directions with differential speeds. One of the shafts has a fixed position while the other is adjustable to obtain desired clearance

between a pair of rolls. Friction is created as a result of differential speed of the rolls. Threshing occurs in this arrangement by squeezing action, rubbing action or a combination of both. Rubber rolls are known to give maximum head yield and minimum percentage broken grains, but the rate of wear of rubber and the operating cost are high (Mistra et al., 1983).

2.1.8. Spiral flow thresher

The spiral flow thresher was developed in Japan for the threshing of soybean (Ichikara and Sugiyama, 1991). This thresher is relatively small in size but with a high threshing capacity and less grain loss. The threshing and separating mechanism are spiral flow type, unlike the axial flow type. Figure 2.6 shows the sectional view of the thresher.

The main portion of the thresher is the two screw augers, one as a base for threshing unit and the other for the separation unit. The threshing unit consists of a threshing cylinder and concave. The threshing cylinder (30 cm x 140 cm) has a spiral fin of 5 cm height with 15 cm pitch and independent teeth to facilitate smooth revolving of the threshed material in the threshing chamber. The separator unit is made up of a 18 cm pitch screw auger and a concave below the screw auger, the mesh of the concave in the separation unit is smaller than that of the threshing unit. The machine has a stable performance. Unthreshed grain was 0.5%, that is, about 99.5% threshing efficiency with only 1% grain loss and 1% grain damage. The machine has a feed rate of 500 - 700 kg/h.

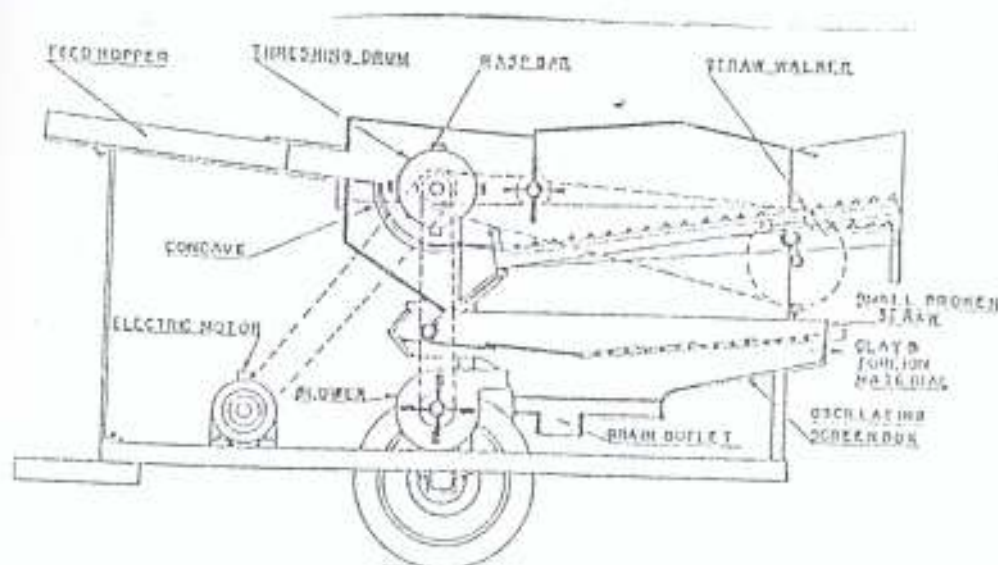
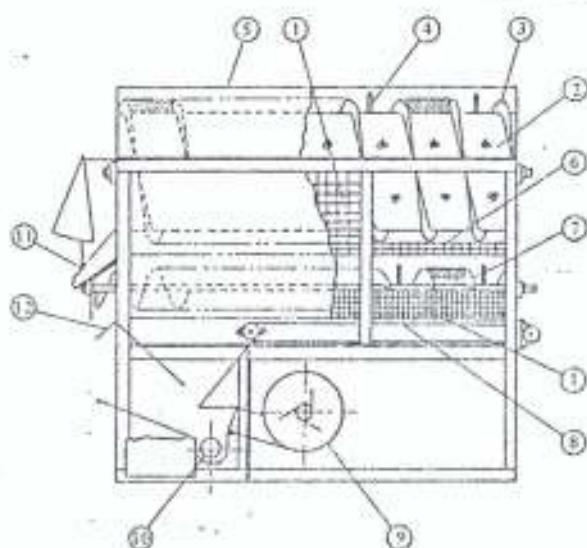


Fig. 2.5: LCT Thresher

Source: Singhal and Thierstein, 1987



- | | | |
|--|----------------------|-----------------|
| ① Concave | ② Threshing cylinder | ③ Spiral fin |
| ④ Tooth | ⑤ Cylinder chamber | ⑥ Feeding inlet |
| ⑦ Separating auger | ⑧ Rubber belt | ⑨ Cleaning fan |
| ⑩ Clean-grain auger (to bucket conveyor) | ⑪ Stalk outlet (I) | |
| ⑫ Stalk outlet (II) | | |

Fig. 2.6: Sectional View of the Spiral Flow Thresher

Source: Ichikara and Sugiyama, 1991

2.1.9 Cowpea threshers

Ige and Ajayi (1979) recorded three types (models) of cowpea thresher. The schematic diagrams of the threshers are shown in Fig. 2.7. The three models used the spike tooth threshing mechanism. For models 1 and 2, separate shaft operate the threshing and fan units. For model 3 the same shaft operates both the threshing and fan units, hence the fan and threshing unit operate at the same speed. Model 1 could not complete the threshing operation per pass and required two operators. While Model 2 performed better than Model 1, the construction cost was higher. Construction cost for Model 3 was reduced and the performance was best, with a threshing efficiency of 100% at a single pass.

Ige (1978) also recorded the performance of a locally built thresher with a square cross-sectioned threshing drum. The square cross section of the threshing drum is to assist the fanning process in the threshing drum. The threshing efficiency of the machine increased from 86% at a drum speed of 300rpm to 99.1% at 550 rpm for Ife brown with pod moisture content of 18.3%.

2.2. Threshing Mechanisms

Actual threshing of crop takes place in the threshing unit which houses the threshing mechanism. The choice of the threshing mechanism affects the power requirements, threshing efficiency, grain damage and the optimum conditions for machine operation (Gupta et al, 1986).

Commonly available threshing mechanism include the wire loop type, beater type, syndicator type, rasp bar type, angle iron type, spike tooth type and rubber strip mechanism (Culpin 1986; Singhal and Thierstein, 1987; Gupta et al., 1986). Most threshing mechanisms are of the cylinder – concave arrangement.

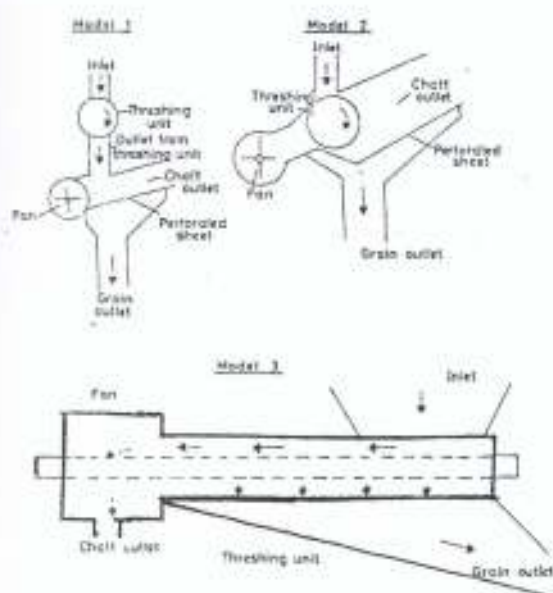


Fig. 2.7: Three Models of Cowpea Thresher

Source: Ige and Ajayi, 1979

Figure 2.8 shows the different types of threshing mechanism. Threshers with rasp bar and spike tooth cylinder primarily designed for paddy threshing are quite safe in operation but need several modifications for threshing other cereals and pulse crops effectively (Singhal and Thierstein, 1987).

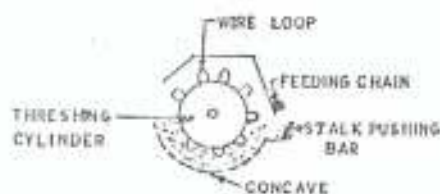
2.2.1. Wire Loop Threshing Mechanism

This is the simplest and the most widely used arrangement. The cylinder has wire loops on its periphery and no concave. The grains are combed out easily while a handful of material are held against the wire loop of the rotating cylinder. It is generally used in pedal operated threshers (Singhal and Thierstein, 1987).

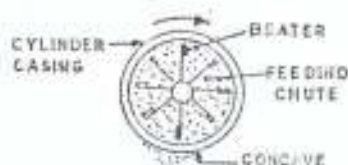
The mechanism seems adequate for cereals such as paddy, millet and sorghum with long stem but may not be effective for legume threshing. Sarwar and Khan (1987) carried out a comparative study on the performance of wire loop and rasp bar mechanism for rice threshing. They found out that the wire loop mechanism, irrespective of feed rate and moisture content, showed higher threshing efficiency at low speed and all concave setting.

2.2.2 Beater Type Threshing Mechanism

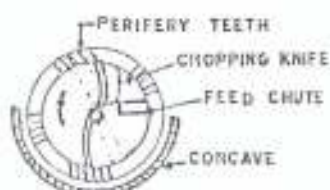
This type operates like an hammer mill. It is mostly used for wheat threshing. The beater or hammer is mounted on a shaft rotating inside a closed housing. As material is fed into the threshing compartment, the beaters subject it to impact and works on it until the grains are detached and drop through the screen located at the lower part of the threshing unit. This threshing mechanism lost its popularity because of the high power requirements (Sexena et al., 1978).



(A) WIRE LOOP MECHANISM



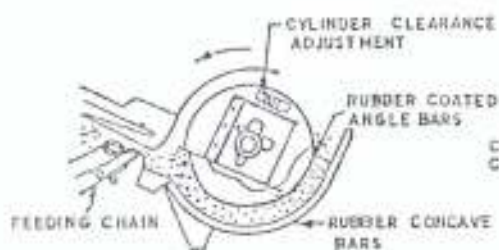
(B) BEATER TYPE MECHANISM



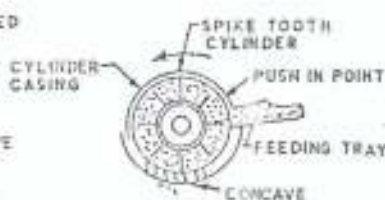
(C) SYNDICATOR MECHANISM



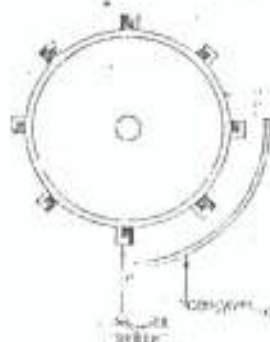
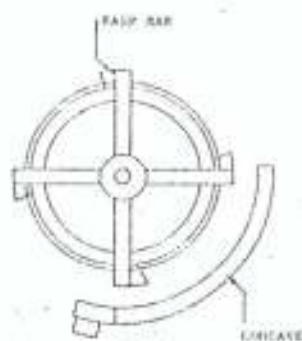
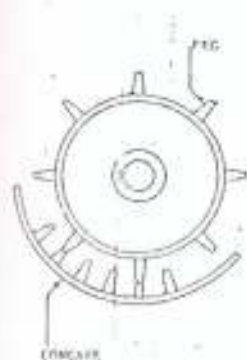
(D) RASP BAR MECHANISM



(E) ANGLE BAR CYLINDER MECHANISM



(F) SPIKE TOOTH CYLINDER



Drum types and concave used. (a) Peg tooth; (b) Rasp-bar; (c) Rubber strips

Fig. 2.8 Different types of threshing mechanism

Source: Singhal and Thierstein, 1987

2.2.3 The Syndicator Type Threshing Mechanism

This type is similar to the beater type but uses serrated flywheel instead of beaters. The flywheel rotates inside a closed casing and concave. The crop is fed axially into the threshing compartment. The material makes three quarter turn during which threshing occurs before engaging the chopping knives which cut the straws into pieces. The syndicator type threshers have advantages of low energy requirements, uniform size straw and capacity to handle crops of high moisture content (Gupta et al, 1986). However, a high percentage of grain damage and accident are associated with this type of mechanism (Banga, 1981; Verma and Bhatia, 1981).

In a study conducted by Verma and Bhatia (1981), percentage of accident of 45.16%, 32.42%, 14.19%, 1.94% and 1.29% was recorded for the drum type, syndicator type, beater type, rasp bar type and spike tooth type threshing mechanisms respectively in Punjab, India.

2.2.4. The Rasp Bar Threshing Mechanism

It is made up of a number of corrugated grooved steel bar attached to the circumference of the threshing cylinder. Corrugated steel bars are occasionally used on the concave as well. Threshing is done between the corrugated cylinder bars and the stationary bars built into or attached to the concave (Culpin, 1986). This threshing mechanism is quite common and is primarily designed for paddy rice. The major disadvantage of this type of mechanism is that the percentage of grain damage is high.

2.2.5 The Angle Bar Threshing Mechanism

This threshing mechanism is similar to the rasp bar type. Helitically mounted rubber faced angle iron rather than corrugated bars are attached to the circumference of the cylinder while the concave is ordinarily fitted with a rubber faced shelling plate

or steel – jacketed rubber bars. The percentage of grain damage is greatly reduced but the rate of wear is high (Culpin, 1986).

The angle bar threshing mechanism is mostly used for paddy, alfalfa and clover (Jacob and Harrel, 1983). The operation is safe with minimum records of accident. Klein and Harmond (1986) studied the effect of cylinder speed and clearance on three different threshing cylinders. They used spike tooth, rubber covered angle bar and rubber covered flat bar cylinders. They found out that the rubber covered flat bar cylinder recorded about 10% more clover seeds than the other two cylinders and the unthreshed seed lost was reduced to about 5%.

2.2.6 Spike Tooth Threshing Mechanism

This type of threshing mechanism is otherwise called the peg type. It is made up of short beaters arranged in transverse sections on the cylinder which thresh the grains as they revolve through similar tooth on the concave. The pegs or spike tooth can be made of short steel rods or rubber depending on the crop resistance to breakage or impact. The number of teeth needed in the concave depends on the crops and the threshing condition (Culpin, 1986). The arrangement of the spike tooth is such that the cylinder teeth pass midway between staggered tooth on the concave, thus producing an aggressive combing action.

The spike tooth mechanism has a simple and compact design with low grain damage but can handle only very dry crops with grain moisture content below 10% (Gupta et al., 1986). A spike tooth arrangement with pegs made of 11mm diameter bolts gave a better threshing performance and longer life in comparison with wire loop threshing cylinder (IRRI, 1972).

2.2.7 Rubber Strip Threshing Mechanisms

The arrangement is like the beater type but the impact members are made of tyre or reinforced rubbers bolted to the cylinder at inclined angle. The arrangement may not have a concave for tender crops like legumes. It is an axial flow arrangement with the crop entering through one end, the trash leaving through the other end and the grains dropping through holes on the concave. The chaffs are separated from the grain by an aspirator located at the lower part of the machine. This machine seems efficient for legume threshing.

2.3 Parameters Affecting the Performance of Threshers

In order to develop grain threshers, parameters such as cylinder peripheral speed, type of beater, concave clearance and moisture content have to be studied. Singh and Pathak (1973) explained that the maximum differential stress required to thresh by an impact machine is a function of parameters such as peripheral speed, modulus of elasticity of impact members and the material of construction, representative geometrical dimension of crop, specific gravity and radii of curvature. These parameters affect the quality, efficiency and power requirement during threshing.

The various parameters that affect the performance of crop processing equipment can be classified as crop, machine and operational parameters (Tandon et al., 1988; Singh and Singh, 1981; Hoky and Pickett, 1973). Very little information is however available on crops, machine and operational parameters with respect to the performance of pulse threshers (Tandon et al., 1988).

2.3.1 Crop Parameters.

These are parameters related to crop characteristics. The performance of mechanical systems, including threshers, depends on the physico-mechanical

properties of crops such as strength of kernel, bond strength of grain in panicle, grain hardness, strength of hull, type of ear head, grain size, grain uniformity and moisture content (Kulprit, 1967). Culpin (1986) also identified some crop parameters such as crop type and variety, green matter content and ratio of grain to straw weight. Bilanski (1966) studied the damage resistance of seed grains and concluded that the grain size, moisture content and position of grains all influence the damage resistance of seed grains.

The grains size is known to have significant effect on the clearance adjustment of threshing and dehulling machines (Joshi, 1981; Adewumi and Olalusi, 1998; Adewumi and Igbeka, 1996). Normally, the concave – cylinder clearance should be greater than the mean axial dimension of crop. Otherwise, the grains would be damaged during threshing or dehulling (Adewumi and Igbeka, 1996). Grains with uniform size have higher threshing efficiency compared to non uniform ones (Kulprit, 1967).

Crops maturity equally affects the performance of threshers. Fully matured crops require less power to detach them from the earhead (Kulprit, 1967). Reichart et al (1980) found that the ease of dehulling by mechanical method is a function of the degree of adhesion between the endosperm and bran layer, as well as the hardness of the grains. The bond strength between the hulls and the kernel, and the strength of the hulls are different for different varieties of the same crop.

Moisture content is a very important single crop parameter that has a very great influence on the performance of mechanical systems. It was found to have a significant effect on threshing efficiency and invisible damage at 1% level (Tandon et al., 1988). Threshing efficiency and percentage damage of grains increase as moisture content decreases (Ige, 1982; Singh and Singh, 1981). Singh and Pathak

(1973) explained that the bond strength between the grains and the straw, and the elastic constant of the grains and straw are dependent on moisture content. Increase in moisture content reduces the elastic constant of the grain and straw, and an increasing portion of the kinetic energy transferred to grain is utilized in the elastic deformation of grains. Hence, the impact stress of the effective force acting in detaching the grains from the ear head becomes weak and more energy is required to thresh at high moisture content. Reduced pod moisture content favour high threshing efficiency while increases moisture content shows appreciable reduction in grain damage (Ige, 1977; Olukunle, 2002).

The energy required to bruise wheat and barley straw was significantly dependent on the moisture content of crop. Specially designed mechanism like the axial cylinder with serrated tooth was much efficient in the size reduction of straw than hammer mill type. Singhal and Therstein (1987) recommended an optimum moisture range of 9 – 12% and 9 –11% for threshing pigeon and chicken pea respectively using a modified axial flow threshers with spike tooth mechanism.

At higher moisture content beyond the optimum point, more energy is required to operate threshers with higher record of crushed grains and lower operational efficiency. Also, at a moisture content lower than the optimum point, the percentage of broken grain increases with a decrease in machine throughput (Dash and Das, 1989) . For an impact threshing system, Singh and Pathak (1973) found that the moisture content of grain had an inverse and non linear relationship with the percentage of grain threshed. They attributed the relationship to the low elastic constant possessed by high moisture grains. Singh and Singh (1981) in their investigation found that a direct relationship exist between pod moisture content and the unthreshed soybean grains. This is because the seam attachment strength of pod

is high at higher moisture content. The pods open only when the impact force applied to the pod is greater than the seam attachment strength of the pods.

Both the grains moisture content and the pod moisture content have their respective importance (Goel and Nanda, 1994). Studies on edible beans and soybean threshed with mechanical threshers indicate that the threshing effectiveness is dependent on the pod moisture content whereas grain damage is greatly affected by the grain moisture content (Hoky and Picket, 1973). Singh and Singh (1981) investigated the effect of moisture content, threshing speed and length of storage period after threshing on the threshing performance and quality of two varieties of soybean. They found that threshed grains increased with an increase in pod moisture content whereas the grain damaged decrease with an increase in grain moisture content.

2.3.2. Machine Parameters

Machine parameters are the parameters dependent on machine characteristics. They are basic parameters considered during machine design. These include cylinder type, number and shape of beater element, angle of wrap of concave, beater spacing, beater dimension, angle of inclination of impact members, concave clearance, concave screen size and elastic constant of impact members. (Culpin, 1986; Makanjuola, 1979; Singh and Singh, 1981)

Singh and Pathak (1973) conducted a study on the impact phenomena during threshing in order to assess the effect of construction material of beater and the shape of beaters on grain threshability. Three types of construction materials were used for the impact members namely mild steel ($E = 1.95 \times 10^6 \text{ kgcm}^{-2}$), aluminum ($E = 0.675 \times 10^6 \text{ kgcm}^{-2}$) and rubber ($E = 0.206 \times 10^6 \text{ kgcm}^{-2}$). Three shapes of impact members namely flat surface, triangular surface and circular surface were used for the study.

They found out that the percentage of grain threshed increased with an increase in the elastic constant of the hammer. Mild steel with the highest modulus of elasticity ($E = 1.95 \times 10^6 \text{ kgcm}^{-2}$) recorded the highest percentage of grain threshed. The shape of impact member was equally found to have significant effect on the threshing phenomena. Flat surface had the highest percentage of grain threshed, followed by triangular shape and least for circular surface. They concluded that the radius of curvature of impact members affects the energy transferred to the crop.

Many researchers agree that the clearance between the concave and cylinder affects the threshability of both cereal and legume. Increasing the concave cylinder clearance and the feed rate results in an increase in grain output while the energy consumption remains the same. Also, if the clearance setting is too close grain damage will increase. A clearance of 2.54cm was recommended for a rasp bar cylinder operating between 8-13 ms^{-1} . Tandon et al. (1988) stated that concave clearance and cylinder peripheral speed were found to have significant effect on the threshing efficiency and grain damage for pulse threshers. While cereal could accommodate smaller concave setting and higher cylinder speed, legume crops such as beans and peas need a wider concave setting and lower speed to avoid cracking.

Lovegrove (1976) observed that insufficient concave clearance and/or excessive cylinder speed will result in over threshing and this may produce cracked, skinned or bruised kernel, and excessive quantity of chaff and lacerated straw. Also, excessive concave clearance and/or low cylinder speed result in under threshing and majority of the grain may not be extracted from the stem or pod. Generally, the smaller and finer the grain to be shelled or threshed, the smaller the required concave clearance and the higher the speed requirements (Klein and Harmond, 1986).

Ademosun and Adesuyi (1995) observed that the percentage of grain damage decreases as concave clearance increases for a maize dehusker - sheller.

2.3.3. Operational Parameters

These are parameters related to the operation of machine namely crop orientation, feed rate, cylinder speed and air flow rate. (Joshi, 1981 and Ige, 1978). The orientation of material as it enters the cylinder has a considerable effect on the concave and cylinder performance (Joshi, 1981). Singh and Pathak (1973) found out that increase in the peripheral speed of impact members increased the percentage of crop threshed. This is because at a very low speed of impact members, the energy transferred to the ear head is not enough to separate the grains. Ademosun and Adesuyi (1995) found out that for higher feed rate, higher concave clearance is required. They also found out that the percentage grain damage increases with cylinder speed.

Vas and Harrison (1969) studied the effect of selected mechanical parameters on kernel damage and threshability of wheat. They reported that the cylinder speed is the primary influencing parameter, while concave clearance, although of lesser significance, was an important parameter as well. They confirmed that the mechanical parameters causing significant variation in threshability are cylinder speed and concave clearance, while those causing significant variation in percentage mechanical damage are cylinder speed, concave clearance and feed rate. The study also indicated that increase in feed rate for an impact model resulted to a decrease in the mechanical damage on grain, though the grain threshability was not affected. This was attributed to the cushioning effect of straw at higher feed rate. Increase in feed rate however, increases the power requirement at the main shaft (Joshi, 1981).

Ajayi (1991) found out that the threshing efficiency of a locust bean thresher increases with an increase in the beater speed and feed rate. Ige (1978) reported that the threshing efficiency of a locally built cowpea thresher (drum and concave type) increased with the drum speed. He observed that the efficiency of the machine increased from 86% at a drum speed of 300 rpm to 99.1% at 550 rpm for Ife brown variety of cowpea. Singh and Thouthwantory (1983) also stated that the shelling efficiency of a power operated peanut sheller was significantly affected by the feed rate and cylinder clearance. The machine recorded the highest shelling efficiency of 96% with 5% breakages and a throughput of 172 kg/hr at a concave clearance of 2 cm and feed rate of 280 kg/hr.

Harrington (1970) concluded that for a multipurpose thresher the amount of trash in the clean grain was less than 1% for air velocity of 350m/min and less. Misener and Lee (1973) found out that air velocity of 9ms^{-1} at a direction of $40 - 45^\circ$ causes minimum loss in the aerodynamic separation of wheat material.

2.4. Evaluation of Grain Threshers

Singhal and Thierstein (1987) highlighted the criteria for thresher selection to include multi-purpose potential, performance, operational safety, crop characteristics and labour requirements. They indicated that low cost, light weight threshers with few moving parts and multipurpose crop potentials are preferred by farmers in India. A good thresher must be able to thresh high moisture crop efficiently with minimal separation losses. It has been reported that one thousand and two hundred (1,200) persons are being incapacitated by the use of poorly designed threshers every year in India (Verma,1981). Threshers with a good operation safety are preferable. Also, threshers with reduced labour requirements are preferred.

It is necessary to evaluate mechanical systems in order to obtain the optimal performance parameters for the systems. Syed et al (1993) conducted a comparative study on the performance of three different threshing drums for sunflower. They conducted the study using the peg, rasp bar and rubber strip drum with a speed range of 400 – 600 rpm and concave clearance range of 2.54 – 6.35 mm. They concluded that the peg type cylinder with a speed range of 400 – 500 rpm and concave clearance range of 2.54 - 3.10 mm is best for sunflower threshing.

Singhal and Thierstein (1987) measured the performance of an axial flow thresher in terms of grain output per hour (throughput), threshing efficiency, broken grain percentage (external and internal damage), separation losses, quality of blown grain along with the straw, cleaning efficiency and power requirements. They found out that some modifications on the peg type IRRI axial thresher could make the thresher to be adapted as a multi crop thresher and improve the threshing efficiency, separation loss and throughput of the machine. Ghaly (1985) evaluated the performance criteria of a wheat stationary thresher in terms of machine capacity, power consumed in the threshing - chopping process, length of straw and total seed loss and total seed damage. He observed that the machine capacity increased with cylinder speed until the optimal speed of 1000 rpm was attained after which the machine capacity reduced. The total seed damage however increased with cylinder peripheral speed.

Prusty et al. (1996) carried out a comparative performance evaluation of groundnut decorticator using parameters such as output capacity, decorticating efficiency and percentage broken kernel. Duraisamy and Minian (1990) evaluated the performance of some castor bean shellers and groundnut decorticators using

parameters such as shelling efficiency, cleaning efficiency and breakage of kernel using the relationships below:

$$\text{Shelling efficiency} = \frac{[\text{Total pod input} - (\text{unshelled pods} + \text{unshelled capsules})]}{\text{Total pod input}} \dots\dots\dots(2.1)$$

$$\text{Cleaning efficiency} = \frac{\text{Husk in blower outlet}}{\text{Husk in blower outlet} + \text{Husk in kernel outlet}} \dots\dots\dots(2.2)$$

$$\text{Breakage of kernel} = \frac{\text{Broken kernel}}{\text{Broken kernel} + \text{whole kernel}} \dots\dots\dots(2.3)$$

Singh and Singh (1981) determined invisible grain damage using the germination test. Also, they determined the percentage unthreshed grain and percentage damaged grain for soybean threshed with a rasp-bar mechanism using the relationship:

$$\% \text{ unthreshed grain} = \frac{\text{Weight of unthreshed grain}}{\text{Weight of total grain}} \times 100 \dots\dots\dots(2.4)$$

$$\% \text{ damaged grain} = \frac{\text{Weight of damaged grain}}{\text{Weight of total grain}} \dots\dots\dots(2.5)$$

Ajayi (1991) determined the threshing efficiency (%) and machine capacity (kg/hr) of a locust bean thresher for the purpose of evaluation of the performance of the machine using the relationship.

$$\text{Threshing Efficiency} = \frac{\text{Total weight of bean threshed}}{\text{Total weight of products fed into the machine}} \dots\dots\dots(2.6)$$

$$\text{Machine capacity} = \frac{\text{Total weight of seed threshed}}{\text{Time}} \dots\dots\dots(2.7)$$

Lazado and Simalanga (1994) evaluated a bean thresher using parameters such as threshing capacity, threshing effectiveness, seed damage and winnowing effectiveness. They determined the winnowing effectiveness using the relationship:

$$I = \left[\frac{a}{a+c} \right] \left[\frac{d}{b+d} \right] \dots\dots\dots(2.8)$$

where ;

a = weight of seeds in the seed collector (kg)

b = weight of chaff in seed collector (kg)

c = weight of seed blown off with chaff (kg)

d = weight of chaff blown off (kg)

Agbetoye and Ogunlowo (2001) evaluated the performance of a cowpea thresher for small scale farmers using parameters such as threshing efficiency, threshing capacity, grain loss, grain cracking losses, and unthreshed grain losses.

Multiple regression technique is an accepted method of determining the relationships between some set of independent threshing parameters and dependent threshing variables. Tandon et al. (1988) used the stepwise multiple regression technique to study the relationship among different variables namely cylinder type, concave clearance, cylinder peripheral speed and moisture content in relation to the two dependent variables namely threshing efficiency and invisible grain damage. They generated two sets of equations showing the relationships between the threshing parameters as stated:

$$T = 121.77845 - 7.11953X_1 - 0.66994X_2 + 0.0234X_3 + 2.945X_4 \dots (2.9)$$

$$D = 4.68525 + 1.39208X_1 - 0.21800X_2 + 0.00671X_3 - 0.084918X_4 \dots (2.10)$$

Where,

T = threshing efficiency (%)

D = invisible grain damage (%)

X₁ = moisture content (%)

X₂ = cylinder concave clearance (mm)

X₃ = cylinder peripheral speed (m/min)

X₄ = type of cylinder beater (X₄ = 0 for rasp bar beater and X₄ = 1 for peg type beater).

The two equations showed that the moisture content (X_1) had a significant influence on threshing efficiency and invisible grain damage. Singh and Singh (1981) also developed a set of equations using regression technique for the threshing of two varieties of soya bean as stated:

$$U_{an} = 19.68 - 1.265S + 0.56 M_p \quad \dots (2.10)$$

$$U_{pk} = 19.86 - 1.452S + 0.385 M_p \quad \dots (2.12)$$

$$D_{an} = -0.626 + 0.288S - 0.095 M_g \quad \dots (2.13)$$

$$D_{pk} = 0.929 + 0.426S - 0.235 M_g \quad \dots (2.14)$$

Where

U_{an} = unthreshed grain for ankur variety (%)

U_{pk} = unthreshed grain for PK - 1 - 21 variety (%)

D_{an} = damaged grain for ankur variety (%)

D_{pk} = damaged grain for PK 71 - 21 variety (%)

S = cylinder speed (ms^{-1})

M_p = grain moisture content (%)

M_g = pod moisture content (%)

2.5 Motion Equation and Particle Trajectory in vertical Flows

The solution to the motion of particles in fluid attracted various approaches by different researchers. Some of the mathematical and numerical approaches are as enumerated below:

2.5.1. Kiker and Ross' Approach

Kiker and Ross (1966) developed an equation of motion for multiple grain particles for a free fall in an enclosed vertical duct. The following assumptions were made for the gravitational flow:

- the motion of the particles and air in the enclosed duct are in same downward direction.
- the particle velocity is greater than air velocity.
- particle motion is unidirectional
- particle concentration is high and air flow is turbulent as a result of particle collision
- all particles have same velocity regardless of particle position in the duct cross section
- particle profile is blunt.
- there is low-pressure difference. Hence pressure gradient is negligible.

Newton's law of motion was used to develop the equation, that is,

$$F = Ma \dots\dots\dots (2.15)$$

where,

F = force (N)

a = acceleration (ms^{-2})

M = mass of particle (Kg)

The forces acting on average particle were identified to include the weight (F_w), drag force F_d and frictional force (F_f).

Therefore,

$$\therefore \sum F = Mp \frac{dV_p}{dt} + F_w + F_d + F_f \dots\dots\dots (2.16)$$

where ,

Mp = particle mass (kg)

dV_p = change in particle velocity (ms^{-1})

dt = change in time (s)

For single particle, eqn (2.16) is rewritten as:

$$M_p \frac{dV}{dt} = M_p \cdot g \left[\frac{\ell_p - \ell_a}{\ell_p} \right] - C_d A_p \ell_a \left[\frac{V_p - V_a}{2} \right] - \left[\frac{f_p V_p M_p}{2D_d} \right] \dots (2.17)$$

where,

C_d = drag coefficient

ℓ_p, ℓ_a = specific densities of particle and air respectively (Kg m^{-3})

f_p = friction factor of fluid

A_p = projected area (m^2)

V_a = velocity of air (ms^{-1})

D_d = duct diameter (m)

V_p = particle velocity (ms^{-1})

V_p can be measured with respect to displacement, hence

$$\frac{dV_p}{dt} = V_p \frac{dV_p}{dl} \dots (2.18)$$

Therefore,

$$M_p V_p \frac{dV_p}{dl} = M_p \left[\frac{\ell_p - \ell_a}{\ell_p} \right] g - C_d A_p \ell_a \left[\frac{V_p - V_a}{2} \right] - \left[\frac{f_p V_p^2 M_p}{2D_d} \right] \dots (2.19)$$

For all the particles in a multi particle system,

$$\sum_{i=1}^N i M_p V_p \frac{dV_p}{dL} = \sum_{i=1}^N i M_p \cdot g \left[\frac{\ell_p - \ell_a}{\ell_p} \right] - \sum_{i=1}^N i C_d A_p \ell_a \left[\frac{V_p - V_a}{2} \right] - \sum_{i=1}^N i \frac{f_p V_p^2 M_p}{2D_d} \dots (2.20)$$

or

$$N M_p \cdot v_p \frac{dv_p}{dl} = N M_p \cdot g \left[\frac{\ell_p - \ell_a}{\ell_p} \right] - N C_d A_p \ell_a \left[\frac{V_p - V_a}{2} \right]^2 - \left[\frac{N f_p V_p^2 M_p}{2D_d} \right] \dots (2.21)$$

where,

$$N = \frac{G_B \ell_B l}{V_p \ell_p V_p} \dots\dots\dots (2.22)$$

and

ℓ_B = bulk density of particles, (kgm^{-3})

G_B = bulk flow rate of particles (kgs^{-1})

2.5.2. Rumble and Lee's Approach

Rumble and Lee (1970) developed a differential equation of motion to enhance the separation of straw/chaff from grains by aerodynamic means before the mat gets to the upper sieve of the combine harvester. This is to ensure that the material to be sifted by the upper sieve is reduced to the minimum, hence optimising the performance of the upper sieve.

The following assumptions were made in the derivation of the equations:

- the coefficient of particle resistance remains constant
- the particles were accelerated by the air stream as free bodies and not as mat.
- the velocity of air through the upper sieve has a constant value.

The resultant force on the particle, F_r , is given in eqn. 2.23

$$F_r = F_g - F_d \dots\dots\dots (2.23)$$

Where,

$$\text{Gravitational force, } F_g = Mg \dots\dots\dots (2.24)$$

and

$$\text{Drag force, } F_d = C_R V_p^2 \dots\dots\dots (2.25)$$

at equilibrium,

$$F_g = F_d = Mg = C_R V_T^2 \dots\dots\dots (2.26)$$

$$\therefore F_d = Mg \left[\frac{V_p^2}{V_T^2} \right] \dots\dots\dots (2.27)$$

and

$$F_r = Mg - Mg \left[\frac{V_p^2}{V_T^2} \right] = Ma \dots\dots\dots (2.28)$$

Therefore,

$$a = g - g \left[\frac{V_p^2}{V_T^2} \right] \dots\dots\dots (2.29)$$

In y-direction;

$$\frac{\partial^2 y}{\partial t^2} = g \left[1 - \frac{V_p^2}{V_T^2} \right] \dots\dots\dots (2.30)$$

In x-direction;

$$\frac{\partial^2 x}{\partial t^2} = g \left[\frac{V_p^2}{V_T^2} \right] \dots\dots\dots (2.31)$$

These differential equations of motion (equations. 2.30 and 2.31) were solved simultaneously on an analog computer to determine the displacement of the particles for various air and initial particle velocities. Separate programs were run for wheat and chaff. The transition of the particles was thereafter simulated. The optimum values of air and particle velocities were also obtained for effective performance.

2.5.3 Farran and Macmillan's Approach

A theoretical approach was proposed by Farran and Macmillan (1979) for a single kernel of grain with polystyrene dropping in a vertical column at different feed rates. A computer program was written. The program was adapted from the

incremental technique developed by Lapple and Shepherd (1940). The following assumptions were made to derive the equations:

- both grain and polystyrene balls are spherical
- the standard drag coefficient – Reynolds number relationship for sphere is applicable.
- influence of acceleration on drag coefficient was negligible.
- influence of turbulence was negligible on drag coefficient.

The computer program developed was used to calculate the trajectories of a ball and a grain when injected at four optimum velocities.

2.5.4. Gorial and O'Callaghan's Approach

Gorial and O'Callaghan (1991a) proposed a mathematical model, which was solved numerically to simulate the path of grain and straw particles in an air stream.

The following assumptions were made:

- the drag coefficient remains constant over the range of velocities considered
- the grains were spherical
- the diameter of equivalent sphere was used to calculate projected area

The theory behind the mathematical model is as stated:

The net force, F , on a particle moving vertically in an air stream is the difference between the drag force (F_d) and gravitational force (F_g)

$$F = F_g - F_d \dots\dots\dots (2.32)$$

From Rumble and Lee's deviations (Rumble and Lee, 1970);

$$\frac{\partial^2 y}{\partial t^2} = g \left[1 - \frac{V_p^2}{V_T^2} \right] \dots\dots\dots (2.33)$$

$$\frac{\partial^2 x}{\partial t^2} = g \left[\frac{V_p^2}{V_T^2} \right] \dots\dots\dots (2.34)$$

For a downward injection, the relative velocity of particle is stated below:

$$V_{ry} = V_a + V_i \cos \alpha \dots\dots\dots (2.35)$$

And, for upward injection, the relative velocity of particle is as given:

$$V_{ry} = V_a - V_i \sin \alpha \dots\dots\dots (2.36)$$

where

V_{ry} = relative velocity of particle to air in y-direction ms^{-1}

V_a = velocity of air, ms^{-1}

α = angle of inclination between the axis of the injection conveyor and the direction of air flow.

V_i = injection velocity, ms^{-1}

Equations 2.35 and 2.36 were integrated twice to obtain the displacement. For falling particles;

$$S_y = \frac{V_T^2}{g} \ln \cosh \left[\frac{gt}{V_T} \right] \dots\dots\dots (2.37)$$

while for rising particles;

$$S_y = -\frac{V_T^2}{g} \ln \sinh \left[\frac{gt}{V_T} \right] \dots\dots\dots (2.38)$$

In the x-direction;

$$S_x = V_a t - \frac{V_T^2}{g} \ln \left[\frac{C}{\left[C \pm \frac{gt}{V_T} \right]} \right] \dots\dots\dots (2.39)$$

where,

$$C = \frac{1}{V_a - V_p} \dots\dots\dots (2.39a)$$

Equations 2.37 to 2.39 are used to plot the particle trajectories to predict the path of the light and dense materials.

2.5.5 Macmillan's Approach

Macmillan (1999) developed a computer program to solve fluid particle problem for single kernel drop. The program was used to analyse separation that occurs when grain and chaff are winnowed by being thrown through or dropped in wind. The program is a simulation of the traditional winnowing of grain and chaff/straw in the wind. During the process of winnowing, the lighter fractions are blown further than the grains. The program is based on numerical integration of the equations of motion. The program specified some parameters of the particles such as equivalent diameter, mass, magnitude and direction of the particle velocity (relative to the earth); and air parameters including density, viscosity, and magnitude and direction of air velocity (relative to the earth).

The program provides a plot of vertical displacement (y) vs horizontal displacement (x) of the particles at the various time intervals (t); and x , y , t together with the magnitude and direction of the particle velocity.

2.5.6. Ogunlowo and Coble's Approach

Ogunlowo and Coble (2000) developed a mathematical model for two phase motion of sugarcane (chopped components) in a vertical counter current air stream. They adapted the Kiker and Ross approach. The model is however 2D model with more complexities compared to Kiker and Ross. In deriving the equation, the following assumptions were made:

- the billets are cylindrical in shape and vary in size, density and weight.
- the drag in billets is mainly due to the differences between the velocity of billets and air stream

- the only external force on the billets is gravity
- turbulence is high hence force due to static pressure difference (because of velocity fluctuation)
- the billets exhibit both linear and rotational motion as a result of velocity gradient
- the billets trajectories in duct are influenced by feed rate and air distribution in the duct
- positive direction of travel of billets is taken from top to bottom of duct.
- the effect of temperature and environmental conditions are neglected.

The resultant force in the system is given by

$$\frac{d}{dt} (m_p v_{pi}) = F_g + \sum_{i=1}^N F_i \dots\dots\dots(2.40)$$

where, F_i = Forces acting on the particle apart from gravity including pressure gradient force, collision force, drag force, friction force, and so on.

Two sets of motion equations were developed in the duct for two distinct regions (Region I and II). Region I is the region below the elbow where the particle have no contact with the wall while Region II falls within 180° deflector elbow (see Fig. 2.9) and the resultant equations derived are as stated.

For Region I,

$$\frac{d^2x}{dt^2} = \frac{dx}{dt} = 0 \dots\dots\dots(2.41)$$

$$\frac{d^2y}{dt^2} = \beta^1(n) v_r \left[v_s - \frac{dy}{dt} \right] + C_a + F_p \frac{dy}{dt}^2 + C_n \frac{dV_a}{dt} + 2Cn^1 F_{cy} + \beta_r^0 F_\theta \dots\dots\dots(2.42)$$

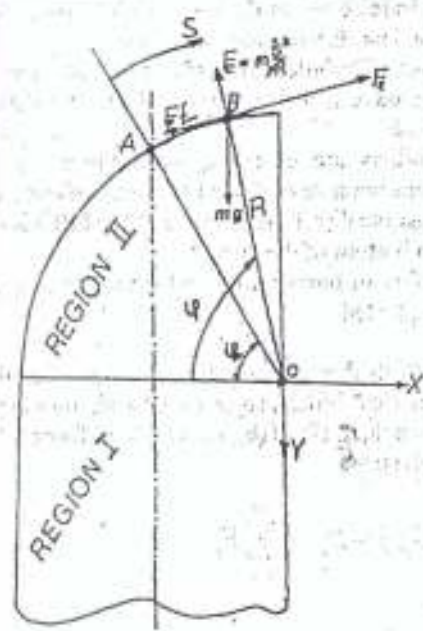


Fig 2A: The two regions identified in a separation duct with elbow.

Source: Ogunlowo and Coble, 2000; Ogunlowo, 1983

For Region II

$$\frac{d^2x}{dt^2} = \frac{dx}{dt} = 0 \quad \dots\dots\dots (2.43)$$

$$\frac{d^2y}{dt^2} = \beta' (n) v_r \left\{ v_a - \frac{dy}{dt} \right\} \pm C_G \cos \left(\frac{\gamma}{R} \right) - F_p \left(\frac{dy}{dt} \right)^2 + Cn' \frac{dva}{dt} + 2Cn' F_{cy}$$

$$F_t = \frac{1}{R} \left(\frac{dy}{dt} \right)^2 - g \sin \frac{Y}{R} \quad \dots\dots\dots (2.45)$$

where

$\beta' (n)$ = net resistance coefficient

v_p = relative velocity of particle, ms^{-1}

va = air velocity, ms^{-1}

c_G = weight term

F_t = friction coefficient between the particle and wall

β_t = coefficient of friction resistance

F_{cy}, F_{cx} = Collision forces in y and x directions respectively

c_G	=	weight term
F_f	=	friction coefficient between the particle and wall
f_{ϕ_f}	=	coefficient of friction resistance
F_{cy}, F_{cx}	=	Collusion forces in y and x directions respectively
F_p	=	particle friction coefficient
Y	=	distance of particle travel in y-direction
R	=	elbow radius,
C_n	=	$n_p M_p / \rho_p$
C^n	=	apparent weight correction C_n/M_t

The acceleration forms of the equation (eqns 2.40 – 2.45) were integrated twice to obtain the displacement component. The trajectories of the particles were obtained by solving the final equation numerically using Adam – Bashforth and Adams – Moulton (ABM) techniques.

2.6 Particle – Air Dynamics

The study of the behaviour of particles in moving air is an essential aspect of cleaning and separation of threshed materials. The knowledge flow of solid particles in air, the forces involved and the parameters effecting grain separation are required.

2.6.1 Aerodynamic Parameters

The three primary aerodynamic parameters of paramount importance include the drag coefficient, terminal velocity and Reynolds number.

2.6.1.1 Drag Coefficient, C_d

The drag coefficient include the coefficient of pressure drag and coefficient of friction drag. Hence, the resistance of a sphere to motion in an air flow is the sum of frictional effect (Skin drag) and pressure gradient effect otherwise known as form drag (Tabak and Wolf, 1998). It is a function of the Reynolds number and geometric

mean diameter (Gorial and O'Callegam 1990). The form drag is closely associated with the mechanism of flow in the wake region while the skin drag depends on surface characteristics. The form drag is dependent on the form or shapes of the particle and decreases to the minimum as a body approaches eccentric ellipsoid (Idelchik, 1986).

Becker (1959) developed a relationship for calculating C_d as shown below for $Re > 2000$.

$$C_d = 2.53 - 0.284 \psi^{24} \dots\dots\dots (2.47)$$

where

ψ = surface sphericity.

$$\psi = A_s/A_p \dots\dots\dots (2.48)$$

A_s = surface area of sphere of same volume with particle, m^2

A_p = particle surface area, m^2

2.6.1.2 Terminal Velocity, V_T

The terminal velocity otherwise called suspension velocity is the velocity at which the drag force and the gravitational force are at equilibrium. It is a function of particle moisture content, increasing with an increase in moisture content (Joshi et al, 1993). If a particle is suspended in a vertical air flow the drag is balanced by the particle weight such that:

$$Mg = \frac{1}{2} C_d \ell_s A V_T^2 \dots\dots\dots (2.49)$$

Thus, the terminal velocity is given by

$$V_T = \left[\frac{2Mg}{C_d \ell_s A} \right]^{1/2} \dots\dots\dots (2.50)$$

where,

- A = projected area of particle, (m²)
M = mass of particle, (kg)
G = acceleration due to gravity (ms⁻²)
 ℓ_a = air density (Kg/m³)

Equation 49 applies to a perfect sphere. The shape of most agricultural material is not a perfect sphere. A shape factor ($\pi/6Z$) is therefore introduced to equation 49 to account for the irregular and non-uniform shape of agricultural material (Gorial and O'Callaghan, 1990). Z is the volume shape factor. Hence, the terminal velocity of grains could be better determined using the relationship in equation 2.51.

$$V_T^2 = \frac{2 Mg \{ \delta Z / \pi \}}{C_d \ell_a A} \dots\dots\dots (2.51)$$

where,

$$Z = \frac{\pi}{6} \left[\frac{d}{d_e} \right]^3 (\text{Sphericity}) \dots\dots\dots (2.52)$$

d & d_e = geometric mean diameter and equivalent diameter respectively (m).

The Reynolds number in pneumatic separation or pneumatic conveyance is usually in the range of 10³ to 2 x 10⁴. For spherical particles in the range 500 < Re < 5 x 10⁵, the Newton's law is applicable and the value of C_d is approximately constant and equal to 0.44 (Tabak and Wolf, 1998).

The mass (M) of particle could be obtained using geometric mean diameter (d) as stated in equation 2.53 (Gorial and O'Callaghan, 1990).

$$M = \ell_p \pi \frac{d^3}{6} \dots\dots\dots (2.53)$$

Taking C_d = 0.44,

$$V_T^2 = \frac{4g d \rho_p (6Z/\pi)}{3 (60.44) \ell_p} \dots\dots\dots(2.54)$$

If air velocity is assumed to be constant ($\rho_a \approx 1.15 \text{ g m}^{-3}$) and for $500 \leq \text{Re} < 2 \times 10^5$,

$$V_T \approx 7 \sqrt{Z \ell_p d} \dots\dots\dots(2.55)$$

The volume shape factor for most grains range between 0.2 and 0.5 (Gorial and O'Callaghan, 1990). From equation 54, the terminal velocity is a function of Z , ℓ_p and d and could be determined by the direct measurement of Z , ℓ_p and d . The values of ℓ_p , d and Z for some common grains is given on Table 2.1.

Table 2.1: Values for Volume Shape Factor, Grain Density and Geometric Mean Diameter for Some Common Grains

Grain	Density ρ_p (Kg/m)	Volume shape factor, (Z)	Geometric mean diameter, d (mm)
Maize	1260	0.29	6.22
Wheat	1320	0.27	3.36
Barley	1020	0.23	3.70
Soybean	1340	0.46	6.22
Rice	1370	0.27	2.75
Rape seed	1000	0.41	2.05
Sorghum	1250	0.38	3.61

Source: Gorial and O'Callaghan, 1999

2.6.1.3 Reynolds number, Re

Reynolds number is an essential aerodynamic parameter that determines the nature of flow. Flow could be turbulent, laminar, uniform, non-uniform depending on the Raymond number. The Reynolds number in pneumatic system is usually in the range of 10^3 to 2×10^4 (Tabak and Wolf, 1998). It is obtained mathematically using the relationship in equation 2.56.

$$\text{Re} = \frac{D_p V_p \rho_a}{\mu} \dots\dots\dots(2.56)$$

where ,

D_p = average diameter of particle (m)

μ = viscosity of fluid

2.6.2 Forces involved in air-solid interaction in bulk flow

A number of forces influence air-solid interaction in bulk flow. Such forces include gravitational force, drag force, frictional force, pressure gradient force, lift force, transverse force caused by Magnus effect, collision force due to momentum and tangling, and so on (Ogunlowo and Coble, 2000; Macmillan, 1999; Rumble and Lee, 1970; Kiker and Ross, 1966; Ogunlowo, 1983).

2.6.2.1 Drag, Force, F_D

Drag force is principal among the forces acting on particle moving in air. It acts in a direction opposite to the velocity of the particle relative to air (Macmillan, 1999; Hauhouot -O'Hara, et al. 2000). It measures the net resisting effect due to friction between fluid and surface of solid, when the solid is made to move relative to fluid. It is proportional to the square of particle velocity relative to air (V_p). At equilibrium it is proportional to the square of the terminal velocity (V_T), that is

$$F_D = C_R V_T^2 \text{ ----- (2.57)}$$

Where, C_R is the coefficient of resistance. C_R is a function of drag coefficient (C_D), projected area of particle (A_p) and fluid density (ρ_a) as stated by Kiker and Ross (1966). That is,

$$C_R = \frac{1}{2} C_D A_p \rho_a \text{ (2.58)}$$

2.6.2.2 Gravitational Force, F_g

Gravitational force acts vertically and is dependent on the weight of particle. Generally, it is the product of mass and acceleration due to gravity. In a flowing fluid, the effective weight of particle is found by subtracting the buoyant force from the actual weight of particles and is given by Mohsenin, 1986, and Kiker and Ross, 1966 as stated in equation 2.59

$$F_G = M_p \cdot g \frac{\ell_p - \ell_a}{\ell_p} \dots\dots\dots (2.59)$$

where, ℓ_p = particle density (kg m^{-3})

ℓ_a = air density (kg m^{-3})

M_p = mass of particle (kg)

2.6.2.3 Frictional Force, F_f

The frictional force between the particles of materials flowing in air could be obtained by adapting the Darcy – Weisback equation as stated by Kiker and Ross (1966) in equation 2.60

$$F_f = \frac{f_p V_p^2 M_p}{2D_d} \dots\dots\dots (2.60)$$

where,

f_p = friction factor of particle

D_d = diameter of air duct (m)

V_p, M_p = velocity and mass of particle respectively (ms^{-2} , kg)



2.6.2.4 Lift Force, F_L

Lift force hinders the preferred settling motion of solid in fluid medium. It is caused by magnum effect. It is a transversely induced force which becomes apparent as the particles are spin in the shear layer. It occurs in the flow near the duct wall. It is equally produced when there is velocity gradient in the fluid medium.

Lifting effect occurs when there is over pressure (velocity deficit) below the particle and under-pressure (velocity surplus) above the particle. These results in a vortex being super imposed on the vecti linear velocity of the approaching fluid. Daugherty and Franzini (1977) gave the expression for the lift force for a cylindrical particle as stated in equation 2.61.

$$F_L = 2\pi \ell_p L_p V_p r_p \dots\dots\dots (2.61)$$

where

- ℓ_p = density of particle, (kg m⁻³)
- V_p = particle velocity (ms⁻¹)
- L_p = length of particle (m)
- r_p = particle radius, (m)

2.6.2.5 Pressure gradient Force, F_p

Sufficient pressure gradient could be generated within a flow system. This could generate sufficient force that can influence particle flow in air-solid bulk flow system. The force generated by the pressure gradient could be obtained in the y-direction using eqn 61 as stated by Ogunlowo and Coble, 2000.

For cylindrical particle,

$$f_p = \frac{\pi}{4} d_p^2 L_p \frac{dp}{y} \dots\dots\dots (2.62)$$

where,

d_p = diameter of particle (m)

L_p = length of particle, (m)

$\frac{dp}{dy}$ = change in pressure gradient in y-direction

2.6.3 Factors and Parameters affecting the Separation of Particles in

Fluid Flow

A number of parameters were identified to influence the separation of particles in a fluid medium. These include the fluid velocity, particle direction in air flow, direction at which particle is injected, particle feed rate, loading ratio, resilience time of particle in the separation chamber, the ratio of grain to material other than grain (MOG) and air turbulence intensity (Hamilton and Butson, 1970; Shellard and Macmillan, 1978).

Macmillan (1999) developed a computer program to study the separation of chaff from wheat by winnowing. He experimented with wind velocity of 1 and 2 ms^{-1} , particle release height of 1, 2 and 3m, particle flow velocity of 0, 1 and 2 ms^{-1} and a throw angle of 0.90 and 180°. He found that increasing the height of throw and air velocity have a near linear effect on separation, while increasing the throw velocity has a slightly curvilinear effect. He equally deduced the following from his study:

1. For a given throw velocity, increasing the air velocity increases the separation for the angle of throw.
2. For a given air velocity, increasing the throw velocity increases the separation for angles greater than 10°.
3. For all combination of air and throw velocity, the maximum separation is achieved at air angle of throw of about 140°.

Aguirre and Garay (1999) found out that a mean air velocity of 14.6 ms^{-1} is required for the cleaning and upgrading of bean seed. MacAulay and Lee (1968) recommended a feed rate of 50 – 75 kg/min for effective separation of straw and chaff from wheat in combine harvester.

Farran and Macmillan (1979) showed that the speed and direction (relative to main air stream) of injected material are important in determining the effectiveness of separation and the level of grain loss. Yekutieta (1985) found that the efficiency of separation was reduced by particle collisions with the duct wall, low air velocity near the walls and at higher feed rate, when the particles tend to unite together and form clumps within the air stream.

Injection velocity, air velocity, terminal velocity and the direction of injection have a combine effect on the trajectory of light and heavy particles in a mixture. For mixture injected upward, the horizontal displacement of the straw was appreciable high compared to the mixture injected downward ($x > 1.0\text{m}$) compare with $x < 0.5\text{m}$ at the plane of injection. However, the horizontal displacement of the wheat was slightly greater at some plane for wheat respectively. The difference between these two cases is due to the momentum of the initial injection, which forces the particle in a certain direction before they were affected by the air stream (Gorial and O'Callaghan, 1991a). But once a particle enters the air stream in the duct, the air, based on its terminal velocity, soon directs it.

For straw, the smaller the terminal velocity, the closer is the particle to the inner wall of the duct. But for the wheat, the higher the terminal velocity of particle, the closer it is to the inner wall of the duct. The best condition for separation is where the lighter material is injected so as to move up the centre plane of the column (Farran and Macmillan, 1979). Poor separation occurs when an unfavourable combination of

speed of injection and air velocity present the material to only a part of the air stream. In this case the wall effect hinders separation.

The variation of the terminal velocity of the group of material in the mixture to be separated must be distinct to ensure effective separation. Generally, the terminal velocity of wheat straw increases with its size. Large size straw (length $\approx$ 5cm) have a terminal velocity almost equal to the value for small grain wheat. Complete separation of such mixture is only possible by breaking or reducing the size of straw to short lengths (Gorial and O'Callaghan, 1991; Uhl and Lamp, 1966).

2.6.4. Separation of Particles in a Horizontal Air Stream.

A lot of literatures are available on the aerodynamic theory of separation of threshed material in vertical air stream (Uhl and Lamp, 1966; MacAuly and Lee, 1968; Rumble and Lee, 1970; Jiang et al, 1984; Misner and Lee, 1973; Gorial and O'Callaghan, 1991a). Only few literatures are found on the aerodynamic theory of particles in horizontal air stream (Gorial and O'Callaghan, 1991b). Unlike flow in vertical ducts, which is a concurrent and counter current in nature, the flow in horizontal duct is cross flow.

The studies of Kashayap and Pandya (1986), and Gorial and O'Callaghan (1991b) are major contributions to the study of the aerodynamics of threshed material in horizontal air stream. Kashayap and Pandya (1986) studied the winnowing of paddy rice crop separation in a horizontal air stream. They found that air speed of between 4 and 6.6ms⁻¹ were required to separate grains from material other than grain (MOG). Their results indicated that the horizontal displacement between two dissimilar particles decreased as the height of free fall above the air stream increased. It was also found that the separation was improved by providing either a free space below the air stream or by incorporating an upward inclined air blast.

Gorial and O'Callaghan (1991b) proposed a theory for the separation of particles in horizontal air stream as discussed below:

The aerodynamic drag force (F_d) exerted upon a particle by a stream of air is given by

$$F_d = \frac{1}{2} C_d \lambda_a A V_r^2 \text{-----} (2.63)$$

The drag force accelerates the particles until it acquired the velocity of the air stream. The equation of the acceleration is given below.

$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{2} C_d \lambda_a \left[\frac{A}{M_p} \right] V_r^2 \text{-----}(2.64)$$

Assuming the particles are spherical and using the diameter of equivalent sphere (d) to calculate the projected area (A) as discussed in Gorial and O'Callaghan (1990), the acceleration is written as;

$$\frac{\partial^2 y}{\partial x^2} = \frac{3}{4} C_d \left[\frac{\lambda_a}{\lambda_p} \right] \left[\frac{V_r^2}{d} \right] \text{-----}(2.65)$$

Equation (2.65) suggests that if two grains of different size are introduced with the same initial velocity unto an air stream, the acceleration imparted to the grains is dependent on their drag coefficients and the velocity of particle relative to air, and inversely on their diameters and densities.

Assuming the same density and drag coefficient, for the same type of grain, small grains have a greater acceleration and hence, will travel a greater distance in the air stream than the larger grain. A similar conclusion can be drawn for two grains of equal size but different densities introduced into the air stream. This theory suggests the possibility of separating grains into size and density grades in horizontal air stream.

CHAPTER THREE

MATERIALS AND METHOD

The research work is in three stages namely the pre-design; design, fabrication and machine assembly; and experimental stages. The pre-design stage involved the planting of some varieties of cowpea, soybean and pigeon pea (twelve all together, one variety per plot) on the farm of the teaching and research farm of the Federal University of Technology, Akure, Nigeria. Only four varieties of cowpea and soybean eventually survived. The physical properties of the stem pod and grain of the crops that survived were measured to aid the design of the equipment.

The threshing and cleaning equipment was thereafter designed using relevant engineering principles and theories. The components were fabricated and assembled at the Agricultural Engineering workshop of the Federal University of Technology, Akure, Nigeria. Appendix 1 shows the bill of quantities of the equipment. Series of experiments were carried out to evaluate the performance of the equipment using Ife bimpe variety of cowpea. Some studies were conducted on grain classification and characteristics, and particle. An aerodynamic model for a 2D particle trajectory was also developed during the study.

3.1 DESIGN, FABRICATION AND ASSEMBLY OF THE EQUIPMENT

Prior to the design of the equipment, some varieties of cowpea and soybean were planted and some physical properties of the crop (including seed, pod and stem) related to the equipment design were determined in the laboratory. Appendices 2 to 4 show the summary of the result of the experiments.

The equipment consists of the conveyor unit, threshing unit, centrifugal fan and cleaning chamber. The conveyor and threshing units and the centrifugal fan were

designed using conventional procedures, principles and theories. The design of the cleaning chamber was based on the aerodynamic theories of separation proposed by Gorial and O'Callaghan (1991a and 1991b). The details of the design calculations of the conveyor unit, threshing unit and the centrifugal fan are shown in Appendix 5.

3.1.1 Design of the Conveyor Unit

The belt conveyor, with flights, was designed following the procedures recommended by Jacob (1988) and Schultz (1985). Design data and specifications for roller and belt were also obtained from those authors and REX Manual (1976).

The conveyor unit has a maximum capacity of 350 kg/hr and moves the material through a height of 2.2 m. The design depth of the conveyor flight is 4 cm. A-4 rollers each with a diameter of 10 cm were used (Rex manual, 1976). The conveyor requires a maximum of 650 W powers for its operation.

3.1.2 Design of the Thresher Unit

The thresher unit was designed to have a concave clearance of 28.2 mm, concave diameter of 46 cm and concave length of 99.8 cm. The threshing drum has a diameter of 18 cm with a thickness of 3 mm and length of 99.5 cm. The threshing mechanisms are clamped to the drum with bolts and nuts. The length of each of the pegs and the pitch of each of the wire loop mechanism is 11.5 cm.

From the design, the power required to drive the drum with the threshing mechanism and thresh the pods is 622.8 W. The designed maximum power requirement for the threshing unit, considering a factor of safety of 2, is 1.25 kW.

3.1.3 Design of the Centrifugal Fan

The design calculation shows that a maximum drag force of 72.5 N is required for the grain separation. The fan requires a maximum of 787 W to clean threshed product discharged into it at 3.69 kg s^{-1} . Fan pressure and air flow rate are 843.30 Nm^{-2} and $3.25 \text{ m}^3\text{s}^{-1}$ respectively.

3.1.4 Design of the Cleaning Chamber

The lateral dimension of the cleaning chamber is the main design parameter for the cleaning chamber. The aerodynamic theories of grain separation proposed by Gorial and O'Callaghan (1991a and 1991b) were adapted for the design of the lateral dimension of the chamber.

The force resolution of the drag and gravitational force was carried out. The resulting equation was numerically solved using Matlab software to obtain the particle trajectory in x and y directions. The Matlab package indicates the effect of air velocity, air direction (angle of inclination of fan) and terminal velocity on the particle trajectory.

Allowance is given below the airflow to ensure the free fall of grains as recommended by Kashayap and Pandya (1986). The sides of the cleaning chamber is constructed such that the movement of the particles can be observed visibly and taken with camera. While one side of the cleaning chamber is painted white and calibrated, the other side is covered with a plain Perspex sheet. This is to allow visibility and particle tracking with optical equipment.

3.1.5 Fabrication and Assembly of the Equipment

The equipment was fabricated in the machine workshop of the Agricultural Engineering Department, Federal University of technology, Akure, Nigeria. Marking out of material was done using rule and scribe operations as cutting, drilling, casting, machining, welding, and milling were done. The various components were thereafter assembled. Appendix 6 provides detailed information on the fabrication and assembly of the equipment.

3.2 DESCRIPTION AND OPERATION OF THE EQUIPMENT

The threshing and cleaning equipment for legumes is made up of three (3) main units namely the conveyor unit, the threshing unit and the cleaning unit. A frame fabricated from a mild steel angle iron supports each of the units. The units are operated by electric motors via belt pulley transmission system. Speed regulation or selection is done by varying the pulley ratios. Plate 3.1 to 3.3 show the photograph of the assembly of the three views of the equipment. The equipment requires a total of about 2.03kW power for its operation.

Poded materials are loaded into the hopper of the conveyor and are transported into the threshing unit. The wire loop mechanism in the threshing unit threshes the pods as it moves it spirally toward the discharge end, where majority of the pods are collected. The grains are dropped through the screen on the concave and deposited into the cleaning chamber, where the cleaning and grade of the grains occur simultaneously.

3.2.1 The Conveyor Unit

The conveyor unit transfers poded materials into the threshing unit and regulates the feed rate. The conveyor unit is made up of a looped belt, rollers, frame,

guide, hopper, tensioning plate and screw, bearing, bearing guide plates and flights. Podded materials are loaded into the conveyor through the hopper. The feed rate of the threshing unit is regulated by changing the pulley ratio or speed of the conveyor unit. The design capacity of the conveyor unit is 350 kg/hr. It is inclined at 60° to the horizontal.

Twelve (12) flights made of gauge 18 metal sheets are riveted to the looped belt to keep the podded materials in position on the conveyor belt. The flights are spaced at 38.5 cm interval. Each of the flights has a dimension of 5 cm x 30 cm. The belt is made of reinforced rubber material. It has a width of 30 cm and total length of 4.2 m.

Three (3) rollers, each having a diameter of 10 cm, are mounted on the conveyor frame via a 25 mm diameter pillow block bearing. The conveyor belt is adequately tensioned by the tensioning plates and screws located near the top end of the conveyor frame. The two sides of the head and tail rollers are provided with guide plates to prevent the sliding of the conveyor belt during operation.

The flight conveyor belt is protected by a metal sheet guide. The guide has a total length of 2.35 m, width of 31 cm and depth of 14 cm. A clearance of 4 cm is between the guide and the tip of the flights to ensure free movement of the flight conveyor. Plate 3.4 shows the photograph of the conveyor unit (without the metal sheet guide)

The electric motor driving the conveyor and threshing units is mounted on the conveyor frame. The frames of the conveyor and threshing units are clamped together with bolts and nuts to ensure rigidity

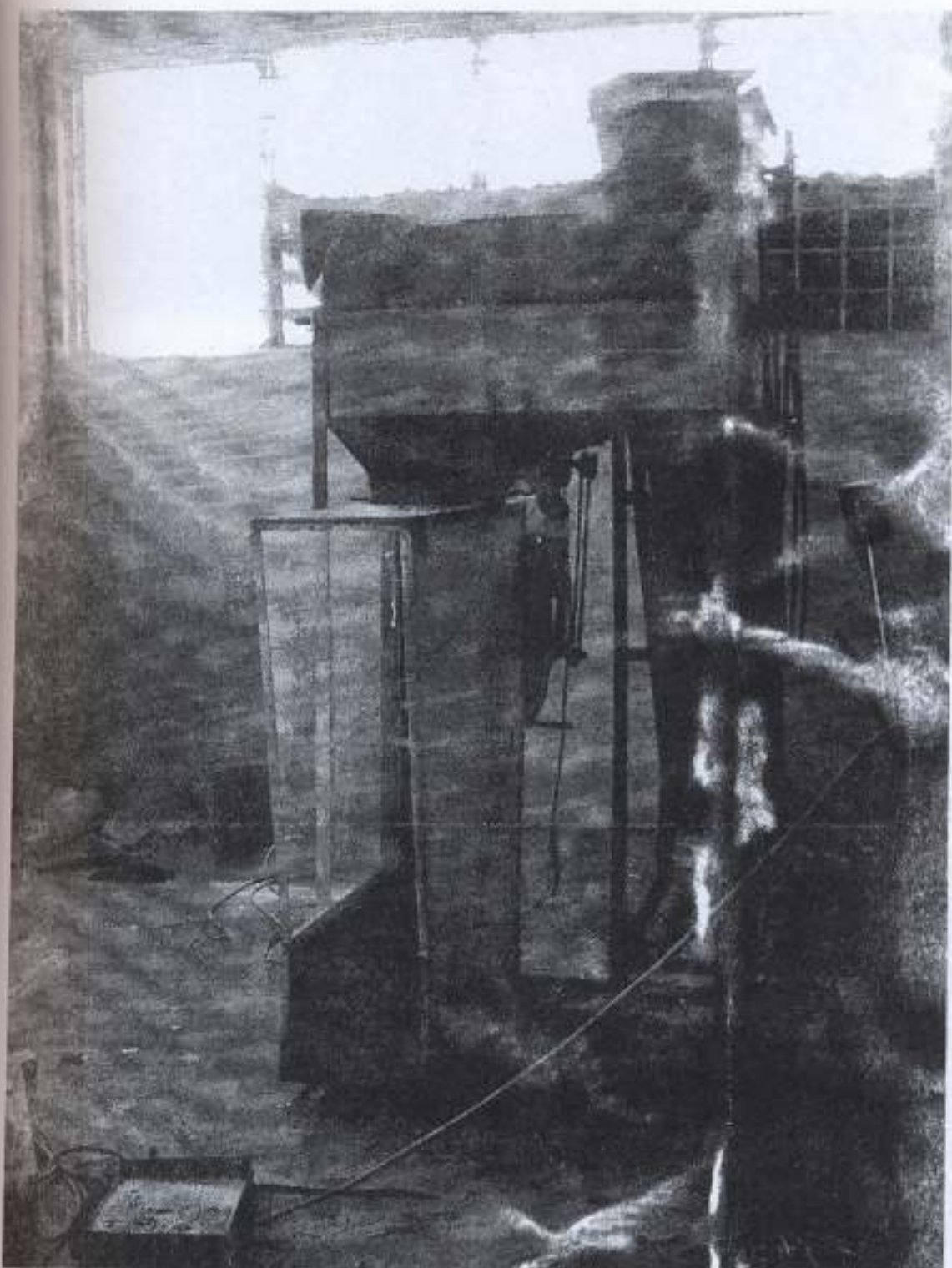


Figure 3d: Photograph of the front view of the equipment



Figure 32: Photograph of the side view of the equipment

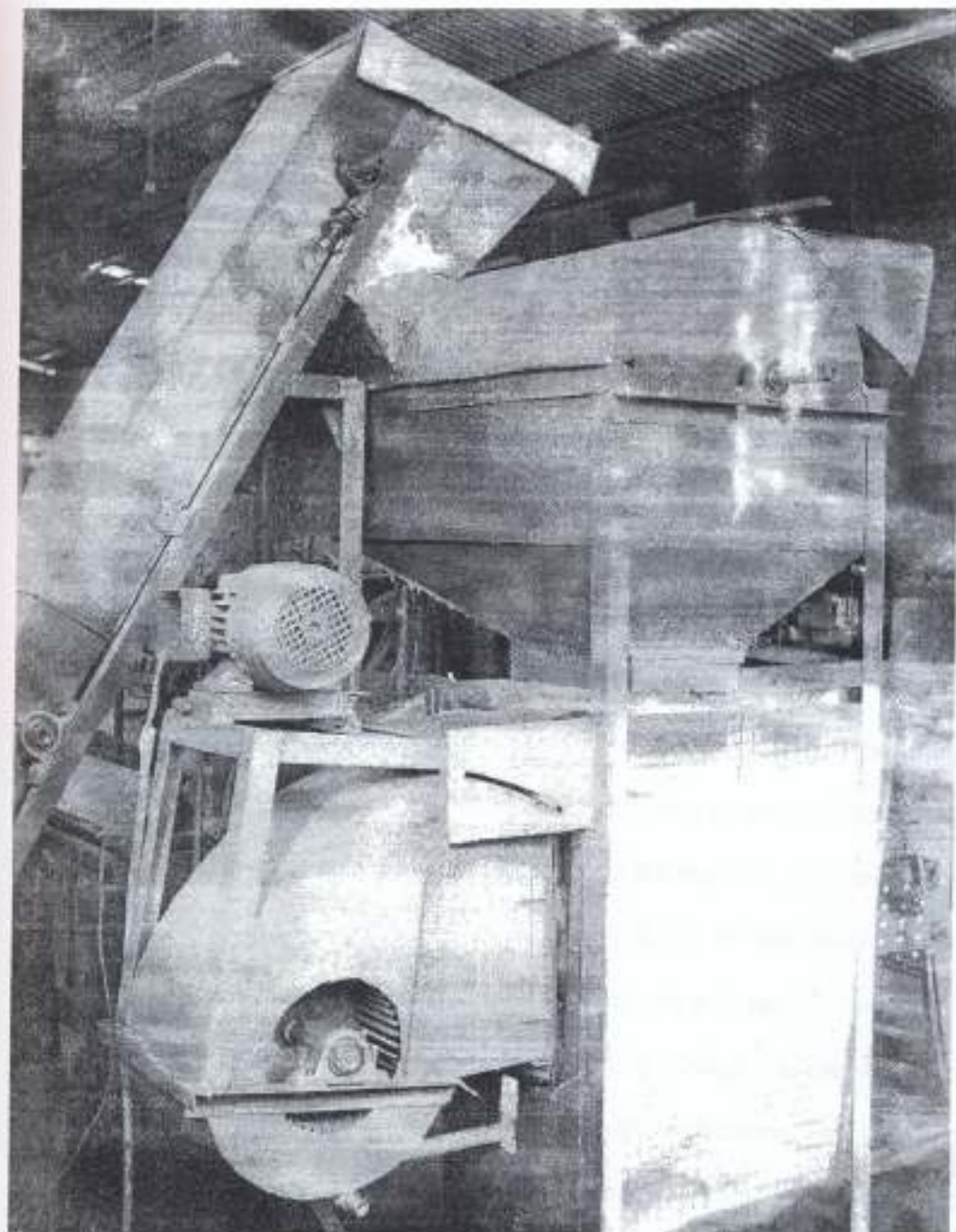


Figure 33. Photograph of the back view of the equipment

3.2.2 The Threshing Unit.

The threshing unit detaches the grains from the pods. It is the axial flow type. It consists of the threshing drum, threshing mechanism (changeable/couple able), bearing, concave, concave cover, inlet chute, exhaust chute, and frame. The cover of the threshing unit has a diameter of 42 cm. An inlet chute is welded to the left end of the concave cover while an exhaust chute is located at the right side. The inlet chute and the open end of the conveyor unit guide are provided with a metal sheet cover to allow effective centrifugal discharge of the podded grains from the conveyor into the threshing unit. This sheet metal cover also prevents the loss of the materials from the conveyor. Threshed pods are discharged through the exhaust chute (see Plate 3.3).

The threshing mechanisms are arranged and bolted on the drum to have spiral turns such that threshed materials can easily flow in the threshing unit. The concave of threshing unit has a diameter of 46 cm. It has a screen of 10 mm diameter and open area of 20%. The concave and concave cover of the threshing unit are bolted to the frame of the threshing unit with four pairs of M8 bolts and nuts. Plate 3.5 shows the transmission pulleys of the conveyor and threshing unit with the idle pulley.

Grains and smaller pod particles that pass through the concave screen are directed to the inlet of the cleaning unit via the discharge chute. The discharge chute is provided with a gate to regulate the inlet speed of material into the cleaning unit. The threshing drum is driven by a 25mm diameter shaft and supported on the frame by a pair of pillow block bearing.

3.2.3 The Cleaning Unit

This unit is made up of a centrifugal fan, fan casing, fan frame, rubber bellow, angle adjuster, collector tray, bearing and the cleaning chamber. Plate 3.6 shows the



Figure 3-4: The Conveyor Unit

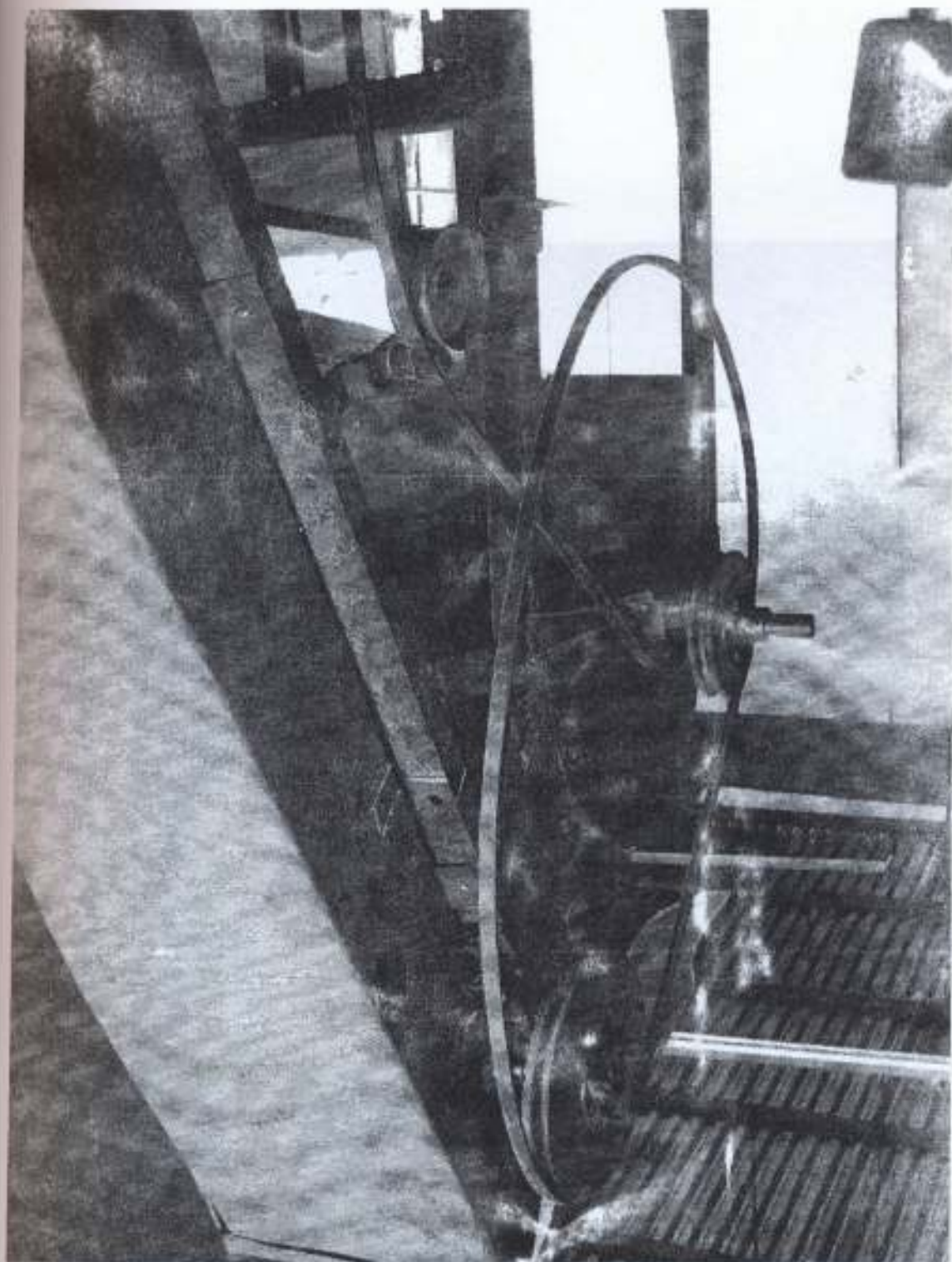


Figure 3-5: The Transmission Pulley of the Conveyor and threshing units

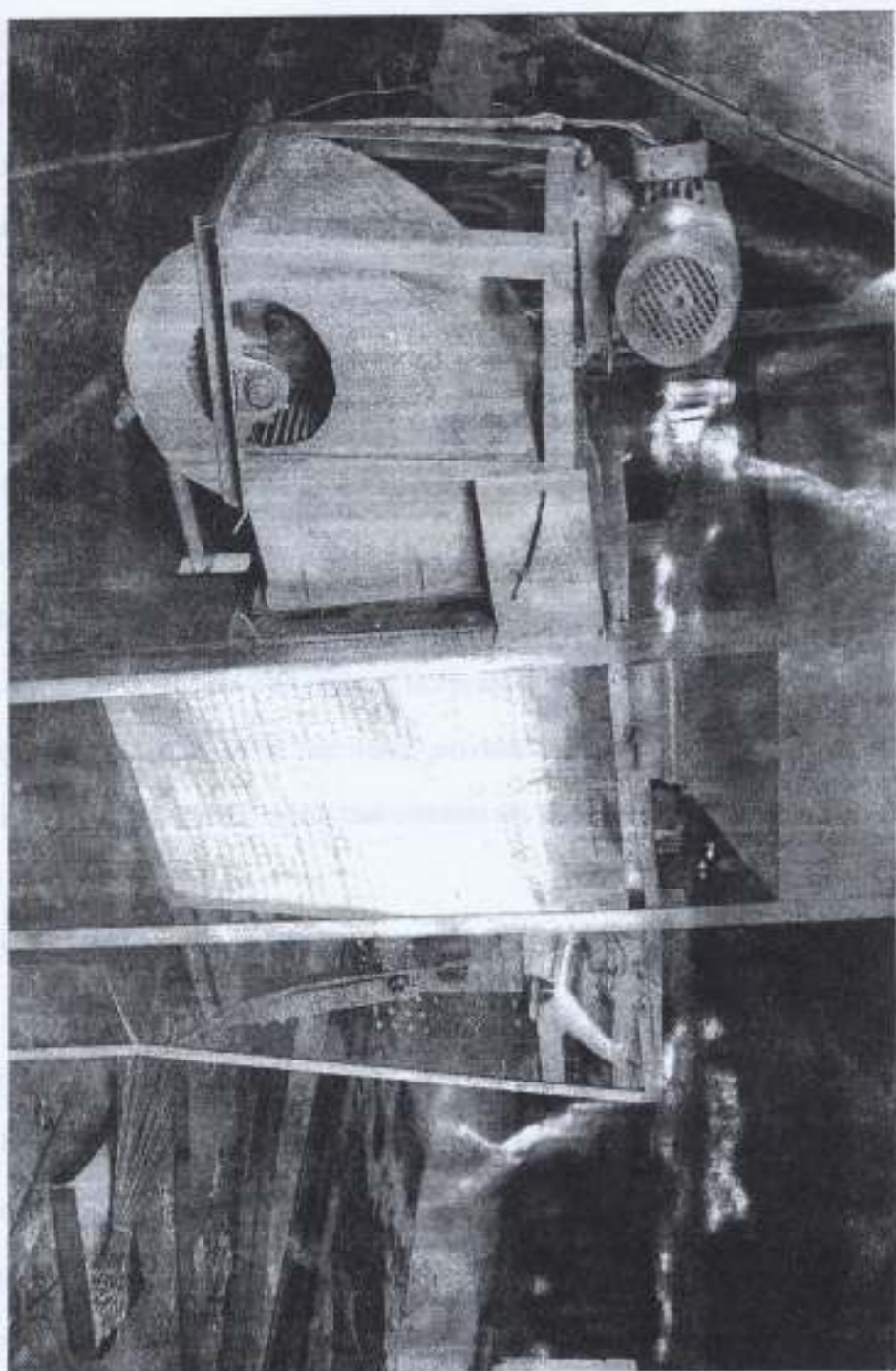


Figure 3-6: Side view of the Cleaning Unit

photograph of the cleaning unit. This unit separates the lighter particles from grains and simultaneously classifies the grains into size grades.

The cleaning chamber is made up a 2.5 mm angle iron frame with a total height of 1.3 m, width of 0.3 m and maximum breadth of 0.99 m. The collector tray, divided into eight (8) compartments is located at the lower part of the cleaning chamber. It has a length of 80 cm, width of 30 cm and height of 30 cm. A metal sheet (painted white) is welded to the inner breadth of the cleaning unit while a Perspex glass is bolted to the outer breadth to ensure visibility and photographic tracking of particle movement.

The fan casing is coupled to the frame of the cleaning chamber via a rubber bellow. The rubber bellow is flexible and could allow the angular movement of the fan casing. The fan casing houses the centrifugal fan and directs the air from the fan into the cleaning chamber. The fan casing could be inclined between 0° to 30° relative to the horizontal plane. The angle of inclination of the fan casing is calibrated on the angle adjuster plate. The fan frame provides support for the centrifugal fan, the bearings and the electric motor that operates the fan.

3.3 PRELIMINARY TESTING OF THE EQUIPMENT

The machine was assembled after fabrication. A 1,420 rpm, 1kW single phase electric motor was mounted on the frame of the fan casing to drive the fan unit while a 1,420 rpm 3.5kW, 3 phase electric motor was mounted on the motor seat built into the conveyor frame to run the conveyor and threshing units. The electrical connections of the motors were done. A contactor switch was provided to simultaneously operate the motors. The electric motor operating the conveyor and

threshing units rotates clockwise. The belts transmitting power to the conveyor and threshing units were therefore crossed to ensure they rotate anticlockwise.

A-belts are readily available in the market. They were purchased for the testing the machine. A-83 (12.5 cm x 1350 cm); A-100 (12.5 cm x 2250 cm) and A-84 (12.5 cm x 1950 cm) belts were used for the fan, conveyor and threshing units respectively. The tensioning of the fan unit belt was achieved using screw adjusters; while the tensioning of the conveyor unit and threshing unit belts was achieved by moving the electric motor longitudinally, either up or down as applicable, in the slot provided on the motor seat. The belt available for the threshing unit was too long. An idler pulley was therefore provided. The idler pulley was welded to the conveyor frame.

The equipment was thereafter subjected to rigorous preliminary tests in order to identify its functional defects and correct them before experimentation. The equipment was run when no crop was loaded and under loading conditions.

A number of functional defects were identified on the equipment during preliminary tests. The defects were associated with lack of precision, lack of appropriate tools and machine for fabrication and human errors. The defects identified include the following:

- i. misalignments of the conveyor belt
- ii. high record of loss of crop at the discharge end of the conveyor inlet to the threshing unit.
- iii. high velocity head loss of the air produced by the centrifugal fan

Details of the defects and corrections effected on the machine are recorded in Appendix 9

3.4 EXPERIMENTAL PROCEDURE AND METHODOLOGY

One quarter of a hectare of Ife bimpe variety of cowpea was planted for the research experiments on the crop research farm of the Federal University of Technology, Akure. The pods were harvested, dried to moisture content of 14.0% (wet basis), kept in the store for about two years and protected with chemicals. The performances evaluation of the equipment was done using Ife bimpe variety of cowpea, and the trajectory and spread pattern of the materials loaded into the cleaning chamber was monitored.

The performance evaluation of the equipment was done at a conveyor speed of 400 rpm, threshing speed of 600 rpm, fan speeds of 900 and 1,500 rpm, fan angles of inclination of 90, 105 and 120°, concave clearance of 20 mm, pod moisture contents (PMC) of 14.0, 18.0 and 22.0% (wet basis) and corresponding grain moisture content (GMC) of 15.3, 17.2, and 18.8% (wet basis). A wire loop threshing mechanism were also used for the evaluation. The effects of these parameters were studied as they affect threshing efficiency, conveyor loss, and the cleaning and grading of cowpea seeds. 400 g of poded materials wer fed into the equipment per operation.

Study was also carried out on particle grading in the cleaning chamber. The materials were classified as shown in Table 3.1. The quantity of each of the materials collected per tray per experiment was noted. The size range of the various sizes of grains obtained in each of the collector tray was measured using micrometer screw gauge, veneir caliper or steel rule, as applicable; and the percentage frequency of the grains in each of the trays was thereafter determined. The photographic trajectories of the particles in the cleaning chamber were also obtained using a high speed video camera and the spread pattern of the materials in the collector trays was studied using

Excel, S - Plus Professional, Harvard graphics 3.0 and SPSS Professional 10.00 packages.

Table 3.1: Classification of Materials in the Trays in the Cleaning Chamber

Material	Specification	Size range (mm)
Cowpea (Whole Seeds)	Big size	$7.00 < x < 10.00$
	Medium size	$5.00 < x < 7.00$
	Small size	$3.80 < x < 4.99$
Cowpea (Damaged Seeds)	Broken seeds	< 5.00
	Infested seeds	$3 < x < 10.00$
	immature seeds	< 3.00
Pods	Unthreshed	$40 < L < 120$
	Whole size	$100 < L < 120$
	Medium size	$40 < L < 99$
	Small size	$5 < L < 39$

3.4.1 Moisture Content Determination

Three levels of the cowpea pod moisture content (14.0, 18.0, and 22.0%) were used. These moisture contents (wet basis) correspond to typical storage, processing and harvest moisture levels respectively (Ige, 1977, 1978, Olukunle, 2002; Ige and Ajayi, 1979; Ickikawa and Sugiyama, 1991). Moisture content was determined using the electronic moisture meter. Water was added to the dried pods at 14.0% moisture content to attain higher levels of moisture content. The weight of water (W_w) added to bring the moisture content from the initial condition (M_1) to a higher level (M_2) is given by the relationship below (Osunade and Lasisi, 1994):

$$W_w = W_s (M_2 - M_1) / (1 - M_2) \text{ -----(3.1)}$$

Where,

W_s = initial weight of material (kg)

and, M_1 & M_2 are in fraction

About 50 cl and 105 cl of water was added to 1 kg of the podded cowpea to raise its moisture content from 14.0% to 18.0% and 22.0% respectively. The water was gently and slowly sprayed on the material, which was well spread on a table with a non-absorbent surface. The podded materials were gently mixed at interval to ensure even distribution of moisture. The exercise took about 6 hours after which samples were taken for experiments. Each moisture determination was carried out in triplicate.

3.4.2 Axial Dimensions and Geometric Mean Diameter

The three axial dimensions of the seeds at moisture contents of 15.3%, 17.2% and 18.8% were measured using the Nail micrometer screw gauge. The geometric mean diameters (d_g) of the big, medium and small seeds were determined using the relationship in equation 70.

$$d_g = (abc)/3 \quad (3.2)$$

Where,

a = major diameter (mm)

b = minor diameter (mm)

c = thickness (mm)

3.4.3 Performance Evaluation of the Equipment

The equipment was tested using cowpea at a conveyor speed of 400 rpm, threshing speed of 600 rpm and fan speeds of 900 and 1500 rpm, and a concave clearance of 20mm as recommended by various authors for adequate and optimum performance (Ige 1978; Ademosun, 1993; Agbetoye and Ogunlowo, 2001; Aheneku

et al., 2003; Dauda, 2001; Joshi, 1981; Kashayap and Pandya, 1986; Olukunle, 2002).

The wire loop threshing mechanism was used during the test because of its gentle impact on threshed material, high threshing efficiency and low grain damage records (Sarwar and Khan, 1987; Singhal and Thierstein, 1987; Tandon et al., 1988)

The feed rate ($\dot{M}_c$) of materials into the threshing unit was obtained using the relationship below;

$$\dot{M}_c = \frac{60 N_c M_c}{6 \pi} \quad (3.3)$$

Where,

N_c = Convey or speed (rpm)

M_c = Mass of material loaded into the conveyor (kg)

About 0.4 kg of podded cowpea was feed into the hopper of the conveyor.

Some material losses were observed between the discharge end of the conveyor and the inlet hopper to the threshing unit. This accounted for the conveyor losses.

The conveyor loss (C_L) is the ratio of the mass of podded grain delivered to the threshing unit to the actual mass of material loaded into the conveyor unit expressed in percentage is as expressed in equation 3.4. The threshing efficiency ($\int_T$) was obtained using the relationship in equation 3.5

$$C_L = \frac{M_{CH} - M_{CL}}{M_{CH}} \times 100 \quad (3.4)$$

$$\int_T = \frac{(M_T - M_{UT})}{M_T} \times 100 \quad (3.5)$$

$$\text{Note that, } M_T = M_{CH} - M_{CL} \quad (3.6)$$

Where,

M_{CH} = actual weight of material loaded into the conveyor unit (kg)

M_{CL} = weight of material lost during conveyance (kg)

M_T = mass of material loaded into the threshing unit (kg)

M_{UT} = mass of unthreshed material collected at the thresher exit (kg)

The cleaning effectiveness of the equipment ($\int_{CL}$), in this study, was measured in relation to chaff material blown away from the trays expected to collect grains or those retained within the trays expected to collect grain with respect to the total chaff loaded into the cleaning chamber as shown in equation 3.7

$$\int_{CL} = 1 - (M_{pc} / M_p) \quad (3.7)$$

Where,

M_{pc} = Mass of pod retained within the expected seed trays (g)

M_p = Total weight of pod loaded into the cleaning unit (g)

3.4.4 Size Distribution and Material Characteristics

The size distribution of whole grains in the sample was obtained using the random sampling technique. Samples of the threshed cowpea seeds were collected with a cup at random and thoroughly mixed. A representative sample between 20 and 160 seeds was thereafter collected from the mixed bulk and the major diameter was measured with a Neil micrometer. The ratio of the big, medium and small seeds in the representative moisture was noted. See the size classification in Table 3.1.

The characteristics of the podded and threshed materials were assessed at the various stages of threshing and cleaning. The materials were classified into categories such as whole seeds, damaged seeds, threshed pods and unthreshed pods, according to their percentage composition. Experiments were conducted in triplicates.

The characteristics of the materials discharged into the cleaning chamber from the outlet of the threshing unit, those collected at the cleaner unit and those blown out of the cleaner unit were also assessed. The frequency distribution or spread pattern of the materials collected at each of the trays from the cleaning chamber was obtained.

3.4.5 Particle Trajectory Study

Particle trajectory study in the cleaning chamber was done using a high speed camera in order to track some traced particles. Attempts to obtain motion camera for the study were abortive. Hence, a high-speed video camera was used for the study in order to have a picture of the particle trajectory in the cleaning chamber.

Some of the cowpea seeds were painted in black colour to represent trace particles. The cleaning chamber was painted white to give a visible background with grids at 25mm interval (in x and y directions) in black colour. Podded cowpeas loaded into the conveyor hopper were mixed with the traced particles so that they moved along and were discharged together with the threshed materials in the cleaning chamber.

The video recording of the materials discharged through the outlet of the thresher unit into the cleaning chamber including the trace particles was taken during the experiments. The manner in which the materials dropped in the various collection trays below the cleaning chamber was also noted.

3.4.6 Grain Classification in the Cleaning Chamber

It was observed that the video camera could not identify the trace particles despite the fact that they were painted black. Though the video camera could pick the particles moving in the cleaning chamber it could not identify colours. The video camera could not therefore do the particle tracking effectively though it could give a picture of the spread pattern of the materials deposited into the cleaning chamber. The effectiveness of the air in the cleaning chamber to separate the grains into size grades was also determined by classifying the materials collected in each of the trays in the cleaning chamber as whole cowpea seeds (broken, infested and immature seeds) and pods (unthreshed, whole, medium and small size)



3.5 STATISTICAL ANALYSIS

The data were summarized in tabular form using descriptive statistics. Statistical tools such as correlation, linear regression, stepwise regression and analysis of variance (ANOVA) were used for the analysis of the experimental data. Statistical packages such as Excel, S - Plus Professional, Harvard graphics 3.0 and SPSS Professional 10.00 packages were used.

2 – DIMENSIONAL MODELING OF PARTICLE TRAJECTORY IN A CROSS FLOW SYSTEM

The vertical and horizontal dimensions of the cleaning chamber were determined using aerodynamic principles. The models proposed by Gorial and O'Callaghan (1991a & b) were adopted and modified for a 2-D particle trajectory in a cross flow system. Gorial and O'Callaghan (1991b) examined the separation of particles in a horizontal air stream and studied the effects of air velocity and feed rate on the cleaning and grading of grains. They also studied the path of grain and threshed crop material in the horizontal air stream.

4.1 GORIAL AND O'CALLAGHAN MODEL

Gorial and O'Callaghan (1991b) observed that the separation of particle in a vertical flow could only divide a mixture into two distinct fractions - heavy and light particles. Whereas in many situations the separation problem is a more complicated and difficult one, requiring the separation of particles with similar aerodynamic properties. Therefore, they proposed a solution by introducing the particles into a horizontal air stream, which would subject the particles to lateral drift as they settle under gravity (Gorial and O'Callaghan, 1991b). Such a separation process could subdivide a mixture of particles into several fractions, deposited at different distances from the point of feed, depending on the relationship between the tendency of particle to settle vertically under gravity and the drift horizontally under the drag force of the air stream (Gorial and O'Callaghan, 1991b).

The aerodynamic drag force, F_d , exerted upon the particle by the stream of air is a function of the drag coefficient, C_d , projected area of the particle, A , the air density, ρ_a , and the relative velocity between the air and the particle, V_r , as expressed in equation 69

$$F_d = \frac{1}{2} C_d \rho_a A V_r^2 \dots\dots\dots (4.1)$$

When a particle is introduced into the air stream, the drag force accelerates the particle until it acquires the velocity of the air-stream. This acceleration, Acc , is given by

$$Acc = \frac{1}{2} C_d \rho_a (A/M) V_r^2 \dots\dots\dots (4.2)$$

Where,

M = Mass of the particle (kg)

For a grain assumed to have spherical shape and the projected area, A , obtained using diameter of equivalence sphere, d , as suggested by Gorial and O'Callaghan (1990);

$$Acc = C_d/8 (\rho_a/M) (\pi d^3/6)/(d/6) V_r^2 \dots\dots\dots (4.3)$$

Rearranging,

$$Acc = (3C_d/4) (\rho_a/\rho_p) (V_r^2/d) \dots\dots\dots (4.4)$$

Where, ρ_a and ρ_p = air and particle density respectively, kgm^{-3}

Equation (4.4) suggested that separation of small and low-density grain from the bulk can be achieved aerodynamically. Hence, if two grains of different size are

introduced into an air-stream, the acceleration imparted to the grains is dependent on their drag coefficient and the velocity of the particles relative to the air stream, and inversely to their diameters and densities. Assuming the same density and drag coefficient, for same type of grain, small grains will have a greater acceleration and hence will tend to travel a greater distance in the air- stream than larger grains. A similar conclusion could be drawn for two particles of equal size but different densities.

Gorial and O'Callaghan (1991a) also developed a mathematical (analytical) model for particle motion to simulate the path of grain and straw in air stream, and determined both the vertical (S_y) and horizontal (S_x) distances of particles from the point of feed. The resulting equations (as earlier state in eqns 2.37 and 2.39, and all the parameters as also defined) from the model are restated below:

$$S_y = \frac{V_T^2}{g} \ln \cosh \left[\frac{gt}{V_T} \right] \dots\dots\dots (2.37)$$

$$S_x = V_a t - \frac{V_T^2}{g} \ln \left[\frac{C}{\left(C + \frac{gt}{V_T} \right)} \right] \dots\dots\dots (2.39)$$

4.2 2 -D PARTICLE TRAJECTORY MODEL DEVELOPED FOR THE STUDY.

The design of the cleaning unit used for the study, particularly the determination of the lateral and vertical dimensions, is based on the model developed during this study. Gorial and O'Callaghan (1991 a & b) models stated in equations 36, 38 & 72 were adapted and modified by incorporating parameters such as particle

injection velocity of threshed material, V_i , air velocity, V_a , angle of air flow (θ), and terminal velocity, V_t , using the matlab software.

Having developed the model, the 2-D trajectory of the threshed materials injected into the cleaning unit in the x and y directions was also plotted using the matlab software for the following practicable and applicable boundary conditions: (Adedayo and Anjorin, 2000; Ademosun, 1993; Ahaneku, et al, 2003; Farran and Macmilliam, 1979; Gorla and O'Callaghan, 1991 and b; Gummert et al, 1992; Ige, 1978; Ige and Ajayi, 1979; Kashayap and Pandya, 1986; Ogunlowo and Adesoyi, 1999)

$$0.05 \leq V_i \leq 0.25 \text{ m s}^{-1}$$

$$3.6 \leq V_a \leq 7.5 \text{ ms}^{-1}$$

$$0.08 \leq V_t \leq 18 \text{ ms}^{-1}$$

$$60 \leq \theta \leq 120^\circ$$

4.2.1 Model assumptions

The following assumptions were made in developing the theoretical model to predict the particle dynamics and displacement (trajectory) for the cross flow system as supported by various authors (Ogunlowo and Coble, 2000; Rumble and Lee, 1970; Kiker and Ross, 1966; Faran and Macmillan, 1979; Gorla and O'Callaghan, 1991 a & b):

1. The average terminal velocity in both x and y direction is equal

2. The drag coefficient of the grain is constant over the range of velocity considered for the study.
3. The air flow rate is uniform
4. Only drag and gravitational forces are responsible for the movement of material
5. Particle flow is two dimensional (2D)
6. Materials are closely packed and there is free fall and no tangling.
7. Pressure drop is negligible across the system
8. Magnus effect is negligible since material shall not be feed to clogging situation.
9. The effect of temperature and environmental condition are negligible
10. The grain tend to a spherical shape
11. Influence of acceleration on drag coefficient is negligible.

4.2.2 Formulation of the theoretical model

Drag and gravitational forces were assumed to be the main factors responsible for materials movement in the system. Therefore the total forces (F_T) acting on the material is the sum of drag (F_d) and gravitational (F_g) forces.

Therefore,

$$F_T = F_d + F_g \dots\dots\dots(4.5)$$

$$F_d = C_R V_p^2 \dots\dots\dots(4.6)$$

$$F_g = Mg \dots\dots\dots(4.7)$$

$$C_R = 3/4 C_d (\rho_a/\rho_s) \dots\dots\dots (4.8)$$

$$V_p = V - V_a \dots\dots\dots(4.9)$$

Therefore,

$$F_d = 3\pi/4 d(\rho_p/\rho_a)(V - V_a)^2 \dots\dots\dots(4.10)$$

Where,

C_R = coefficient of resistant

M = mass of particle, kg

V_p = relative velocity of particle, ms^{-1}

V_a = velocity of air, ms^{-1}

V = inlet velocity of particles, ms^{-1}

For a 2D situation, equation 4.5 could be re written as stated below:

In the y – direction,

$$M \frac{dv}{dt} = C_R (V - V_a)^2 + Mg \dots\dots\dots(4.11)$$

$$\frac{dv}{dt} = C_R/M (V - V_a)^2 + g \dots\dots\dots(4.12)$$

In the x –direction,

$$M \frac{du}{dt} = C_R (U - U_a)^2 \dots\dots\dots(4.13)$$

$$\frac{du}{dt} = C_R/M (U - U_a)^2 \dots\dots\dots(4.14)$$

Where, U and U_a are particle and air velocity components respectively in x – direction.

Equations 4.12 and 4.14 were solved numerically using Fortran 77. The program is shown in Appendix 8. The numerical solution involves iteration at 0.01 second interval until a steady state was achieved. Iterative schemes are accepted numerical method for trajectory studies because of the associated high accuracy (Seibert, 1993; Kahl, 1996; Haagenson, et al., 1987)

Appendix 9 shows some typical input parameters for plotting the particle trajectory. The plots of the trajectory of the particles were (Appendix 10) also obtained using the program shown in Appendix 11. From the plot, particles 1-4

represent light material with $V_1 \leq 3.0 \text{ ms}^{-1}$ while particles 5-8 represent heavy material (whole grain) with $V_1 \geq 7 \text{ ms}^{-1}$. From Appendix 10, the heavier materials are expected to have a maximum lateral displacement of 0.8m while the lighter materials are blown off, far ahead. Also the lighter particles are expected to have a maximum of 0.6m vertical displacement. Hence, a lateral axis greater than 0.8m and a vertical axis greater than 0.6m are adequate for the separation unit.

Considering the facilities available for the trajectory study, a practicable dimension of 0.99 m x 1.3 m was used for the cleaning unit. This is to ensure that none or minimum material other than grain (MOG) does not drop in the separation chamber and to give sufficient space below the fan outlet for a force fall of the materials.



CHAPTER FIVE

RESULTS AND DISCUSSIONS

Results from the experiments were collated and the mean values are recorded in the appendices (12 to 17) together with of the statistical analyses (appendix 18).

5.1 MATERIAL CHARACTERISTICS

The axial dimensions, geometric mean characteristics, size distribution and composition of materials at various stages in the threshing and cleaning processes were used to characterize the cowpea.

5.1.1 Axial Dimensions, Geometric Mean Diameter and Size Distribution of Whole Seeds.

The mean axial dimensions and geometric mean diameter of whole seeds at the specified moisture contents are shown on Table 5.1. Appendices 12 to 14 show the details. There is no significant difference in the values of a , b , c and d_g for big, medium and small sized seeds at the various grain moisture contents, at 95% level of confidence.

5.1.2 The Size Distribution Frequency of Whole Grains in the Threshed Samples

The typical size distribution of the whole grains obtainable from the threshed samples is recorded in Table 5.2. The big, medium and small sized seeds have a mean diameter of 7.64, 6.23 and 4.35 mm and standard deviation of 0.53, 0.56 and 0.42 respectively. Results from Table 5.2 indicated that the big sized seeds constituted the highest percentage of the seeds in the randomly selected threshed samples, consisting of 62.5% of the whole sample. The medium sized seeds constituted 29% while the small sized seeds constituted only 2.5%. The low percentage contribution of the

small sized seeds is as a result of the relatively high rate of insect infestations of this category of seeds, which was prominently visible.

Table 2: Axial Dimensions (a, b and c) and Geometric Mean Diameter of Whole Seeds at Specified Grain Moisture Content

Seed Size	Sample Population	Axial Dimension and Geometric Mean Diameter at Different Moisture Content											
		15.30%				17.20%				18.80%			
		a	b	c	dg	a	b	c	dg	a	b	c	dg
Big	50	8.06	6.49	4.64	6.4	8.04	6.33	4.61	6.33	7.76	6.39	4.43	6.19
Medium	50	6.11	5.47	4.43	5.34	7.18	6.06	4.35	5.86	6.11	5.64	3.96	5.24
Small	50	4.37	3.48	3.04	3.75	4.69	4.59	3.43	4.24	4.76	4.51	3.5	4.25

a = major diameter (mm)

b = minor diameter (mm)

c = thickness (mm)

dg = geometric mean diameter (mm)

Table 3: Size Distribution of Whole Seeds in the Threshed Samples

Description	Sample population	Range (mm)	Mean (mm)	Std deviation (mm)
Big seed	100	7.02-9.82	7.64	0.53
Medium seed	56	5.09-6.96	6.23	0.56
Small seeds	4	3.86-4.90	4.35	0.42
Combined sample	160	3.86-9.82	7.07	0.96

5.1.3 Classification of Materials Collected in the Cleaner Trays

The materials collected in the trays at the cleaning chamber were classified as shown in Table 5.3. The materials are classified into three main groups namely whole cowpea seeds, damaged cowpea seeds and pods, with other sub divisions as shown on the Table.

Table 5.3: Classification of Materials in the Trays in the Cleaning Chamber

Material	Specification	Size range (mm)
Cowpea (Whole Seeds)	Big size	$7.00 < x < 10.00$
	Medium size	$5.00 < x < 7.00$
	Small size	$3.80 < x < 4.99$
Cowpea (Damaged Seeds)	Broken seeds	< 5.00
	Infested seeds	$3 < x < 10.00$
	immature seeds	< 3.00
Pods	Unthreshed	$40 < L < 120$
	Whole size	$100 < L < 120$
	Medium size	$40 < L < 99$
	Small size	$5 < L < 39$

5.1.4 Composition of Threshed Materials

Figures 5.1 to 5.4 show the percentage composition of the threshed materials at the various stages of threshing and cleaning. The pod content of the unthreshed cowpea loaded into the conveyor ranged between 60 to 72% for the three pod moisture levels, with 22% PMC having the highest.(Fig 18). The whole seed content

ranged between 20 and 22% while the damaged seed ranged between 8 and 19%. The damage done to the seeds before threshing was due to insect infestation. The poded materials were stored for a reasonable period before testing the equipment.

The material loaded into the conveyor for threshing, despite the relatively high level of infestation, was adjudged acceptable for the study from the viewpoint of the heterogeneous nature of the material. Though the damaged seeds had similar axial dimensions with whole seeds the densities and terminal velocities were not the same. Hence, the behaviour in airflow differed.

The losses that occurred at the exit end of the conveyor unit is due to the clearance between the conveyor exit and the inlet hopper of threshing unit, resulting in a difference in the values of % composition between Figures 5.1 and 5.2, though the respective bar charts had similar pattern for all the pod moisture contents. Higher percentage of whole damaged seeds were loss at PMC of 18 and 22%.

Fig 5.3 shows that percentage unthreshed seed was least at 14% PMC. The percentage pod content was highest at 22% PMC. The PMC was close to 80% at 22.0% PMC. The pods being the outermost part would have absorbed more moisture compared to the seeds.

The greatest percentage of pods or poded material could not pass through the thresher screen into the cleaning unit as shown on Fig. 5.4. In fact, at 14% moisture content, no single pod or poded material was discharged into the cleaning unit. Only 2 to 3% of such materials were found in the cleaning unit at 18 and 22% PMC. The screen of the threshing unit is therefore adjudged effective.

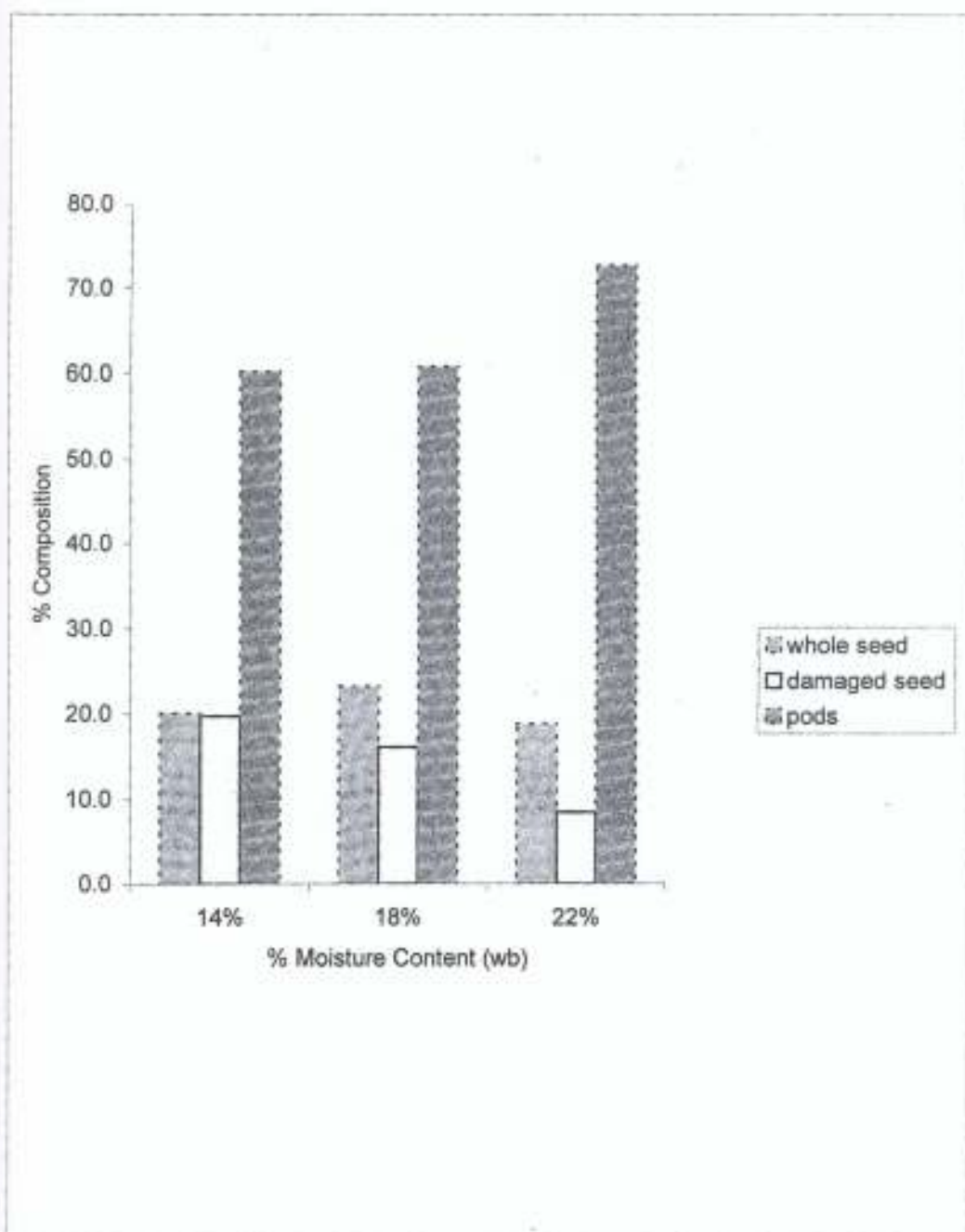


Fig. 5.1: Percentage Composition of the Various Component of Materials loaded into the Conveyor at different Moisture Contents

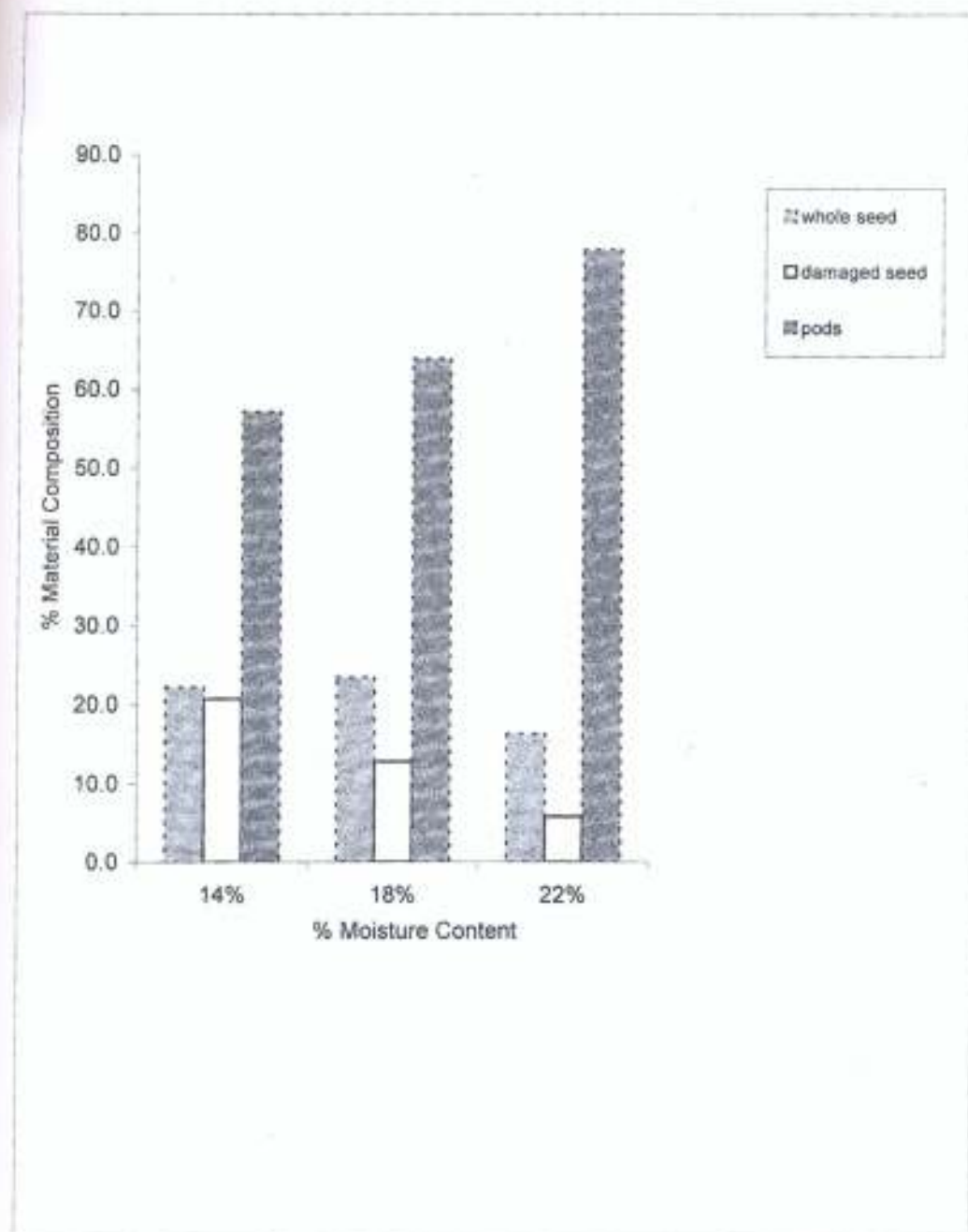


Fig. 5.2: Percentage Composition of the Various Component of Materials discharged into the Threshing Unit at different Moisture Content

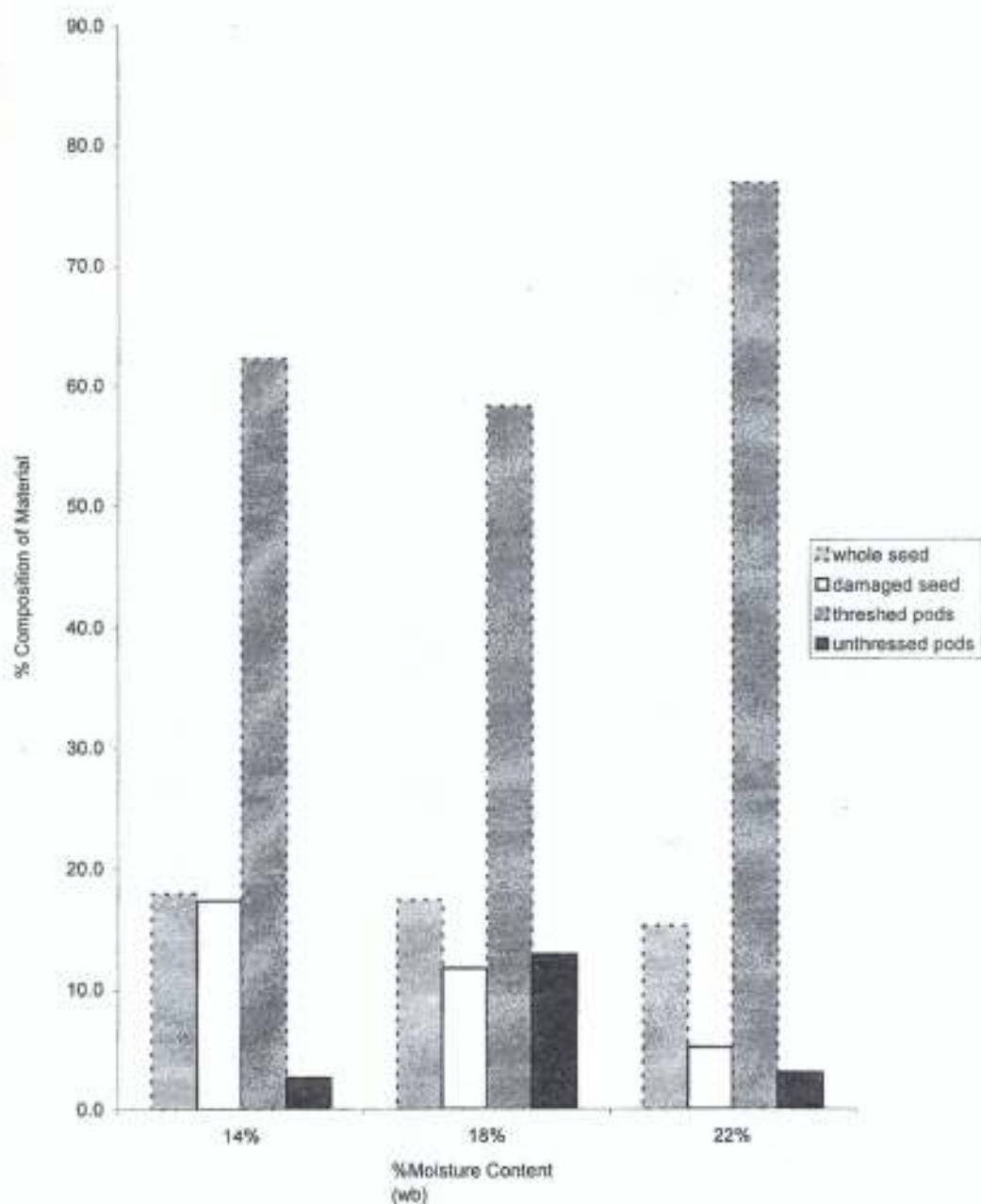


Fig. 5.3: Percentage Composition of the Various Component of Materials loaded into the Cleaning Unit and different Moisture Content

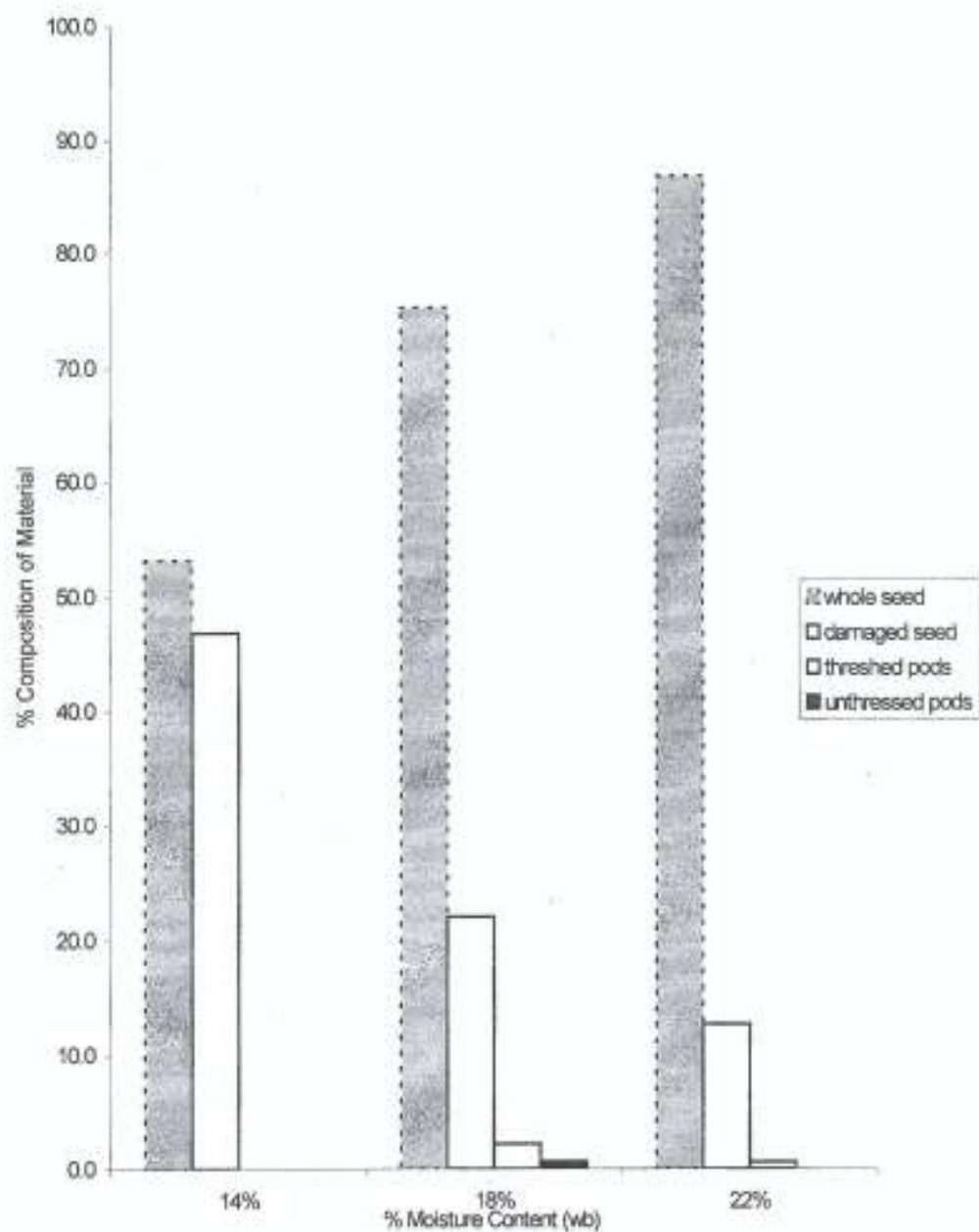


Fig. 5.4: Percentage Composition of Various Components of Material Collected from the cleaning unit

5.2 CONVEYOR AND THRESHING EFFICIENCIES

The conveyor loss and the efficiency of the threshing unit were evaluated. Figures 5.5 and 5.6 present the overall mean results for conveyor and threshing efficiency respectively. Appendix 5 shows the summary of the experimental result. The conveyor efficiency ranged from 56.9% to 74.0%, 53.2% to 73.9% and 60.1% to 79.1%, for moisture content of 14.0%, 18.0% and 22.0% respectively with mean values of 64.6%, 67.2% and 70.3% respectively. The threshing efficiency ranged from 67.5% to 97.7%, 77.1% to 94.4% and 83.1% to 97.0% for same moisture content. The respective mean values are 83.4%, 86.7% and 84.4%.

There is no significant difference in the conveyor loss and the threshing efficiency for moisture content of 14%, 18% and 22% at 95 and 99% level of confidence. This is a contradiction to established trend, but is expected because the experiment was not conducted for material dried from higher moisture level to a lower. The material was allowed to absorb moisture from a lower level of 14.0% to a higher level 22.0%. Cracking and splitting of the pods was already initiated at PMC of 14.0%.

ANOVA was conducted to observe significant differences between the conveyor efficiencies and the threshing efficiencies at the various moisture levels (See appendix 16). There was equally no significant difference at 95% level of confidence

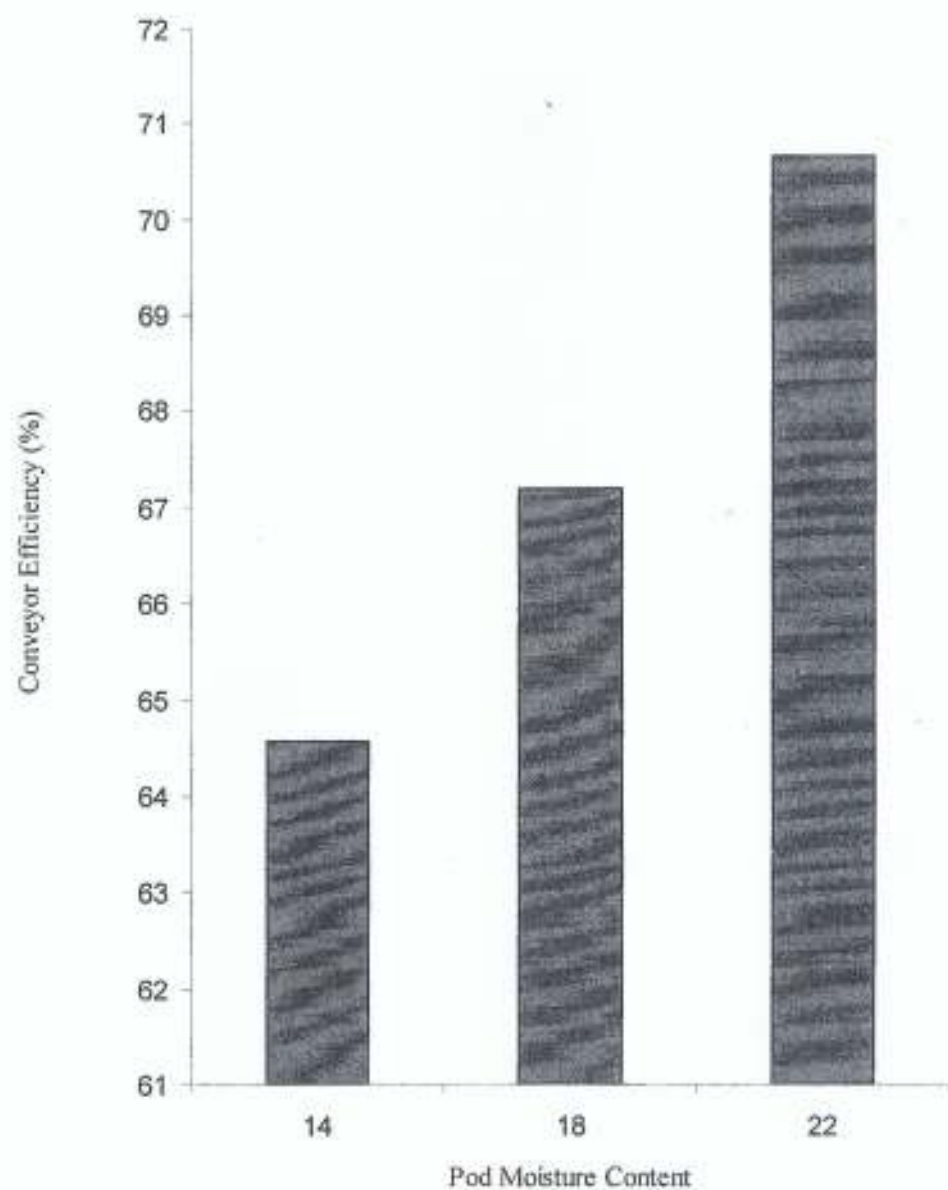


Fig. 5.5: Mean Conveyor Efficiency at various Pod Moisture Content

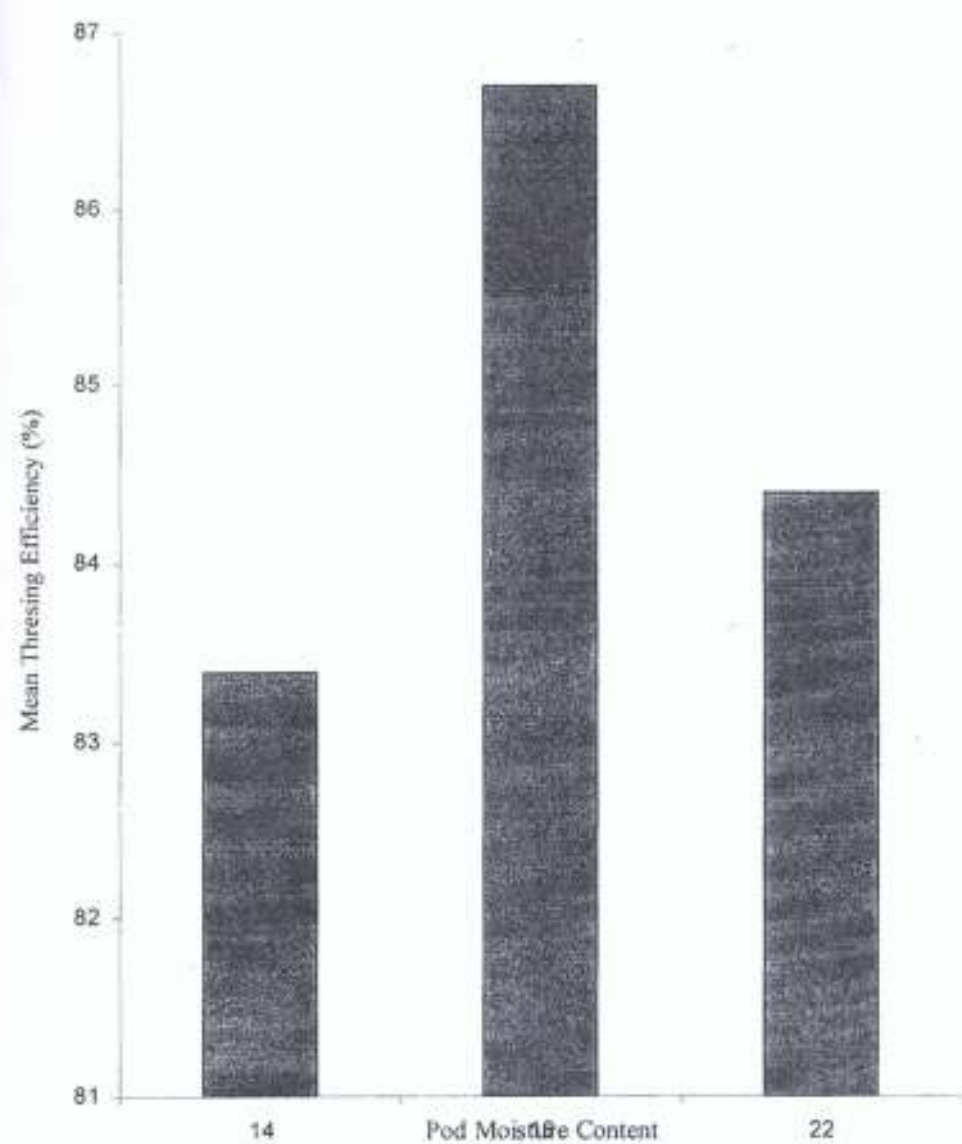


Fig. 5.6: Mean Threshing Efficiency at various Pod Moisture Contents

5.3 SPREAD PATTERN OF MATERIALS IN THE CLEANING CHAMBER

5.3.1 Particle Trajectory Study

A high-speed video camera was used to observe and monitor the particles trajectory in the cleaning chamber during the experiment. The initial aim was to track trace particles and study the trajectory of each of the trace particles in the x and y directions, and to study the spread pattern of the materials deposited in the tray of the cleaning chamber.

The video camera was however not sensitive enough to identify the trace particles but could clearly show the spread of the materials in the cleaning chamber. Plate 5.1 shows the picture of the spread of the materials in the chamber. It is a very good spread and supports the proposal that cross flow systems could be an aerodynamic solution to the problem of particle classification and grading encountered in cross flow systems such as the vertical air separator (Gorial and O'Callaghan, 1991a and b; Farran and Macmillan, 1979; Macmillan, 1999).

Whereas Gorial and O'Callaghan's proposed theory is for cereal grain grading, the spread in Plate 5.1 also verifies that legume grain grading is also possible in cross flow system.

5.3.2 Spread Pattern of Materials Deposited in the Cleaning Chamber

The objective in grading grains is to remove particles that are light or small as well as damaged grains (Gorial and O'Callaghan, 1991b). Therefore the spread pattern of materials in the cleaning chamber relative to the distance from the plane at which the materials are discharged was studied in order to investigate the separation of seeds from material other than grains and the grading of seeds in the horizontal air stream.

It was however observed that majority of the small sized damaged seeds were recovered at the exit end of the threshing unit and the largest proportion of the large sized damaged seeds were deposited into the cleaning unit. Therefore, the damaged seeds were uniformly mixed with the big, medium and small sized whole seed in the trays. This may be because the big sized damaged seeds have comparable terminal velocity with the big, medium and small sized whole seeds depending on the extent of damage and were therefore spatially distributed within the whole seeds in the collecting trays in the cleaning chamber.

From the Tables in Appendix 17 it was generally observed that majority of the materials deposited in the cleaning chamber were void of pods and where pods were found, the percentage of pods (whole, medium or small) and unthreshed pods deposited into the cleaning chamber was relatively small. It was also observed that the pods absorbed more moisture relative to the seeds. Hence, the density of the pods seems to appreciate as the moisture content increased.

Figures 5.7 to 5.20 show the spread pattern of material in the cleaning chamber at specified angle of inclination of fan (θ), grain moisture content (GMC), and fan speed (V_f). The mean data used to obtain Figs. 5.7 to 5.20 are shown in Appendix 17. The data were entered and converted to percentages using excel package, transposed with S-Plus Professional package, while the plots/ graphs (Figs 5.7 to 5.20) were obtained using Harvard graphics 3.0 package. The data were re-transposed using S-Plus and the fit models or regression equations were obtained using SPSS 10.0 package (See Tables 5.4 to 5.15). The regress models were fitted using the approach of Ordinary Least Squares (OLS) so as to get the estimate coefficient of the models, R^2 , and corresponding standard error, t-value and significant value.

A simple computer program was written to generate the output of the OLS result as shown below:

REGRESSSION

/ MISSING LISTWISE

/ STATISTIC CO-EFFICIENT OUTS R ANOVA

/ CRITERA = PIN (0.05) POUT (0.10)

/ NO ORIGIN

/ DEPENDENT Var y_n

/ METHOD = ENTER Var x

The print out of results of the regression analysis for the plots on Figs. 5.7 to 5.20 is shown in Appendix 18. The summary of the regression equations for each of the plot in Figures 5.7 to 5.20 is shown in Tables 5.4 to 5.15 respectively.

The spread pattern of materials in the cleaning chamber relative to the distance from the plane at which the materials are discharged was studied in order to investigate the separation of seeds from material other than grains and the grading of seeds in the horizontal air stream. Figs. 5.7–5.20 show the spread pattern obtained under specified conditions of pod and grain moisture contents, fan speed and fan angle of inclination using the S-Plus and Harvard professional soft wares.

It was generally observed that majority of the materials recovered in the cleaning chamber have a negligible percentage of pods (whole, medium, small and unthreshed pods). Such materials recovered in the cleaning chamber were relatively small in magnitude, mostly less than 1% of the total materials recovered in the cleaning chamber. They were mostly blown out of the cleaning chamber. This is an indication of the effectiveness of the cleaner to remove pods from bulk material loaded into it.

In most of the cases at fan speed of 900 rpm and for all angles of fan inclination of 90 and 105°, more than 85% of the whole seeds were recovered within the first three trays, that is, at a distance of 37.5 cm from the entry point (Figs. 5.7 – 5.12). As the angle of fan inclination increased, to 120° at same fan speed of 900 rpm, the trend gradually changed such that the majority of the materials recovered in the cleaning chamber moved beyond the third tray (Figs. 5.13 – 5.15). But, this trend was not the same at fan speed of 1,500 rpm and fan angle of inclination of 120° (Figs. 5.18 - 5.20). The trend observed in Figs. 5.16 and 5.17 is similar to that observed in Figs. 5.13 – 5.15 but, sizable percentage of whole grains were retained within the first three trays while the highest percentage of the other materials were blown beyond the third tray or outside the cleaning unit.

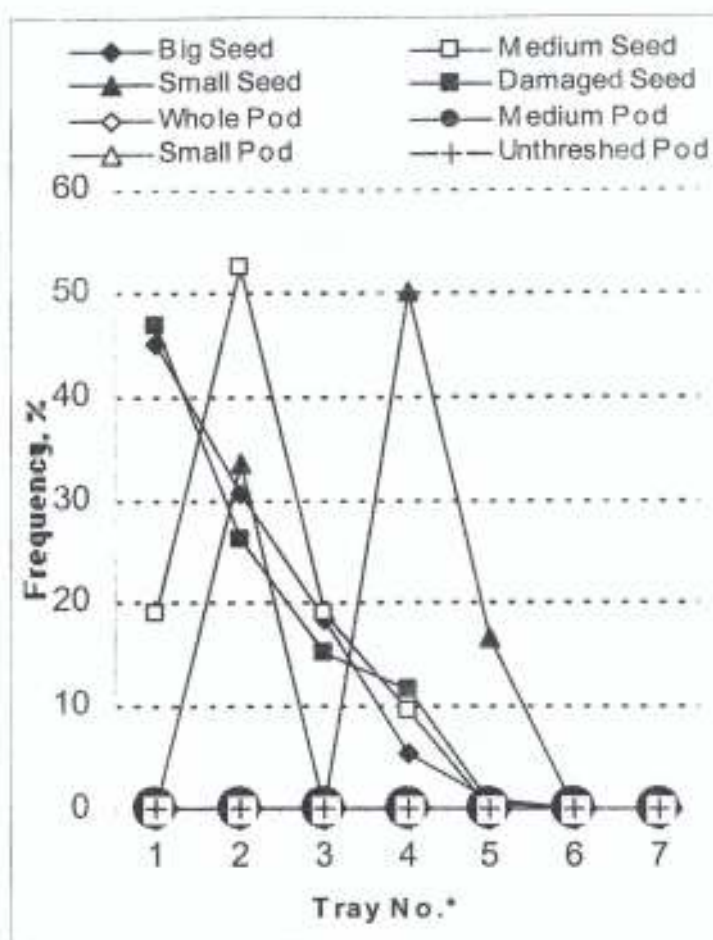


Fig. 5.7: Spread pattern of material in the trays at $\theta = 90^\circ$, PMC = 14.0%, GMC = 15.3 % and V = 900 rpm

* The distance from the entry point or horizontal displacement of materials equivalent to the tray No. 1, 2, 3, 4, 5, 6 and 7 is 12.5, 26.0, 38.0, 50.0, 62.0, 74.5 and 87.0 cm respectively

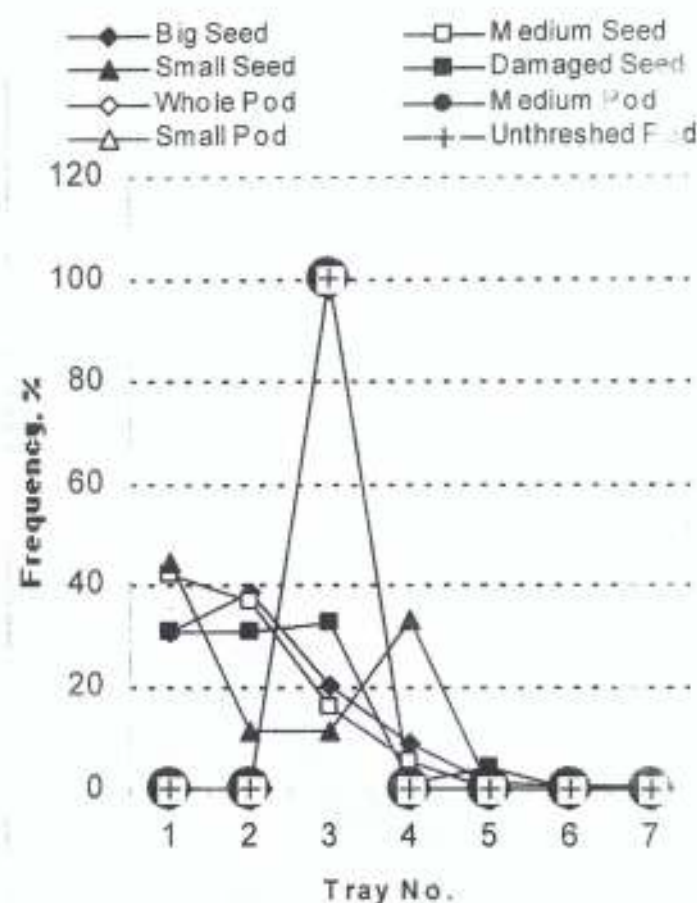


Fig. 5.8: Spread pattern of material in the trays at $\theta = 90^\circ$, PMC = 18.0%, GMC=17.2% and V = 900 rpm

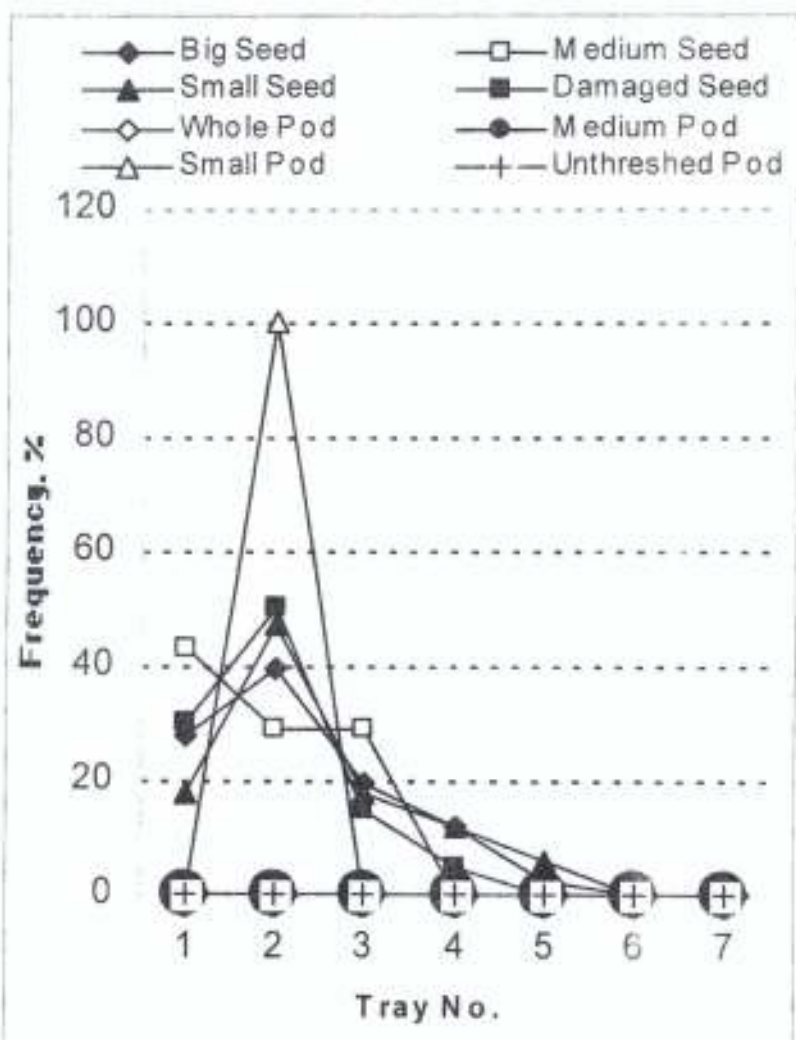


Fig. 5.9: Spread pattern of material in the trays at $\theta = 90^\circ$, PMC = 22.0%, GMC = 18.8 % and V = 900 rpm

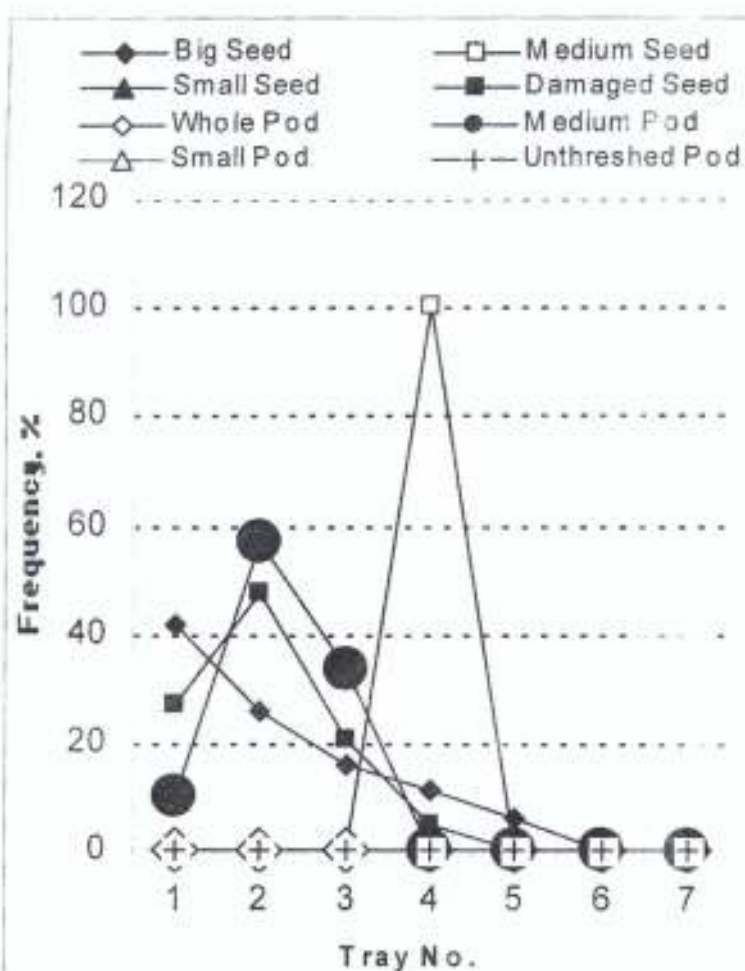


Fig.5.10: Spread pattern of material in the trays at $\theta = 105^\circ$, PMC = 18.0%, GMC = 17.2 % and V = 900 rpm

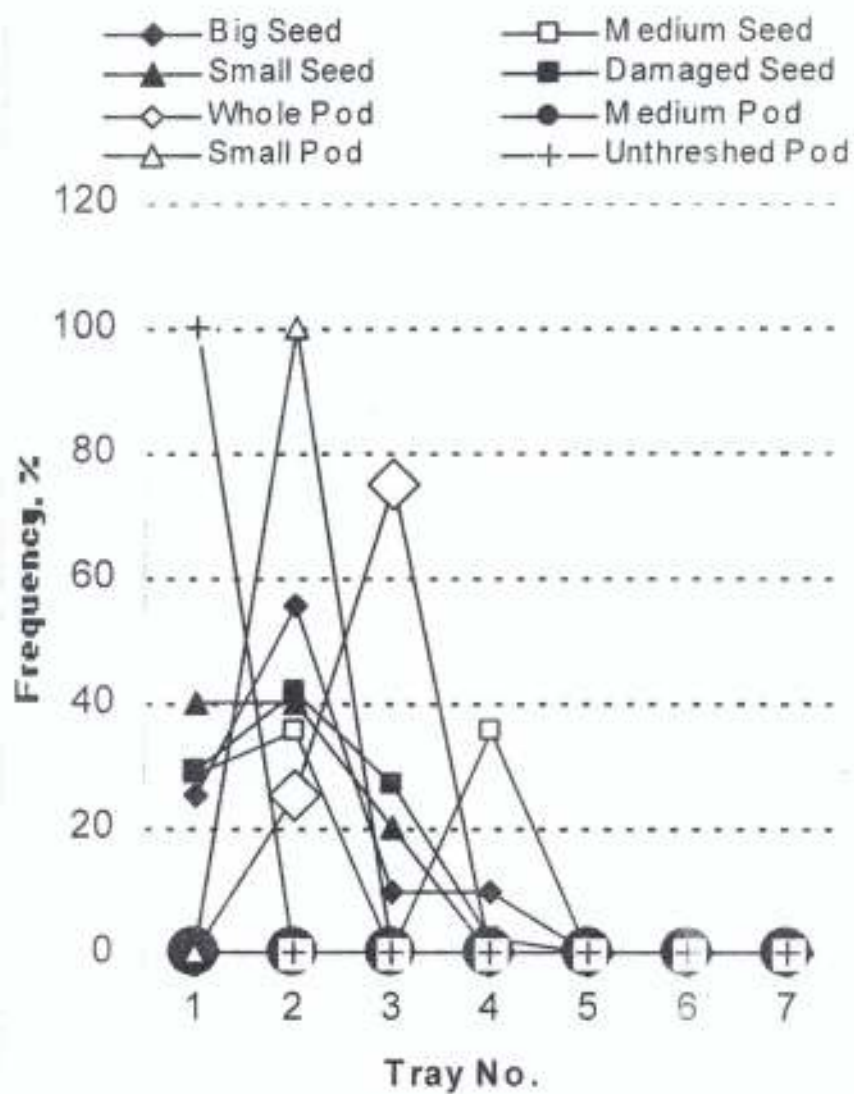


Fig. 5.11: Spread pattern of material in the trays at $\theta = 105^\circ$, PMC = 14.0%, GMC=15.3% and V = 900 rpm

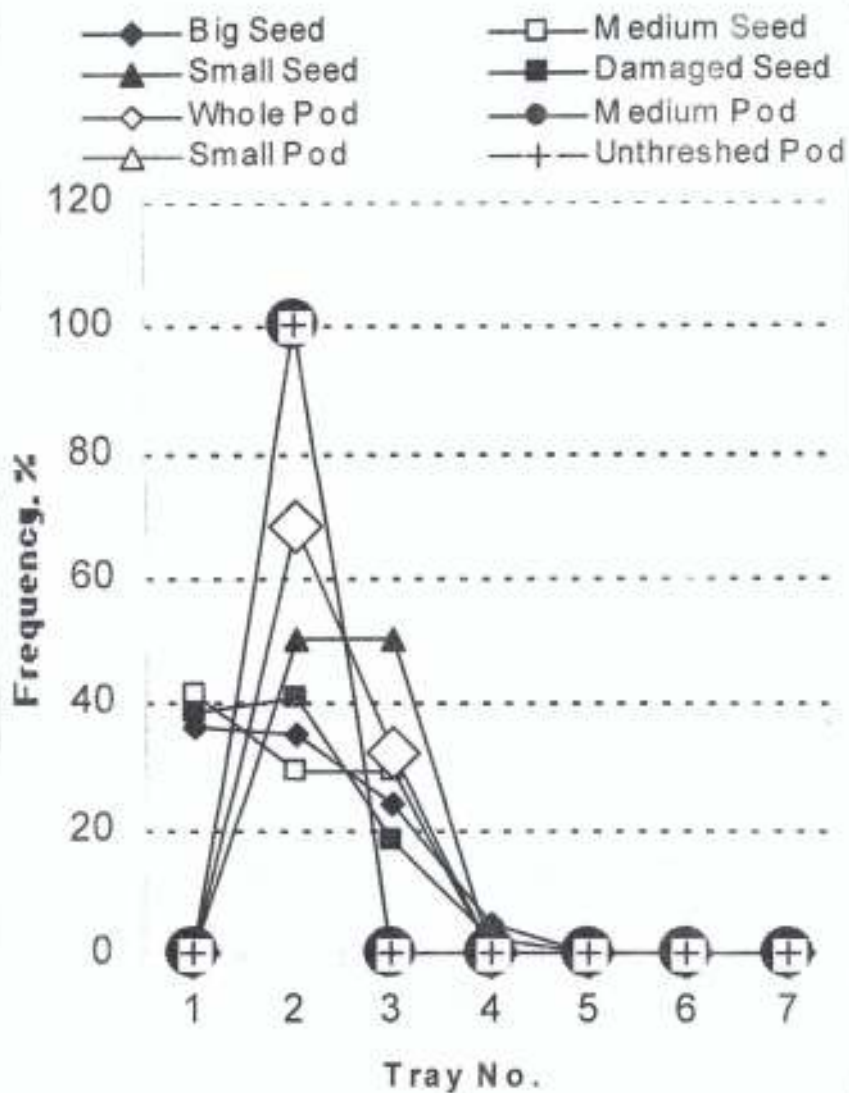


Fig. 5.12: Spread pattern of material in the trays at $\theta = 105^\circ$, PMC = 22.0%, GMC = 18.8% and V = 900 rpm

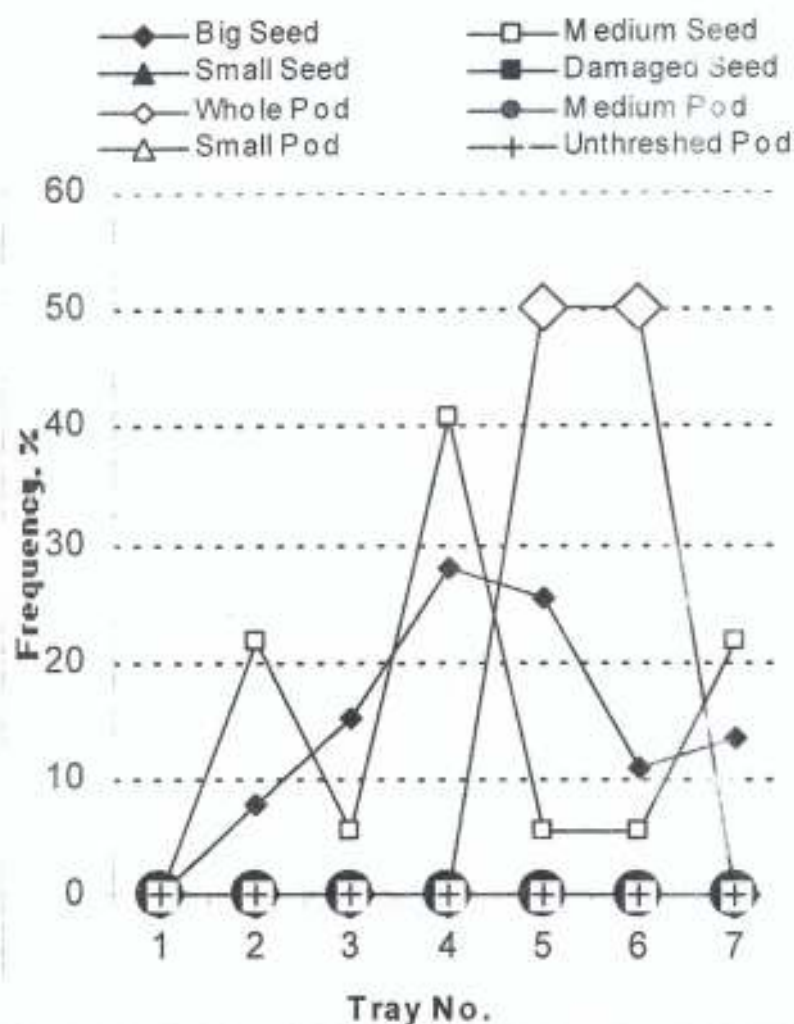


Fig. 5.13: Spread pattern of material in the trays at $\theta = 120^\circ$, $PMC = 14.0\%$, $GMC = 15.3\%$ and $V = 900$ rpm

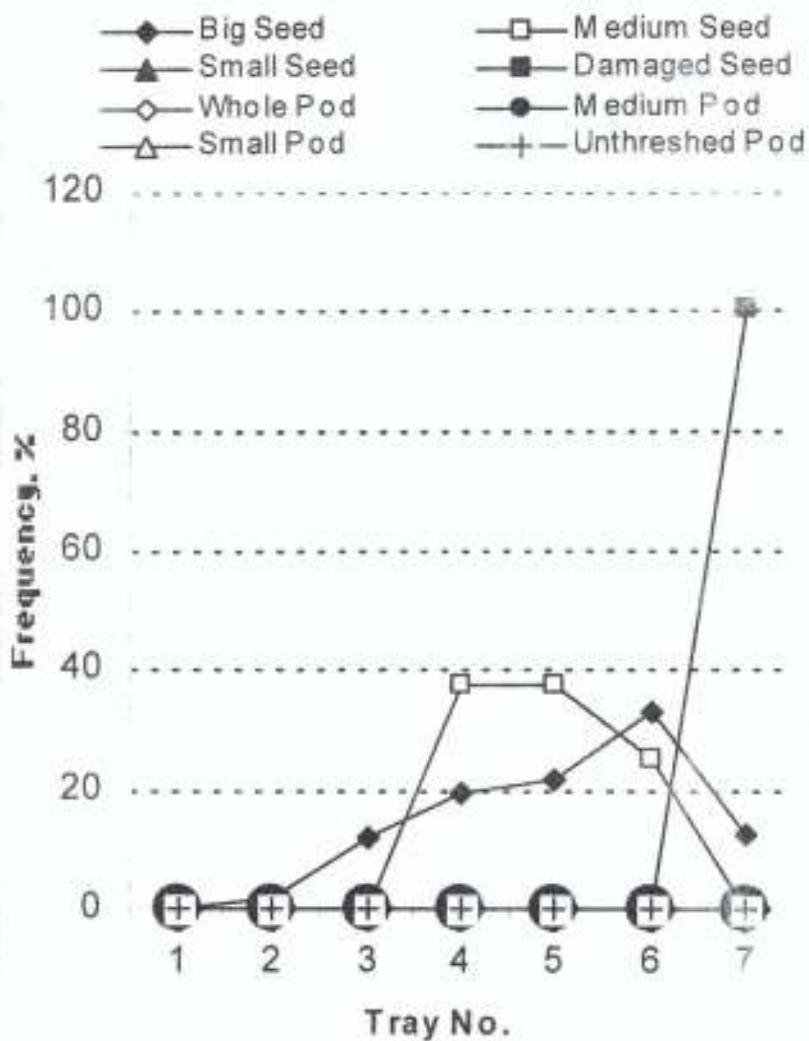


Fig. 5.14: Spread pattern of material in the trays at $\theta = 120^\circ$, PMC = 18.0%, GMC=17.2% and $V = 900$ rpm

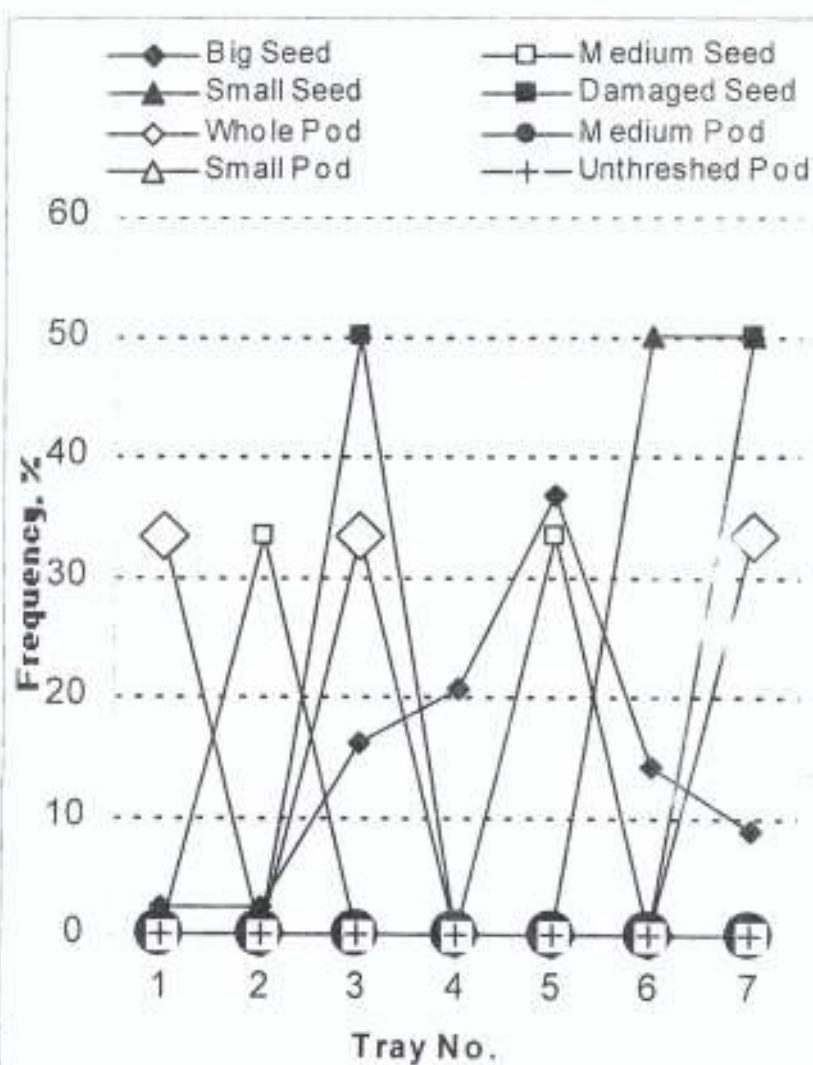


Fig. 5.15: Spread pattern of material in the trays at $\theta = 120^\circ$, PMC = 22.0%, GMC = 18.8% and $V = 900$ rpm

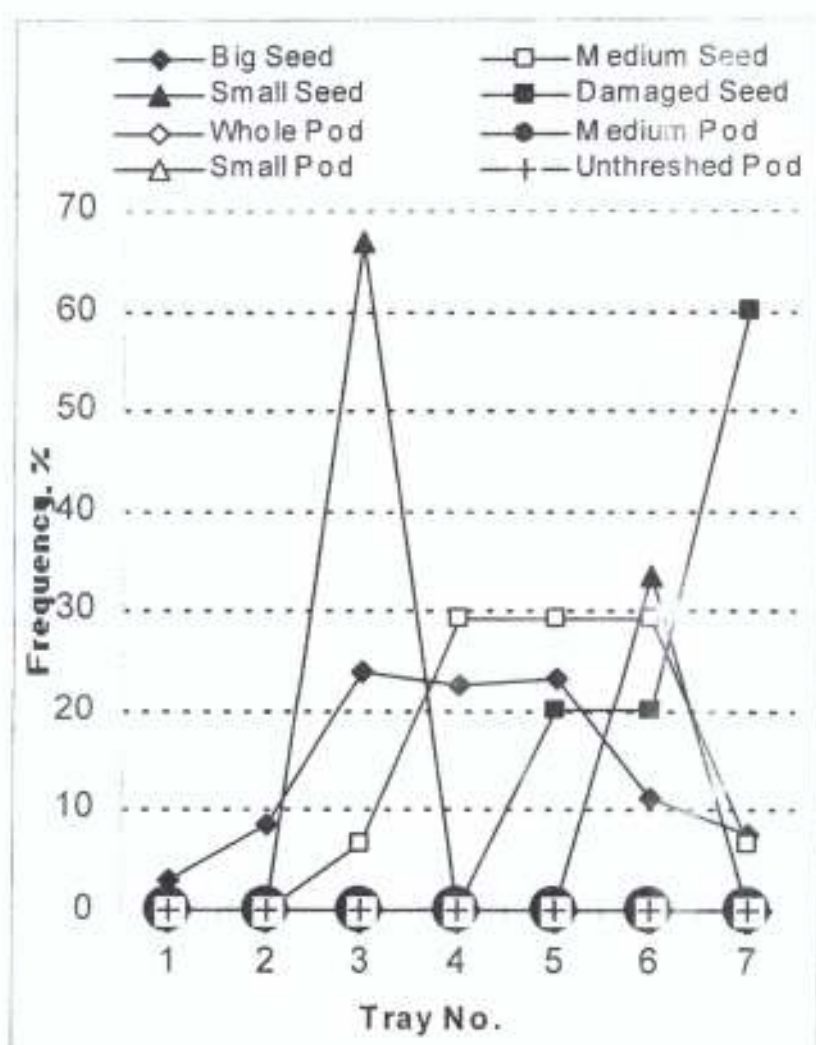


Fig. 5.16: Spread pattern of material in the trays at $\theta = 90^\circ$, PMC = 22.0%, GMC = 18.8 % and $V = 1500$ rpm

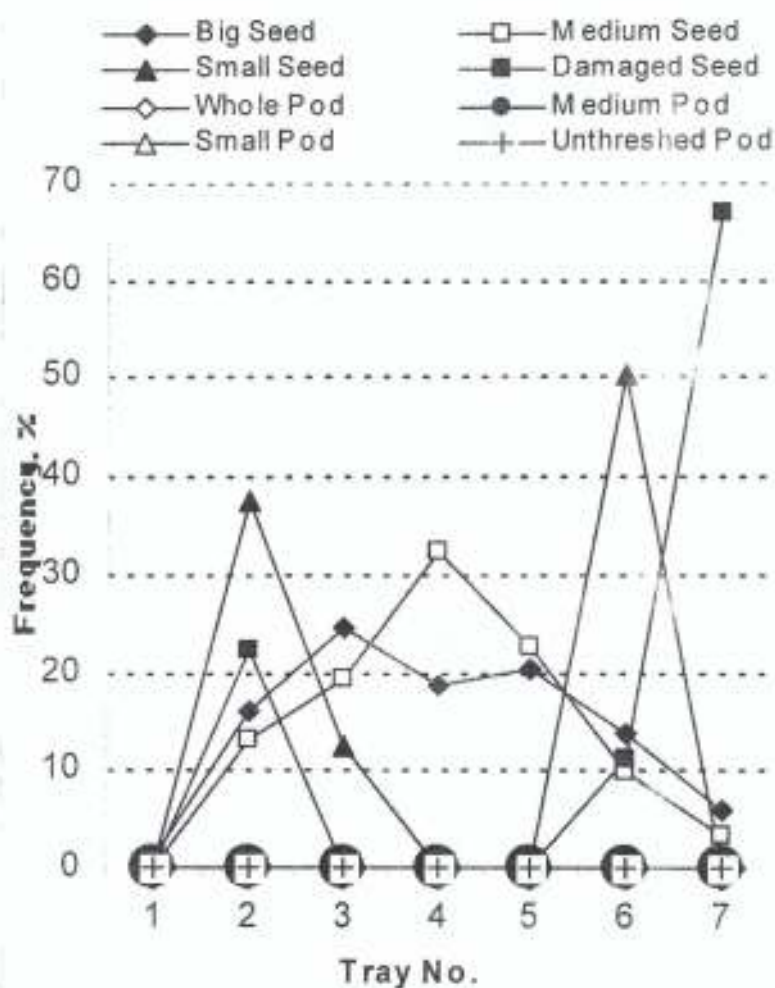


Fig. 5.17: Spread pattern of material in the trays at $\theta = 105^\circ$, FMC = 14.0%, GMC = 15.3% and $V = 1500\text{rpm}$

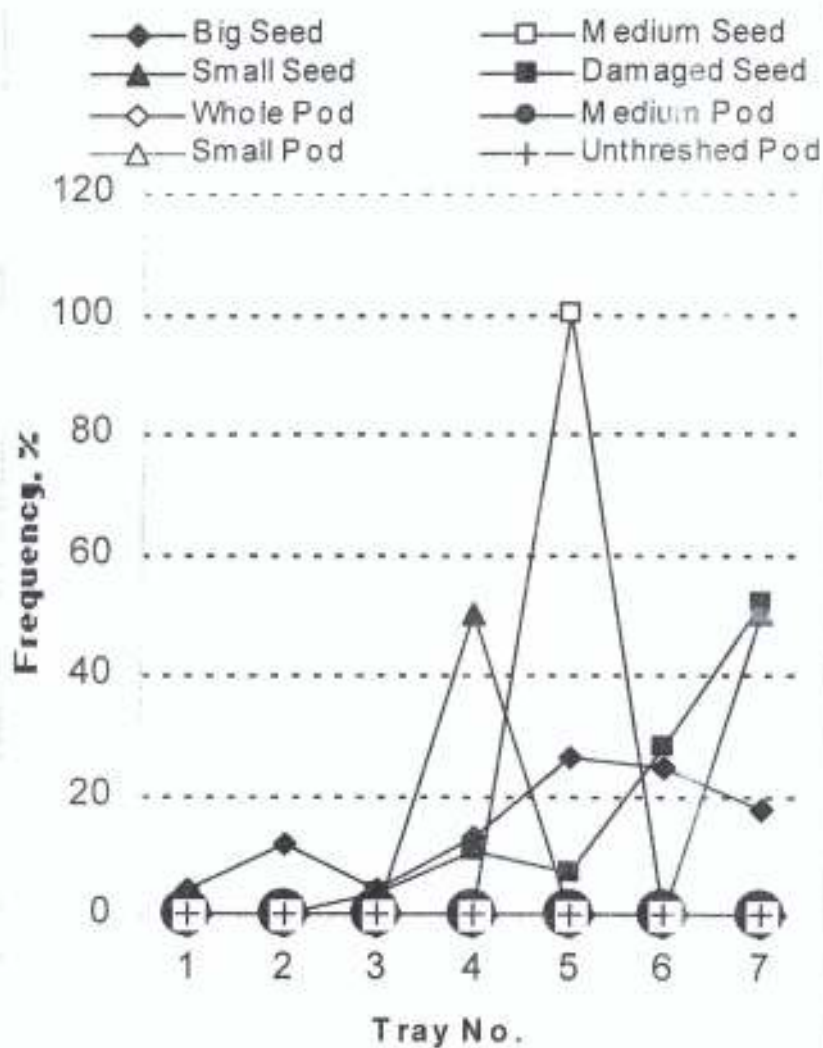


Fig. 5.18: Spread pattern of material in the trays at $\theta = 120^\circ$, PMC = 14.0%, GMC = 15.3% and $V = 1500\text{rpm}$

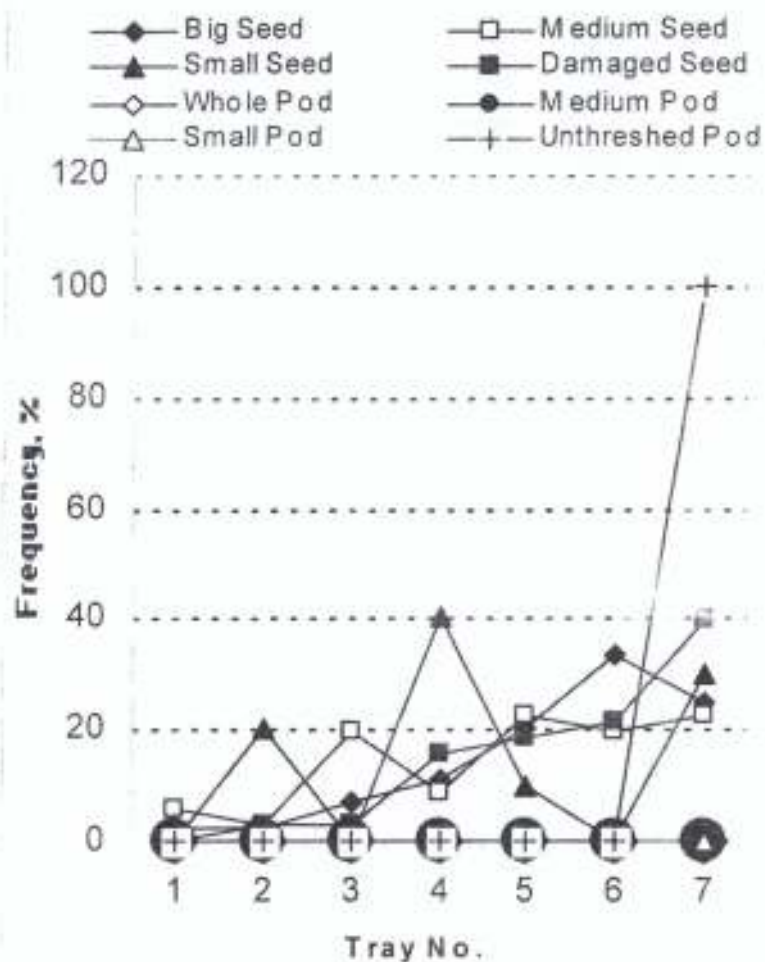


Fig. 5.19: Spread pattern of material in the trays at $\theta = 120^\circ$, PMC = 18.0%, GMC = 17.2% and $V = 1500\text{rpm}$

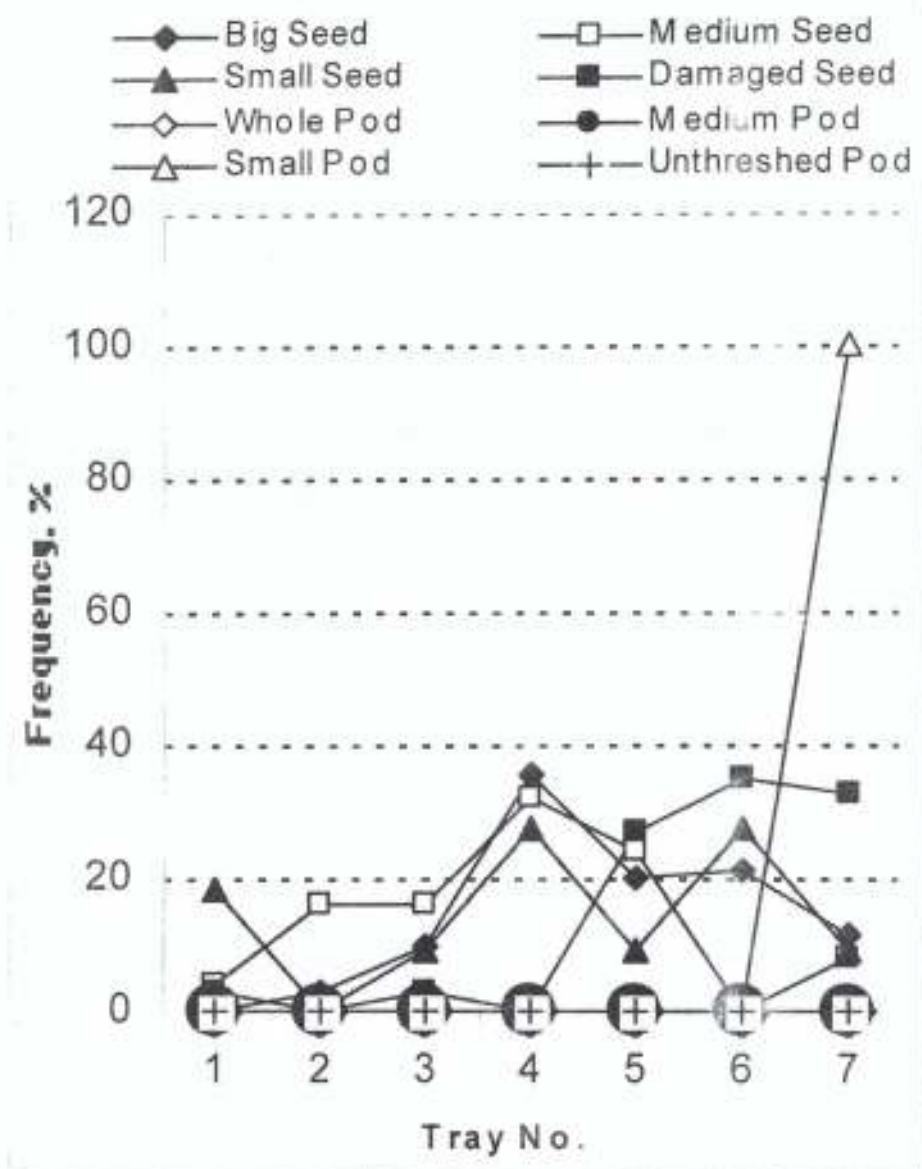


Fig. 5.20: Spread pattern of material in the trays at $\theta = 120^\circ$, PMC = 22.0%, GMC = 18.8 % and V = 1500 rpm

It should be noted that Figs. 5.16 and 5.17 showed the case at fan speed of 1500 rpm and fan inclination of 90 and 105° respectively (less than 120°). The trend observed in Figs. 5.7 – 5.12 was completely reverse at fan speed of 1500 rpm and fan inclination of 120°, where 85% and more of the whole seeds were recovered beyond tray No. 3 (Fig. 5.18 – 5.20). These changes in trend of material distribution could be associated with the combined effects of the moisture contents of pod and grain, angle of inclination of the fan and magnitude of the drag force generated by the fan at the high speed.

The effect of the angle of inclination could not seriously contribute to increase the drag of material at fan speed of 900 rpm (Figs. 5.7 – 5.15). Also, the effect of fan speed of 1500 rpm could not seriously contribute to increase the drag of material at angles of inclinations of 90 and 105° (Figs. 5.16 and 5.17). But, at high fan speed and high angle of inclination, the change in trend was glaring. Therefore, the combined effect of the high angle of inclination of the fan and the high fan speed would have contributed to the change in trend. A higher drag is expected at higher speed and the approach of air at higher angle of inclination must have resulted in the change in trend. Hence the materials were deposited at further distance for a fan inclination and speed of 120, and 1,500 rpm respectively, compare to the other conditions under experimentation.

This change or shift in trend is suggestive. It is suggested that the fan speed and inclination for optimal performance of the cleaner unit may lie between 900-1500 rpm and 105-120° respectively. This deduction or suggestion may require further experiments in the nearest future to verify, but the likelihood may be correct because of the shift in trend observed. There is therefore the need to balance the selection of operating and machine parameters to optimize the performance of the machine

It was generally observed that majority of the small sized damaged seeds were recovered at the exit end or outside of the cleaning chamber and the largest proportion of the large sized damaged seeds were obtained in the cleaning unit. These damaged seeds obtained in the cleaning chamber were uniformly mixed with the big, medium and small sized whole seed in the trays. This is because the big sized damaged seeds are presumed to have comparable terminal velocity with the big, medium and small sized whole seeds depending on the extent of damage and were therefore spatially distributed within the whole seeds in the collecting trays in the cleaning chamber. The removal of damaged grain before loading the cleaner will likely improve the effectiveness of the cleaner to grade grains into size grades. It is therefore suggested that insect infection (leading to infested/ damaged seeds) should be minimal for grains loaded into the cleaner. This shall aid the cleaner to further classify grains into size grades, under the operating conditions of the experiments.

The summary of the regression equations obtained for the individual plots in Figs 5.7 – 5.20 for the various components of the threshed materials are shown in Tables 5.4 – 5.18 respectively.

Table: 5.4 Regression Equations for Figure 5.7

Material Type	Regression Equation	R ²
Big seeds	$y = 45.616 - 0.628x$	0.867
Medium seeds	$y = 40.411 - 0.5255x$	0.538
Small seeds	$y = 21.295 - 0.141x$	0.033
Damaged seeds	$y = 44.604 - 0.608x$	0.861

Table: 5.5 Regression Equations for Figure 5.8

Material Type	Regression Equation	R ²
Big seeds	$y = 41.438 - 0.545x$	0.834
Medium seeds	$y = 45.858 - 0.633x$	0.813
Small seeds	$y = 38.846 - 0.493x$	0.531
Damaged seeds	$y = 40.855 - 0.533x$	0.765
Whole pods	$y = 28.475 - 0.285x$	0.039
Medium pods	$y = 28.475 - 0.285x$	0.039
Small pods	$y = 28.475 - 0.285x$	0.039
Unthreshed pods	$y = 28.475 - 0.285x$	0.039

Table: 5.6 Regression Equations for Figure 5. 9

Material Type	Regression Equation	R ²
Big seeds	$y = 40.097 - 0.518x$	0.814
Medium seeds	$y = 45.656 - 0.629x$	0.808
Small seeds	$y = 37.238 - 0.460x$	0.558
Damaged seeds	$y = 44.091 - 0.598x$	0.670
Small pods	$y = 42.895 - 0.579x$	0.159

Table: 5.7 Regression Equations for Figure 5.10

Material Type	Regression Equation	R ²
Big seeds	$y = 42.784 - 0.572x$	0.611
Medium seeds	$y = 37.113 - 0.458x$	0.452
Small seeds	$y = 46.425 - 0.645x$	0.797
Damaged seeds	$y = 42.866 - 0.573x$	0.763
Whole pods	$y = 32.065 - 0.357x$	0.110
Small pods	$y = 42.835 - 0.573x$	0.159
Unthreshed pods	$y = 58.990 - 0.897x$	0.391

Table: 5.8 Regression Equations for Figure 5.11

Material Type	Regression Equation	R^2
Big seeds	$y = 41.613 - 0.548x$	0.912
Medium seeds	$y = 14.115 - 0.003429x$	0.000
Damaged seeds	$y = 42.863 - 0.573x$	0.679
Medium pods	$y = 39.633 - 0.509x$	0.361

Table: 5.9 Regression Equations for Figure 5.12

Material Type	Regression Equation	R^2
Big seeds	$y = 43.954 - 0.595x$	0.857
Medium seeds	$y = 45.263 - 0.621x$	0.805
Small seeds	$y = 35.655 - 0.429x$	0.214
Damaged seeds	$y = 45.776 - 0.632x$	0.804
Whole pods	$y = 38.226 - 0.481x$	0.228
Medium pods	$y = 42.835 - 0.573x$	0.159
Small pods	$y = 42.835 - 0.573x$	0.159
Unthreshed pods	$y = 46.250 - 0.675x$	0.144

Table: 5.10 Regression Equations for Figure 5.13

Material Type	Regression Equation	R ²
Big seeds	$y = 1.417 + 0.258x$	0.591
Medium seeds	$y = -0.245 + 0.291x$	0.041
Small seeds	$y = -7.425 + 0.432x$	0.221
Damaged seeds	$y = -16.751 + 0.623x$	0.713

Table: 5.11 Regression Equations for Figure 5.14

Material Type	Regression Equation	R ²
Big seeds	$y = -6.468 + 0.416x$	0.842
Medium seeds	$y = 1.733 + 0.252x$	0.624
Small seeds	$y = 5.499 + 0.176x$	0.082
Damaged seeds	$y = -10.574 + 0.499x$	0.881
Unthreshed pods	$y = -28.965 + 0.867x$	0.366

Table: 5.12 Regression Equations for Figure 5.15

Material Type	Regression Equation	R^2
Big seeds	$y = 2.460 + 0.237x$	0.267
Medium seeds	$y = 15.910 - 0.0326x$	0.006
Small seeds	$y = 10.362 + 0.07871x$	0.040
Damaged seeds	$y = -12.438 + 0.536x$	0.747
Small pods	$y = -28.965 + 0.867x$	0.366

Table: 5.13 Regression Equations for Figure 5.16

Material Type	Regression Equation	R^2
Big seeds	$y = 96.837 - 0.480x$	0.661
Medium seeds	$y = 11.323 + 0.08635x$	0.048
Small seeds	$y = 2.830 + 0.03551x$	0.018
Damaged seeds	$y = -10.126 + 0.350x$	0.397

Table: 5.14 Regression Equations for Figure 5.17

Material Type	Regression Equation	R^2
Big seeds	$y = 0.000 + 1.000x$	1.000
Medium seeds	$y = 111.621 - 0.621x$	0.947
Small seeds	$y = -3.030 + 0.305x$	0.504
Damaged seeds	$y = 0.980 + 0.004416x$	0.004
Whole pods	$y = -9.251 + 0.298x$	0.558

Table: 5.15 Regression Equations for Figure 5.18

Material Type	Regression Equation	R^2
Big seeds	$y = 31.168 + 0.535x$	0.248
Medium seeds	$y = 21.747 - 0.04121x$	0.004
Small seeds	$y = -3.025 + 0.118x$	0.170
Damaged seeds	$y = -8.313 + 0.249x$	0.366
Whole pods	$y = -1.277 + 0.04968x$	0.170

Table: 5.16 Regression Equations for Figure 5.19

Material Type	Regression Equation	R ²
Big seeds	$y = 49.990 + 0.537x$	0.157
Medium seeds	$y = 1.157 + 0.06706x$	0.080
Damaged seeds	$y = -4.895 + 0.147x$	0.366
Whole pods	$y = -4.605 + 0.138x$	0.366

Table: 5.17 Regression Equations for Figure 5.20

Material Type	Regression Equation	R ²
Big seeds	$y = 59.350 + 0.281x$	0.108
Medium seeds	$y = 17.697 - 0.160x$	0.053
Small seeds	$y = -5.596 + 0.185x$	0.619
Damaged seeds	$y = -0.832 + 0.082830x$	0.148
Whole pods	$y = 28.664 - 0.367x$	0.280

Grain infestations by insect should be minimized for effective performance of the cleaning chamber of the machine. Where insect infestation is minimized, the cleaning chamber would not only separate the pods from the grains but also classify the grains into size grades. The optimum performance of the cleaner unit is likely obtainable with fan speed of 900 – 1500 rpm and fan angle of inclination of $105 - 120^\circ$.

It was found that the distribution of the small, medium and big whole grains and damaged grains in the cleaning chamber could be predicted by a linear function. The linear regression equations obtained for most of the grains can therefore be used to predict the distribution of the grains in the cleaning chamber, under the conditions of the experiment. The R^2 values for the pods (whole, medium, small and unthreshed) on the other hand, are relatively low, mostly less than 0.4. This indicates spatial and non linear distribution, and are not adequate enough for predicting their distribution.

Table 5.4 – 5.17 show the linear regression equations and R^2 values for the trajectory spread patterns for each of the materials plotted in Fig 5.7 – 5.20 respectively. The equation shows the line of best fit to predict the spread of each of the materials. It is observed from Tables 5.4 – 5.17 that big, medium, small and damaged seeds mostly have relatively high R^2 values ($0.6 < R^2 < 1.0$). This shows a good linear relationship between the % frequency and the position/ distance of displacement of materials and indicating a good spread of the materials in the cleaning chamber.

At $\Theta = 90^\circ$, PMC = 14.0%, GMC= 15.3 %, and V = 900 rpm (Table 5.4), big and damaged seeds had very strong positive correlation ($R^2 = 0.867$ and 0.861 respectively) with the medium seeds having fair positive correlation ($R^2 =$

0.538). There was very poor correlation for small seeds ($R^2 = 0.033$) while none of the other category of materials was found in the tray. At $\Theta = 90^\circ$, PMC = 18.0%, GMC=17.2% and V = 900 rpm (Table 5.5), big, medium and damaged seeds had very strong positive correlation ($R^2 = 0.834, 0.813$ and 0.765 respectively) with the small seeds having fair positive correlation ($R^2 = 0.531$). There was a very poor ($R^2 = 0.039$) correlation for all the pod materials.

At $\Theta = 90^\circ$, PMC = 22.0%, GMC = 18.8 % and V = 900 rpm (Table 5.6), big and medium seeds had very strong positive correlation ($R^2 = 0.814$ and 0.808 respectively) with the small and damaged seeds having fair positive correlation ($R^2 = 0.558$ and 0.670 respectively). There was a very poor ($R^2 = 0.159$) correlation for small pods while none of the other category of materials was found in the tray. At $\Theta = 105^\circ$, PMC = 18.0%, GMC = 17.2 % and V = 900 rpm (Table 5.7), small and damaged seeds had very strong positive correlation ($R^2 = 0.797$ and 0.763 respectively) with the big seeds having fair positive correlation ($R^2 = 0.611$). There was weak correlation for medium seeds ($R^2 = 0.452$), and poor correlation whole, small and unthreshed pods ($R^2 = 0.110, 0.159$ and 0.391 respectively).

At $\Theta = 105^\circ$, PMC = 14.0%, GMC = 15.3% and V = 900 rpm (Tables 5.8), big seeds had very strong positive correlation ($R^2 = 0.812$) with the damaged seeds having fair positive correlation ($R^2 = 0.679$). There was poor correlation for medium pods ($R^2 = 0.361$) while none of the other category of materials was found in the tray. At $\Theta = 105^\circ$, PMC = 22.0%, GMC = 18.8% and V

900 rpm (Table 5.9), big, medium and damaged seeds had very strong positive correlation ($R^2 = 0.857, 0.805, \text{ and } 0.804$ respectively). There was a very poor correlation for small seeds, whole, medium, small and unthreshed pods ($R^2 = 0.214, 0.228, 0.159, 0.159 \text{ and } 0.144$ respectively).

At $\Theta = 120^\circ$, $\text{PMC} = 14.0\%$, $\text{GMC} = 15.3\%$ and $V = 900 \text{ rpm}$ (Table 5.10), only the damaged seeds had strong positive correlation ($R^2 = 0.743$) while the big seeds had fair correlation ($R^2 = 0.591$). Medium and small seeds had very poor correlations ($R^2 = 0.041$ and 0.221 respectively) and none of the other category of materials was found in the tray. At $\Theta = 120^\circ$, $\text{PMC} = 18.0\%$, $\text{GMC} = 17.2\%$ and $V = 900 \text{ rpm}$ (Table 5.11), big and damaged seeds had strong positive correlation ($R^2 = 0.842$ and 0.881 respectively) while medium seeds had fair correlations ($R^2 = 0.624$). Unthreshed pods had weak correlation and small seeds had very poor correlation. None of the other category of materials was found in the tray.

At $\Theta = 120^\circ$, $\text{PMC} = 22.0\%$, $\text{GMC} = 18.8\%$ and $V = 900 \text{ rpm}$ (Table 5.12), only the damaged seeds had strong positive correlation ($R^2 = 0.747$) while the small pods had weak correlation. Big, medium and small seeds had very poor correlation and none of the other category of materials was found in the tray.

At $\Theta = 90^\circ$, $\text{PMC} = 22.0\%$, $\text{GMC} = 18.8\%$ and $V = 1500 \text{ rpm}$ (Table 5.13), none of the seeds also has very strong correlation ($R^2 = \geq 0.700$) But, big seeds had fair strong positive correlation ($R^2 = 0.661$). Damaged seeds had weak

correlation ($R^2 = 0.397$). There was very poor correlation for medium and small seeds ($R^2 = 0.048$ and 0.018 respectively) while none of the other category of materials was found in the tray. At $\Theta = 105^\circ$, $PMC = 14.0\%$, $GMC = 15.3\%$ and $V = 1500\text{rpm}$ (Table 5.14), big and medium seeds had very strong positive correlation ($R^2 = 1.000$ and 0.947 respectively) with the small seeds and whole pods having fair positive correlation ($R^2 = 0.504$ and 0.558 respectively). There was very poor correlation for damaged seeds ($R^2 = 0.004$) while none of the other category of materials was found in the tray.

At $\Theta = 120^\circ$, $PMC = 14.0\%$, $GMC = 15.3\%$ and $V = 1500\text{ rpm}$ (Table 5.15), none of the material has strong correlation ($R^2 \geq 0.700$). The big, medium, small and damaged seeds and the whole pods had very poor correlation ($R^2 = 0.248$, 0.004 , 0.170 , 0.366 and 0.170 respectively) while none of the other category of materials was found in the tray. Similar situations were obtained at $\Theta = 120^\circ$, $PMC = 18.0\%$, $GMC = 17.2\%$ and $V = 1500\text{rpm}$ (Table 5.16).

At $\Theta = 120^\circ$, $PMC = 22.0\%$, $GMC = 18.8\%$ and $V = 1500\text{ rpm}$ (Table 5.17), none of the seeds also has very strong correlation ($R^2 = \geq 0.700$) But, small seeds had fairly strong positive correlation ($R^2 = 0.619$). There was very poor correlation for big, medium and damaged seeds, and whole pods ($R^2 = 0.108$, 0.053 , 0.148 and 0.280) while none of the other category of materials was found in the tray.

CHAPTER SIX

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDIES

6.1 CONCLUSION

Threshing, cleaning and grading of crops are essential primary procedures that determine the final quality of agricultural materials. The combination of cleaning and grading processes in one operation has a lot of advantages including the reduction of unit cost and bulkiness of machine, simplicity and ease of operation and maintenance.

Aerodynamic cleaning and grading is especially advantageous in large-scale equipment such as the combine harvester. An equipment for threshing and cleaning legume crops therefore has been developed and tested. The following conclusion could be drawn from the study:

- The performance of the thresher and cleaning equipment is adequate enough to be adapted as test rig for threshing and cleaning research.
- The performance of the equipment could be further improved by introduction of improved and precision fabrication techniques.
- The research ascertained the possibility of seed cleaning using horizontal air flow.
- The aerodynamic model developed adequately predicted the dimension of the cleaner chamber because the grains did not spread beyond the designed dimensions, as observed in the spread pattern of the materials in the cleaning chamber.
- Results obtained in the cleaning unit indicated the largest percentage of the whole seeds were deposited at a distance 50 mm from the entry point

while the majority of the damaged seeds and materials other than grains (MOG) could be retrieved beyond 50 mm away from the entry point

6.2 SUGGESTIONS FOR FURTHER STUDIES

In the opinion of the author, the following further modifications when added to the present system will lead to an efficient threshing, cleaning and classification of legume crops/grains:

1. Provide more driven pulleys for conveying, threshing and fan units or in the alternative provide variable speed electric motors to drive those units such that the speed of the conveyor, thresher and centrifugal fan would be varied to enhance further studies.
2. Losses between the exit of the conveyor and the entrance of the threshing unit should be minimized to the barest. The hopper of the threshing unit should be reconstructed.
3. The lowest end of the conveyor should also be reconstructed to minimize losses.
4. Safety guides should be provided for the transmission systems.
5. The gritting of the cleaning chamber should be boldly and directly printed on its inner surface using stencils.

The equipment is recommended for threshing and cleaning other soft coat legume such as soybean and pigeon pea. After effecting the modifications suggested and installing measuring devices, the equipment is recommended for conducting a number of researches including:

1. Interactions between crop, machine, and operational parameters affecting legume threshing.
2. Air-particle interaction in cross-flow systems.

3. Material transport in cross flow systems.
4. Aerodynamic modeling of particle flow in a cross flow air stream.

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LIST OF APPENDICES

APPENDIX 1

BILL OF QUANTITY OF THE EQUIPMENT

A. Conveyor Unit

Materials	Specifications	Qty.	Unit Cost (₦)	Total Cost (₦)
Sheet Metal	Gauge 18	1½	1,700.00	2,550.00
Angle Iron	1½"	3	700.00	2,100.00
Belt	Reinforced leather	5m	1,200.00	6,000.00
Roller	■ 10cm x 30cm	3	1,500.00	4,500.00
Pillow Block Bearing	■ 25mm	6	500.00	3,000.00
Bolt and Nut	M12	18	25	450.00
Bolt and Nut	M5	8	5.00	40.00
Rivets	■ 5mm	10 doz.	40.00	400.00
Electrode	Olecon	¼ pkt	1,000.00	500.00
Hack saw	Normal size	4pcs	100.00	400.00
Shaft	■ 25mm	65cm	650.00	650.00
Paint	Silver	3l	300.00	900.00
			Total	21,490.00

B. Threshing Unit

Materials	Specifications	Qty	Unit Cost (₦)	Total Cost (₦)
Sheet Metal	Gauge 18	1	1,700.00	1,700.00
Threshing drum	■ 18cm Iron pipe	1	1,200.00	1,200.00
Iron bar	8cm x 99.5cm	10	200.00	2,000.00
Iron rod	3/8"	2	230.00	460.00
Iron rod	¼"	4	90.00	360.00
Sheet Metal	Gauge 14	½	3,000.00	1,500.00
Pillow Block Bearing	■ 25mm	2	500.00	1,000.00
Shaft	■ 25mm x 80cm	1	800.00	800.00
Bolt and Nut	M12	4pcs	25.00	100.00
Bolt and Nut	M8	8pcs	20.00	160.00
Angle Iron	1½"	4	700.00	2,800.00
Electrode	Olecon	½ pkt	1,000.00	500.00
Hack saw blade	Normal size	4pcs	100.00	400.00
Paint	Silver	4l	300.00	1,200.00
			Total	14280.00

C. Cleaning Unit

Materials	Specifications	Qty	Unit Cost (₦)	Total Cost (₦)
Sheet Metal	Gauge 18	1½	1,700.00	2,550.00
Perspex Glass	¼" thick	1	5,000.00	5,000.00
Fan Blade	■ 20	1	500.00	500.00
Shaft	■ 25cm x 60cm	1	600.00	600.00
Angle Iron	1"	2	500.00	1,000.00
Angle Iron	1½"	½	700.00	350.00
Bolt and Nut	M12	10	25.00	250.00
Bolt and Nut	M10	2	20.00	40.00
Bolt and Nut	M5	20	5.00	100.00
Pillow Block Bearing	■ 25mm	2	500.00	1,000.00
Electrode	Olecon	½ pkt	1,000.00	500.00
Hack saw	Normal length	3 pcs	100.00	300.00
Paint	White	1l	300.00	300.00
Paint	Red oxide	1l	300.00	300.00
			Total	12,750.00

D. Transmission System

Materials	Specifications	Qty	Unit Cost (₦)	Total Cost (₦)
Fan Belt	12.5 x 2250	1	350.00	350.00
Fan Belt	1.25 x 1950	1	250.60	250.00
Fan Belt	1.25 x 1350 mm	1	200.00	200.00
Wood	½" x 18" x 12"	1	1,500.00	1,500.00
Shaft	■ 32mm x 60cm	1	600.00	600.00
Plate	■ 8cm x 6mm thick	11	150.00	1,650.00
Bolt and Nut	M8	36	10.00	360.00
Idler pulley	■ 8	1	500.00	500.00
Aluminum pulley	■ 7 and ■ 8	2	1,500.00	300.00
Sheet Metal	Gauge 20	1	1,500.00	1,500.00
			Total	9,910.00

E. Cost of purchase of material = A + B + C + D = N58,430.00

F. Other Expenses

Description	Specifications	Qty	Unit Cost (₦)	Total Cost (₦)
Transportation	-	-	-	2,500.00
Machining work	Pulley and hub	9	500.00	2,700.00
Machine work	Shaft	1.5cm	1,500.00	1,500.00
Electric motor	3phase, 1hp	1	15,000.00	15,000.00
Electric Motor	3 phase 3hp	1	40,000.00	40,000.00
Workmanship	Fabrication	All units	-	20,000.00
			Total	84,000.00

G. Production cost outside Electric Motor = E + ₦29,000.00 = 87,430.00

H. Total cost of production = E + F = ₦142,430.00

APPENDIX 2

DESIGN RELATED PHYSICAL PROPERTIES OF COWPEA (IT 812 - 994)

Properties	Sample population	Range	Mean	Standard deviation
Seed moisture content, % *	8	14.04 - 18.75	15.53	1.48
Pod moisture content, % *	6	9.52 - 17.5	13.42	3.00
Stem moisture content, % *	14	23.08 - 76.49	65.84	13.33
Good seed: Immature seed, by weight	15	-	3.2:1	-
Pod: seed: stem, by weight	15	-	1:2.4:4.8	-
Stem length, cm	15	7.5 - 23.0	14.48	5.89
Pod length, cm	39	4.5 - 17.0	11.82	3.57
Stem diameter mm	15	3.45 - 7.87	5.79	1.35
Matured seed length, mm	100	7.70 - 11.99	9.67	1.45
Matured seed width, mm	100	6.00 - 8.22	6.88	0.44
Matured seed thickness, mm	100	4.74 - 6.60	5.07	0.52
Immature seed length, mm	100	5.21 - 9.77	7.30	1.10
Immature seed width, mm	100	4.12 - 6.75	5.56	1.91
Immature seed thickness, mm	100	2.84 - 5.87	4.28	0.65
Weight per 1000 seed (matured seeds), g	17	190 - 220	206	12.20
Weight per 1000 seeds (immature seeds), g	11	80 - 120	90	12.40
No. of pod per stem	15	2 - 9	3	1.92
No. of seeds per pod	60	4 - 12	7	2.4
Unit weight of seed, g	100	0.0955 - 0.2818	0.1906	0.051

* Moisture content on wet basis

APPENDIX 3

DESIGN RELATED PHYSICAL PROPERTIES OF COWPEA (IT 81D – 994)

Properties	Sample population	Range	Mean	Standard deviation
Seed moisture content, % *	6	16.92 – 18.00	17.45	0.34
Pod moisture content, % *	5	13.04 – 22.86	18.34	3.14
Stem moisture content, % *	14	66.07 – 80.95	74.95	4.21
Good seed: Immature seed, by weight	14	-	2:1	-
Pod: seed: stem, by weight	14	-	1:2.7:6	-
Stem length, cm	14	13.5 – 23.0	20.10	3.41
Pod length, cm	41	5.0 – 17.0	10.56	3.5
Stem diameter, mm	14	3.15 – 7.89	5.79	1.35
Matured seed length, mm	100	8.35 – 10.66	9.55	1.25
Matured seed width, mm	100	5.69 – 8.19	7.05	0.52
Matured seed thickness, mm	100	4.24 – 6.00	5.21	0.52
Immature seed length, mm	100	5.24 – 10.96	8.45	1.46
Immature seed width, mm	100	3.45 – 7.84	5.74	1.01
Immature seed thickness, mm	100	2.49 – 6.11	4.10	0.00
Weight per 1000 seed (matured seeds), g	12	200 – 260	240	19.00
Weight per 1000 seeds (immature seeds), g	11	90 – 150	130	20.00
No. of pod per stem	14	1 – 13	3	2.94
No. of seeds per pod	40	4 – 11	7	2.02
Unit weight of seed, g	90	0.0889 – 0.2857	0.1923	0.0493

*Moisture content on wet basis

APPENDIX 4

DESIGN RELATED PHYSICAL PROPERTIES OF SOYBEAN(TGX 448-2E)

Properties	Sample population	Range	Mean	Standard deviation
Seed moisture content, % *	8	46.43 – 75.86	62.46	9.94
Pod moisture content, % *	8	46.15 – 95.45	70.48	18.63
Stem moisture content, % *	10	44.74 – 86.36	64.49	15.42
Good seed: Immature seed, by weight	12	-	3.4:1	-
Pod: seed: stem, by weight	12	-	1:1.1:1.2	-
Stem length, cm	21	20.00 – 35.30	26.40	4.20
Pod length, cm	90	2.20 – 4.30	3.41	0.39
Stem diameter, mm	21	20.00 – 35.30	26.40	1.16
Matured seed length, mm	100	5.59 – 11.77	7.88	2.18
Matured seed width, mm	100	4.03 – 6.79	5.47	0.48
Matured seed thickness, mm	100	3.12 – 5.93	4.22	0.52
Immature seed thickness, mm				
Weight per 1000 seed (matured seeds), g	44	80 – 160	129	23.80
Weight per 1000 seeds (immature seeds), g	8	10 – 40	18.80	11.00
No. of pod per stem	12	12 – 70	32.67	17.87
No. of seeds per pod	250	1.8 – 2.1	2.00	0.19
Unit weight of seed, g	400	0.063 – 0.176	0.116	0.037

*Moisture content on wet basis

APPENDIX 5

DESIGN CALCULATIONS

The design procedures and calculations for the flight conveyor, threshing unit, and centrifugal fan are as reported

5.1 FLIGHT CONVEYOR DESIGN

A. Design Specifications Data:

- * Average bulk density of legumes (Cowpea/Soybean), $\ell = 481\text{b/ft}^3$
 $= 768\text{ kgm}^{-3}$
 (ASAE 1970)
- * Conveyor Speed, S:
 $50 \leq S \leq 100\text{ ft/min}$ (Kulweic, 1985 and Jacob, 1988.
 i.e, $0.25 \leq S \leq 0.51\text{ ms}^{-1}$ $32 \leq N \leq 64\text{ rps}$
- selected belt width, $w = 12''$ (30 cm)
- selected angle of inclination of conveyor $\theta = 60^\circ$
- selected conveyor capacity, $T = 0.35\text{ ton/hr}$
- selected maximum conveyor height, $h = 2.20\text{ m}$

B. Determination of the Depth, d, of the Flights:

Schultz (1985) expressed the relationship for estimating the capacity of conveyor, T, as stated in equation (1)

$$T = \frac{\ell w d l N}{3.6} \dots\dots\dots (1)$$

Where,

$$\frac{l^0}{l} l = \text{length of conveyor carrying side}$$

$$l = h/\sin = 2.34 \text{ m}$$

hence,

$$d = \frac{3.6T}{\ell w l N} \dots\dots\dots (2)$$

For a maximum speed of 64 rps, $d = 4 \text{ cm}$ With a clearance of 2 cm between the fight tip and the conveyor housing, a total distance of 6cm is recommended between the belt the conveyor case/guide.

C. Selection of the Size and Number of Roller Support:

A-4 idler roller type is appropriate to provide support for the conveyor. The specified diameter, d_i , of the roller for A4 idler is 10.2 cm (Schultz, 1985), To obtain the number of the rollers required for carrying the idler, n_c , the relationship below was used (REX, 1976).

$$n_c = \frac{l}{s_c} \dots\dots\dots (3)$$

where, l = length of carrying or returning side (28m)

s_c = spacing of carrying idler ($s_i = 1.5 \text{ m}$, REX Manual, 1976)

From eqn 3, a value of 1.4 was obtained for n_c . Hence, two (2) carrying idlers is recommended for the conveyor.

D. Size of Head and Tail Pulleys, d_p :

The diameter of the head and tail pulleys, d_p , was determined using the relationship

$$D_p \geq d_i + \text{clearance} \dots\dots\dots (4)$$

Selecting a clearance of 2cm, $d_p = 12.2 \text{ cm}$.

E. Power Required to Drive Loaded Conveyor, P

Using Jeffrey formulae (Jacob, 1985, and Schultz, 1985),

$$P = \frac{F(1.07L_T + 50) (C + 0.03Q_s) + ch}{1000} \text{ hp.} \dots\dots\dots (5)$$

where

$$Q = 2B + \frac{W_c}{S_c} + \frac{W_r}{S_r} \dots\dots\dots(6a)$$

$$L_T = 2(1 + \pi d) \dots\dots\dots (6b)$$

Q = combined load (lb)

F = coefficient of friction (F = 0.03, Schultz, 1985)

L_T = total length of conveyor belt (ft)

C = conveyor capacity (ton/hr)

S = maximum speed (100 ft/min)

H = conveyor height (ft)

B = belt weight per unit length (B = 2.5, REX Manual, 1976)

W_c, W_r = weight of rotating part of carrying idler and returning idler

respectively. For an estimated value of 71 lb for W_r and W_c, Q = 7.11 lb and

L_T = 13.5 (4.14 m);

$$\therefore P = \frac{0.03[1.007 \times 13.6] + 50}{1000} [0.35 + (0.03 \times 7.1 \times 100)] + [0.35 \times 4.6]$$

$$= 0.44 \text{ hp; (325W)}$$

Using a factor of safety of 2, the conveyor power requirement is 650W (≈ 1hp)

F. Design for Belt Tension:

The good year equation for determining effective belt tension, T_e, is given in eqn (7) as stated by Schultz, 1985.

$$T_e = 1/5 (33,000 \times 0.96 \text{ hp})$$

$$= 13.94 \text{ lb (6.32 kg)}$$

$$\text{Tension at slack side, } T_2 = T_e R \dots\dots\dots (8)$$

where,

R = Pulley wrap and take-up factor (R = 1.25 for bare Pulley, Schultz, 1985)

$$\therefore T_2 = 17.43 \text{ l b (7.91 kg)}$$

$$\text{Tension on the tight side, } T_1 = T_e + T_2 = 31.37 \text{ l b (14.23 kg)}$$

G. Hopper Selection and Capacity:

The recommended angle of inclination of hopper for gravity discharge is $8 - 10^\circ$ higher than the angle of repose of material (Michael and Ojha, 1987). Static angle of repose cowpea ranged between 27.5° to 42.0° for a moisture range of 8.0% to 24.0% while that of soybean range between 28.5° to 33.0° for a moisture range of 12.8% to 23.3% (Chuma et al, 1981; Ademumi, 1997). An angle of inclination of 40° therefore selected for the hopper sides. The volumetric capacity (V_h) of the hopper is given by the relationship in equation (9).

$$V_h = \frac{abc}{6} + \frac{1}{3}(def + ghi) \text{ ----- (9)}$$

Where, a-i are as defined in Fig. 1

Hence, $V_h = 0.058 \text{ m}^3$. This volume is equivalent to 40 kg of podded grain.

Fig. 1 – Conveyor hopper dimensions

5.2 THRESHING UNIT DESIGN

A. Design Specifications/Selected Design Parameters:

- Drum diameter $D_d = 18 \text{ cm}$
- Drum length, $l_d = 99.5 \text{ cm}$
- Peg diameter $D_p = 10 \text{ mm}$
- Peg length $l_p = 11.5 \text{ cm}$
- Peg arrangement = No. on circumference, and 10 No. on rows
- Total No. of pegs, $10 \times 10 = 100$

B. Determination of Concave Diameter; D_c :

Least clearance between spike tooth head C_t at 99.5% level of confidence was given by Igc (1977) as stated in eqn (10)

$$C_t = m + 3.04\sigma c \text{ ----- (10)}$$

where,

m = mean dimension of seed, mm

σ = standard deviation of dimension

Selecting cowpea variety IT 812 – 994, $m = 9.69$ mm and $\sigma = 1.45$

Hence, $C_t = 14.08$ mm

$\therefore$ Total diameter of concave, $D_c = D_d + 2t + 2lp$

$$= 18 + 2.8 + 23$$

$$= 43.8 \text{ cm} \approx 44 \text{ cm}$$

C. Power Required to Thresh, P_t :

The power required to thresh (P_t) is the summation of the power required to drive the drum (P_d) and the kinetic power as a result of the impact of peg on the crop (P_{imp}) as shown in eqns 11 – 14.

$$P_t = P_d + P_{mp} \text{ ----- (11)}$$

$$P_d = M_d \cdot gV \text{ ----- (12)}$$

$$P_{mp} = 3.99433 M_p RN^2gV \text{ ----- (13) IRRI, 1968}$$

$$V = rw \text{ ----- (14)}$$

Where

M_d = total mass of drum with the shaft (kg)

V = shaft max (linear velocity 0.51 ms^{-1})

R = shaft radius (select R 12.5 mm)

w = angular velocity (rad/sec)

N = angular velocity (rps)

R = average radius of grain (m)

M_p = max mass of crop loaded into the threshing unit (kg)

g = acceleration due to gravity (ms^{-2})

For the spike tooth drum;

Total mass of drum = shaft mass + peg mass + drum mass

The relationship below was used to obtain mass, M

$$M = \lambda v \quad \text{-----} (15)$$

$$V = \frac{1}{4} \pi d^2 l \text{.....} (16)$$

Where,

λ = density (kg/m^3),

v = Volume (m^3)

d = diameter, m

l = length, m

$$\therefore \text{Mass of shaft} = \lambda \frac{\pi d_s^2}{4} l_s \text{.....} (17)$$

$\ell = 7.992 \times 10^3 \text{ kg/m}^3$ for steel

For shaft length of 30cm and maximum diameter of 5 cm,

Mass of shaft = 4.7 kg

$$\text{Mass of peg} = \frac{N \ell \pi d_p^2}{4} \text{.....} (18)$$

Where $N = 100$, and $d_p = 10 \text{ mm}$

$\therefore$ Mass of Peg = 7.2kg

$$\text{Mass of drum} = 2 \pi r_d l_d t \rho \text{.....} (19)$$

The galvanized pipe used is 3mm thick with l_d and r_d values of 99.5 cm and 9 cm respectively.

Mass of drum = 13.5 kg.

Hence,

$$\text{Total mass of drum assembly} = 4.7 + 7.2 + 13.5 = 25.4 \text{ kg}$$

The power required to drive the drum P_d from eqn 12 is equal to 127.04 W

To determine impact power, P_{imp} ;

$$P_{imp} = 3.99433 M_p R N^2 g V \text{ ----- (13)}$$

M_p = Density of crop x effective volume of threshing unit.

$$\begin{aligned} \text{Volume of threshing unit} &= \frac{\pi l (0.23^2 - 0.20^2)}{4} \\ &= 0.0122 \text{ m}^3 \end{aligned}$$

legume density = 768 kg m^{-3} (ASAE, 1970)

$$\therefore M_p = 9.38 \text{ kg}$$

$$R = \left(\frac{d_1 + d_2 + t}{6} \right) \text{ (20)}$$

From experiment, cowpea IT 81D – 994 has $d_1 = 9.55 \text{ mm}$ $d_2 = 7.05 \text{ mm}$ and $t = 5.21 \text{ mm}$ (Appendix 4)

Hence, $R = 3.63 \text{ mm}$

Using the relationship in eqn (13), $P_{imp} = 495.73 \text{ W}$

Total power required to drive the threshing unit = $127.04 + 495.73$
= 622.8 W Considering a factor of safety of 2g. The design total power requirement for threshing = 1245.6 W (2hp).

D. Shaft Design for the Threshing Unit:

Select B-type v-belt with sheave pitch of 5.4" diameter and belt speed of 2000ft/min (closest to shaft speed of 800 rpm). The belt has a rating of 2.62hp (Shigley and Mischike, 1989).

$$\begin{aligned}\text{Resultant load/tension on belt} &= \frac{746 \cdot hp}{V} \dots\dots\dots (21) \\ &= 935.18\text{N}\end{aligned}$$

$$\text{Vertical pulley load on shaft} = 935.18 \sin \theta$$

$$\text{Horizontal pulley load on shaft} = 935.18 \cos \theta$$

Where θ = inclined angle of belt.

The motor-threshing shaft belt is arranged to incline at 60° while the threshing shaft conveyor belt is inclined at 45° . The horizontal and vertical shear force and bending moment diagrams are shown below (Figs 2 and 3).

Fig 2: SF and B?M diagrams for horizontal loading on the threshing shaft

Fig 3: SF and BM diagrams for vertical loading on the threshing shaft

Obtain the diameter of shaft from the relationship stated by Hall et al (1988)

$$d^3 = \frac{16}{\pi S_s} \left[(K_b M_b)^2 + (K_t M_t)^2 \right] \dots\dots\dots (22)$$

$$S_s = 4 \times 10^7 \text{ Nm}^{-2}$$

$$P = 1954.52\text{N}$$

$$K_b = K_t = 1.5$$

$$M_t = \frac{P}{W} \dots\dots\dots (23)$$

$$\frac{1954.52}{83.77} = 23.33\text{Nm}$$

$$M_b = (M_x^2 + M_y^2)^{\frac{1}{2}} \dots\dots\dots (24)$$

$$= (66.34^2 + 91.38^2)^{\frac{1}{2}}$$

$$= 112.92 \text{ Nm}$$

$$\begin{aligned} d^3 &= \frac{16}{4\pi \times 10^7} \left[(1.5 \times 112.92)^2 + (1.5 \times 23.33)^2 \right]^{1/2} \\ &= \frac{16 \times 172.96}{4\pi \times 10^7} \\ &= 2.8 \times 10^{-2} \text{ m} = 28\text{mm} \end{aligned}$$

5.3 FAN DESIGN

A. Fan Specifications:

Specifications for radial blade centrifugal fan are stated below as indicated by Salisbury (1950), Osborne (1979) and McGraw-Hill Encyclopedia of science and Technology (1987)

- * Blade member, n $4 \leq n \leq 24$
- * Peak pressure ratio, P : $1.1 \leq P_p \leq 1.4$
- * Peak static efficiency, η_{peak} : $60\% \leq E_{peak} \leq 75\%$ (conventional type)
 $50\% \leq E_{peak} \leq 60$ (paddle type)

For paddle or steel plate centrifugal fan:

- capacity coefficient, $C_0 = 0.18$
- pressure head coefficient, $C_H = 6.3$
- power coefficient, $C_p = 1.7$
- Inlet area, $A_{in} = 0.4D^2$
- Outlet area, $A_{out} = 0.3D^2$
- Blade length (minimum) = $0.4D$

B. Fan Power Requirements:

The drag force (F_d) required by fan for the separation of unit material is given by the relationship in eqns 25 (Mohsenin, 1986).

$$F_D = \frac{1}{2} C_D A_p \lambda_f V^2 \quad \text{----- (25)}$$

Where,

$$A_p = \frac{\pi d_1 d_2}{4} \quad \text{----- (26)}$$

C_D = drag coefficient

A_p = projected area (m^2)

λ_f = mass density of fluid (kgm^{-3})

V = relative velocity between fluid and materials (ms^{-1})

Normally, V is slightly less than terminal velocity of grain (V_T) to ensure the separation of the lighter particles while the crops drop. Table 1 below shows the value of C_D and V_T for soybean by various authors

Table 1: C_D and V_T values for soybean

C_D	$V_T (ms^{-1})$	Source
0.46 – 0.59	12.07 – 13.50	Hawl et al, 1966
0.30 – 0.65	13.5	Bilaski and Lal, 1961
0.50	9.14 – 18.28	Uhl and Lamp, 1966

From Appendices 3 and 4, $d = 9.67 \text{ mm}$ and $d_2 = 7.05 \text{ mm}$ (selecting highest values)

$$\therefore A_p = 7.036 \times 10^{-5} m^2$$

Selecting the highest value of C_D and a value of $V(12m/s)$ slightly less than the least value of V_T on table 6, obtain the drag force required per unit grain from eqn 25.

$$F_D = \quad \quad \quad = 3.75 \times 10^{-3} N$$

The total drag force required to separate the grain bulk is obtain by multiplying the drag force required per unit grain by the total number of grain discharged per unit time. Mass flow rate from threshing unit (M_p)

$$M_p = M_p \times w \dots\dots\dots (27) \text{ (see threshing unit design)}$$

where, w = conveyor speed (rad/sec)

for a maximum threshing speed of 600 rpm, $W = 1.05 \times 10^{-2}$ rad/s

$$\begin{aligned} M_p &= 9.38 \times 0.011 \\ &= 1.032 \times 10^{-1} \text{ kg/s} \end{aligned}$$

For only podded grains, maximum value of Pod: seed = 1:2.7 (Appendix 4)

Therefore, Mass flow rate of grains discharge into the fan unit, $M_p = 1.032 \times 10^{-1} \times \frac{2.7}{3.7}$
 $= 7.5 \times 10^{-2} \text{ kg/s}$

$$\begin{aligned} \text{Hence, } N_p &= \frac{M_p}{\text{grain unit weight}} \dots\dots\dots (28) \\ &= \frac{7.5 \times 10^{-2}}{1.91 \times 10^{-4}} = 3.9 \times 10^2 \end{aligned}$$

$$\begin{aligned} \text{Total drag force, } (F_D)_{\text{Total}} &= N_p \times F_D \dots\dots\dots (29) \\ &= 3.75 \times 10^{-3} \times 3.9 \times 10^2 \\ &= 14.63 \text{ N} \end{aligned}$$

$$\text{Fan Power requirements, } P = \frac{2\pi\tau}{60} \dots\dots\dots (30)$$

$$T = r(F_D)_{\text{Total}} \dots\dots\dots (31)$$

The optimum recommended speed for legume thresher is 600 rpm (Ige, 1979).
 For such speed select pulley diameter of 15cm.

$$\begin{aligned} \therefore P &= \frac{2\pi \times 600 \times 14.63 \times 0.075}{60} \\ &= 69.1 \text{ W} \end{aligned}$$

Using a factor of safety of 2, the maximum power required by the fan = 138.2W.

C. Determination of fan dimensions

From Fan Law (Osborne, 1979)

$$P = C_p \lambda_f n^3 D^5 \quad \text{-----} \quad (32)$$

f_n = fan speed (rps)

D = Fan casing diameter (m)

$$= \left(\frac{P}{\lambda_p \lambda_f n^3} \right)^{1/5} \quad \text{.....} \quad (31)$$

$$= \left(\frac{138.2}{1.7 \times 1.14 \times (23.3)^3} \right)^{1/5}$$

FABRICATION AND ASSEMBLY OF THE EQUIPMENT

The equipment consists of three main units namely the conveyor, threshing and cleaning units. The units were fabricated in the workshop of the Agricultural Engineering Department, Federal University of Technology, Akure, Nigeria. The equipment was fabricated according to design specifications. A few modifications were however made during fabrication where necessary, particularly when the bought out components available in the market were not as specified in the design. The main bought out components used for the machine fabrication included the vane type centrifugal fan, electric motor and pillow block bearings with guides/housing.

The machine was estimated to have a total weight of – kg and occupied a floor space of – m² with a maximum height of – m. The detail machine and assembly drawing of the equipment is shown in appendix 2. Plate 1 shows the photograph of the assembled equipment

6.1 Fabrication and assembly of the conveyor unit

The conveyor unit consists of the frame, looped belt, rollers, guide, flights, tensioning device, and bearings. The frame was made of a 38 mm angle iron. The lengths of the various sides of the frame were measured using tape, cut to size and firmly welded together to form the required shape. The slots to accommodate the bearing housing used were cut on the upper, middle and lower parts of the slantened sides of the conveyor frame using hand drill and file. The slots have a width of 12 mm and a length of 10 cm to allow the shifting of the position of the bearing housing and the rollers. This would allow the tensioning of the conveyor belt.

The tensioning device is located close to the slot at the upper end of the conveyor frame. It is made up of a pair of M12 bolt, two pairs of M12 nuts and two

pairs of angle iron non-plates. One of the angle iron plates was permanently welded toward the upper end of each of the slantened sides of the conveyor frame while the second pair were bolted on the frame together with the bearing housing. Two nuts were welded permanently to these angle iron plates such that the bolt can move through them simultaneously. The bolts push the top bearing housing, and adjust the roller position and the belt tension.

The rollers were fabricated from steel pipes, steel plates and steel rods. Each roller was made of one pipe, two end shafts and four plates. These components were assembled and welded together to form a single unit. The steel pipe, plates and rods were cut to size and faced with the lathe machine. The pipe has an external diameter of 10 cm with a thickness of 5 mm. The steel plates were machine to have a diameter of 9cm such that they can key into the inner diameter of the pipe. An hole of 25 mm was centrally bored on the plates to accommodate the shafts. The rod was machined to a shaft of 25 mm diameter and cut to size on the lathe.

The conveyor belt was made from a fibre reinforced polymer material. The two ends of the material cut to size (30 cm x 3.24 m) were riveted together to form a loop. The flights were made of a gauge 18 sheet metal. A total of fourteen (14) 7 cm x 30 cm sheet metal were cut with guillotine shear machine. An arm of 2 cm was folded at right angle from each of the sheet metal using a shaping machine. The folded arms of the sheet metal was riveted to the looped belt at an interval of 38.5 cm.

The guide for the flight conveyor was made of a gauge 18 sheet metal. The sheet metal has an overall dimension of 0.59 m x 2.35 m. A 14 mm arm was folded at right angle on each of the long side of the sheet metal such that the guide has a $\angle$ - shape. The guide has a width of 31cm. The arms of the guide were bolted to the conveyor frame with five pairs of M5 bolts and nuts. Three pairs of pillow block

bearings (■ 25 cm) with bearing housing were mounted on the frame to support the flight conveyor.

6.2 Fabrication and assembly of the threshing unit

The threshing unit consists of the threshing drum, threshing mechanism, bearing, concave, concave cover, and frame. The fabrication of the threshing drum is similar to that of the rollers reported in 3.3.1. However the steel pipe used for the threshing drum had an external diameter of 18 cm, thickness of 3 mm and length of 99.5 cm. The steel plates have a diameter of 17. cm and a centralized bore of 25 mm to accommodate the shafts. The components were welded together to form a single unit.

The threshing mechanisms were made of steel bars and rods. Two types of mechanisms were fabricated namely: the peg type and were loop type. Five bars of 5 mm x 5 cm x 99.5 cm dimension were used for each mechanism. For the peg mechanisms, nineteen pegs (■ 10 mm x 11.5 cm) cut from a 3/8" metal rod were welded to each bar. For the wire loop mechanism, ten rods (■ 5 mm x 26 cm) cut from a 3/16" metal rod were bent to a form loop shape with a pitch of 11.5 cm were welded to each of the steel bars. The bars containing the pegs and wire loops were respectively arranged equidistantly on the circumference of the drum such that they allow materials to have a spiral movement. They were firmly clamped to the threshing drum with M8 bolts and lock nuts.

The concave was made of a 3 mm thick metal sheet with a dimension of 80 cm x 99.8 cm. The sheet was made into a screen of a diameter of 10 mm. A distance of about 2 cm was maintained between the holes such that the screen has a coefficient of open area of 20%. A lip of 8 cm on each of the long side and 5 cm on each of the short sides of the concave was not drilled to give firmness and rigidity to the screen,

and allow easy folding of the drilled sheet to a semi circular shape on a shaping machine. The drilled sheet metal was thereafter folded into a semi circular shape with a diameter of 46 cm. An arm of 3.8 cm each on the long sides of the concave sheet was folded at right angle to allow the concave to be mounted on the frame of the threshing unit. Four (4) equidistant holes of 8 mm diameter, through which the concave is bolted to the frame of the threshing unit were bored on the concave arm. The open semi circular ends of the concave were covered with a 3 mm thick sheet metal by welding.

The concave cover was fabricated with a gauge 18 sheet metal (80 cm x 99.8 cm) folded into a 46 cm diameter semi circular shape with an arm of 3.8 cm on each of the long sides. Four (4) equidistant holes of 8 mm diameter were bored on each arm using hand drill. The cover is bolted to the frame of the threshing unit via the holes. Spaces of 15cm x 29cm and 15cm and 20cm were cut on the conveyor cover with chisel to accommodate the inlet and exhaust chutes respectively on the conveyor cover.

The frame of the threshing unit was fabricated with a 38 mm angle iron cut into sizes and welded together. Holes of 12 mm diameter were drilled on the frame through which the bearing housings were bolted to it. Four (4) pairs of M8 bolts were welded to the long sides of the frame through which the concave and its cover were clamped to the frame. The frame of the cleaning chamber was welded to the frame of the threshing unit.

6.3 Fabrication and assembly of the cleaning unit

The cleaning unit consists of the centrifugal fan, fan casing, frames, rubber bellow, fan angle adjuster, collecting tray, bearing, and cleaning chamber and strainer.

The vane type centrifugal fan with a diameter of 20 cm was purchased from the market for the fan unit.

The fan casing was fabricated with a gauge 18 sheet metal. It has air inlet diameter of 10 cm and an outlet dimension of 30 cm x 42 cm. It was attached to the main frame of the fan unit using a pipe coupling. The fan casing was provided with a frame on which the pillow block bearing, with housing and the fan motor were mounted. The fan casing was attached to the angle adjusting plates via a pair of bolt and nut. The angle adjusting plates were welded firmly to the sides of the cleaning chamber frame.

The frame of the cleaning chamber was fabricated with a 25 mm angle iron, which was cut to sizes and welded to shape. One side of the frame was connected to the centrifugal fan through the rubber bellow while the opposite side is open. One of the long sides of the cleaning chamber was covered with a gauge 18 sheet metal painted white and calibrated with black lines. The other long side was covered with a perspex sheet of 6.4 mm thickness. The collecting tray (30 cm x 30 cm x 80 cm) partitioned into compartments was fabricated and positioned at the lower part of the cleaning chamber.

The rubber bellow was made with rubber material shaped to direct air from the fan unit into the cleaning chamber. The open ends of the rubber bellow were glued to rectangular sheet metal lips with adhesive. The rubber bellow was coupled to the fan casing and cleaning chamber frame via the sheet metal lips with fourteen pairs of M5 bolts and nuts. A strainer was provided at the end of the rubber bellow to allow uniform air velocity distribution in the clearing chamber.

The fan angle adjuster consists of a pair of adjustment plate and a pair of M8 bolt and three pairs of M8 nuts. A slot of 8 mm diameter was cut on the adjustment

plates to form a curvature corresponding to the angular movement of the fan casing. The adjustment plates were firmly welded to the sides of the cleaning chamber frame. The fan-casing angle was adjusted and held in position with the aid of the lock nuts. The angular movement of the fan casing was calibrated on the adjustment plates using a protractor.

6.4 Fabrication and assembly of the power transmission system

All the pulleys used for the power transmission were machined in the workshop on the lathe. Both wooden and cast iron pulleys were machined. The diameter of the pulley ranged from 58 cm to 7 cm. Altogether, eleven (11) pulleys were machined - nine (9) wooden and two (2) cast aluminum. The cast aluminum pulleys have diameter of 7 cm and 8 cm. The cast aluminum materials obtained from the market were machined into pulleys.

The grooves of all the pulley were cut with tools on the lathe and the holes to accommodate the shafts were bored on the lathe with a 25 mm drill. Each of the wooden pulleys was provided with metal flange to hold the various shafts and prevent damages on the pulleys by the fast moving shafts. Each flange was fabricated with 40mm diameter rod with 25 mm diameter centralized bore; a 8 cm diameter plate with 25 mm diameter central used plate and three 8 mm equidistant holes; and three pair of M8 bolts and nuts. The flanges were clamped to the wooden pulleys with the M8 bolts and nuts. The cast in on pulleys was pounded with screw holes to accommodate allen screws.

DEFECTS AND CORRECTIONS ON THE EQUIPMENT

The defects identified include the following:

- i. Misalignments of the conveyor belt
- ii. High record of loss of crop at the discharge end of the conveyor inlet to the threshing unit.
- iii. High velocity head loss of the air produced by the centrifugal fan

7.1 Misalignment of the conveyor belt

It was observed that the conveyor belt was misaligned and this resulted in the belt running out of the top and end rollers from adjacent sides, the forceful removal of the flights from the belt during operation and the stoppage of the conveyor. The conveyor belt movement was also not concentric. The causes of the misalignments of the conveyor belt was identified and these include the following:

- i. tension differential on the belt or imbalance tensioning of the belts
- ii. the elastic nature of the initial rubber material used for the construction of the conveyor belt and its curvature.
- iii. fabrication defects. The fabrication of the slanted sides of the conveyor frame was not done with precision. It was observed that one of the slanted sides of the conveyor frame was about 1 cm higher than the other.

The following amendments were made to rectify the defects and the attendant problems:

- i. providing the top and end rollers with 12cm diameter guide plates to keep the conveyor belt in position and prevent the conveyor from slipping away on the rollers.
- ii. providing the top and end rollers with a center crown to keep the conveyor belt in position and prevent the conveyor from slipping away on the rollers
- iii. replacing the rubber material of the conveyor belt with a fibre reinforced material which is less elastic and straight
- iv. balancing the tension on both sides of the belt using the tensioning device.
- v. dismantling of the conveyor frame and amending the construction defect such that the two slanted sides are parallel to each other and on the same level.

7.2 High record of loss of crop at the conveyor outlet

It was observed during the preliminary tests that a high percentage of the threshed grains and broken pods were lost at the discharge end of the conveyor belt the inlet end of the threshing unit. This is not desired since it will negatively affect the overall performance efficiency of the equipment. The causes of this high record of crop loss include the following:

- (i) mode of discharge into the threshing unit. It was observed that the conveyor discharge into the threshing unit by a centrifugal mode, not by gravity.
- (ii) the height at which the conveyor discharged to the threshing unit was relatively low and closer to the threshing mechanism. A reasonable percentage of the threshed material is therefore lost through the inlet

hopper of the threshing unit and dropped via the upper part of the conveyor unit.

- (iii) there were gaps (up to 1.5 cm) between the conveyor guide and the hopper of the concave cover (both at the upper and lower part). Threshed materials were also lost through those spaces openings.

The following amendments were made to prevent the excessive losses of the threshed materials:

- i. a gauge 18 sheet metal was welded to the gap between the conveyor guide and the upper part of the hopper of the concave cover. A gauge 18 metal sheet lid was also fabricated to cover the topmost opening of the threshing unit.
- ii. a fibre reinforced polythene material was glued to the lower part of the inlet chute of the threshing unit to eliminate the gap at the lower part of the chute, such that the flights on the conveyor belt just touch the fibre reinforced polythene material.
- iii. the height of the conveyor unit was increased to enable effective discharge into the threshing unit
- iv. the height of the inlet chute of the concave cover was increased such that the conveyor could easily discharge into it.

7.3 High velocity head loss of air

It was observed that due to a lot of frictional losses in the fan unit, the centrifugal fan could not discharge air at appropriate velocities to the cleaning chamber. There was therefore a high loss of velocity head. This defect was caused by the following reason:

- i. slipping of the aluminum pulleys on the fan shaft

- ii. one side of the centrifugal fan was rigorously rubbing the inner wall of the fan casing. This equally resulted in excessive noise.
- iii. the shaft of the centrifugal fan was sliding in the bearing toward the side where the pulley was located.

Making the following amendments rectified the defect:

- i. a key way was provided on the fan shaft to lock the aluminum pulleys to the fan shaft, in addition to the existing allen key provided for the aluminum pulleys
- ii. the inner walls of the fan casing were straightened to allow free movement of the fan.
- iii. the shaft of the centrifugal fan was well positioned in the bearing using allen key and welded tacking.

The equipment was re-assembled and further tested after all the defects were rectified.

Having observed that the performance of the machine was satisfactory, it was thereafter prepared for experimentation.

APPENDIX 8

PROGRAM TO SOLVE THE NUMERICAL EQUATION

```

character filename*15
open (1, file = 'in.dat')
  read (1,*) idata
  read (1,*)
do id = 1, idata
  read (1,*) vt, vspd, vidir, vaspd, vadir, filename
  write (*, '(a)') filename
open (2, file = filename)

c
c -----Constants
g = 9.81
rhoa = 1.0

c set time parameter
dt = 0.001
time = 1
itratn = time/dt

c compute u and v component of inlet and air velocity
ui = -vispd*sind(vidir)
vi = -vispd*cosd(vidir)
ua = -vispd*sind(vidir)
va = -vispd*cosd(vidir)

c set the initial condition of the particles
t = 0
x = 0
y = 0
u0 = ui
v0 = vi

c do the iterations
do it = 1, itratn

```

```

ur = ua - u0
vr = va - v0
ursgn = sign(1.0, ur)
vrsgn = sign(1.0, vr)
u1 = u0 + ursgn*(ur**2/vt**2)*g*dt
v1 = v0 + (-1 + vrsgn*(vr**2/vt**2))*g*dt
dx = 0.5*(u1+u0)*dt
dy = 0.5*(v1+v0)*dt
t = t + dt
x = x + dx
y = y + dy
u0 = u1
v0 = v1
c write out the results
  write ( 2,10) t, x, y, ur, vr
10 format (5(f20, 10, 2x))
11 format (8(f8, 7, 2x))
    enddo
    write (*, *) id
    enddo
end

```

APPENDIX 9

TYPICAL INPUT DATA

vt	spdi	diri	spda	dira	filename
0.8	0.25	0	7.5	50	Particle1
1.5	0.25	0	7.5	50	Particle2
2.5	0.25	0	7.5	50	Particle3
3.0	0.25	0	7.5	50	Particle4
7.0	0.25	0	7.5	50	Particle5
10.0	0.25	0	7.5	50	Particle6
14.0	0.25	0	7.5	50	Particle7
18.0	0.25	0	7.5	50	Particle8

Expt 1
8

vt	spdi	diri	spda	dira	filename
0.8	0.05	0	3.6	90	Particle1
1.5	0.05	0	3.6	90	Particle2
2.5	0.05	0	3.6	90	Particle3
3.0	0.05	0	3.6	90	Particle4
7.0	0.05	0	3.6	90	Particle5
10.0	0.05	0	3.6	90	Particle6
14.0	0.05	0	3.6	90	Particle7
18.0	0.05	0	3.6	90	Particle8

Expt 2
8

vt	spdi	diri	spda	dira	filename
0.8	0.05	0	3.6	105	Particle1
1.5	0.05	0	3.6	105	Particle2
2.5	0.05	0	3.6	105	Particle3
3.0	0.05	0	3.6	105	Particle4
7.0	0.05	0	3.6	105	Particle5
10.0	0.05	0	3.6	105	Particle6
14.0	0.05	0	3.6	105	Particle7
18.0	0.05	0	3.6	105	Particle8

Expt 3
8

vt	spdi	diri	spda	dira	filename
0.8	0.05	0	3.6	120	Particle1
1.5	0.05	0	3.6	120	Particle2
2.5	0.05	0	3.6	120	Particle3
3.0	0.05	0	3.6	120	Particle4
7.0	0.05	0	3.6	120	Particle5
10.0	0.05	0	3.6	120	Particle6
14.0	0.05	0	3.6	120	Particle7
18.0	0.05	0	3.6	120	Particle8

Expt 4
8

vt	spdi	diri	spda	dira	filename
0.8	0.25	0	7.5	120	Particle1
1.5	0.25	0	7.5	120	Particle2
2.5	0.25	0	7.5	120	Particle3
3.0	0.25	0	7.5	120	Particle4
7.0	0.25	0	7.5	120	Particle5
10.0	0.25	0	7.5	120	Particle6
14.0	0.25	0	7.5	120	Particle7
18.0	0.25	0	7.5	120	Particle8

PARTICLE TRAJECTORY PRODUCED FROM THE MODEL (2D)

(a) Air velocity of 3.6 ms^{-1}

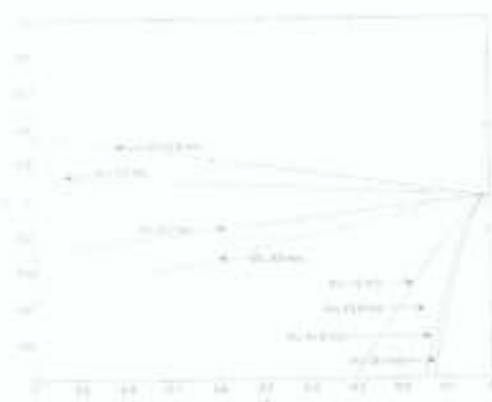
(b) Air velocity of 7.5 ms^{-1}

Particle trajectory produced from the 2D model at fan inclination of 60° and inlet velocity of 0.25 ms^{-1}

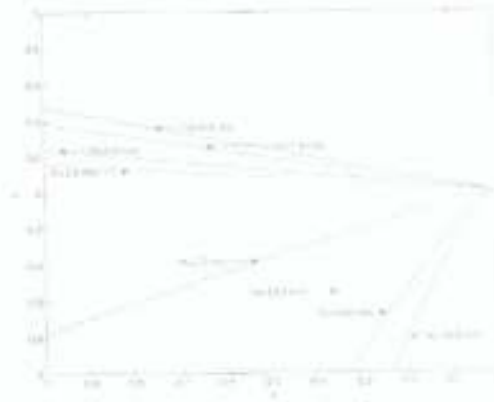
(a) Air velocity of 3.6 ms^{-1}

(b) Air velocity of 7.5 ms^{-1}

Particle trajectory produced from the 2D model at fan inclination of 90° and inlet velocity of 0.25 ms^{-1}



(a) Air velocity of 3.6 ms^{-1}



(b) Air velocity of 7.5 ms^{-1}

Particle trajectory produced from the 2D model at fan inclination of 120° and inlet velocity of 0.25 ms^{-1}

PROGRAMME FOR TRAJECTORY PLOTS (2 - D)



```
clear all
close all

for i = 1:8

    if i == 1
        load ('Particle1')
        finame = Particle1;
        ip = 'r';
    elseif i == 2
        load ('Particle2')
        finame = Particle2;
        ip = '--b';
    elseif i == 3
        load ('Particle3')
        finame = Particle3;
        ip = 'g';
    elseif i == 4
        load ('Particle4')
        finame = Particle4;
        ip = 'y';
    elseif i == 5
        load ('Particle5')
        finame = Particle5;
        ip = 'k';
    elseif i == 6
        load ('Particle6')
        finame = Particle6;
        ip = 'm';
    elseif i == 7
        load ('Particle7')
        finame = Particle7;
        ip = 'c';
    elseif i == 8
        load ('Particle8')
        finame = Particle8;
        ip = '*';
    end

    t = finame(:,1);
    x = finame(:,2);
    y = finame(:,3);
    u = finame(:,4);
    v = finame(:,5);

    figure(1)
    plot(x,y,ip)
    hold on
end

figure(1)
legend('particle1','particle2','particle3','particle4','particle5',
'particle6','particle7','particle8')
```

APPENDIX 12

ESTIMATION OF GEOMETRIC MEAN DIAMETER USING THE 3- AXIAL DIMENSION AT 14% POD MOISTURE CONTENT

SN	BIG SIZE 7.02-9.82			MEDIUM SIZE 5.09-6.36			SMALL SIZE 3.86-4.90		
	A	B	C	A	B	C	A	B	C
1	8.35	6.25	4.20	6.40	5.24	4.40	4.12	4.79	3.16
2	8.00	6.95	4.38	6.65	5.89	4.72	4.28	3.62	3.86
3	8.00	6.30	4.22	6.00	5.40	3.60	4.09	3.89	2.15
4	7.22	6.96	4.25	5.40	5.00	4.55	4.90	4.68	3.10
5	8.27	6.93	4.29	6.17	5.54	4.89	4.90	3.76	2.88
6	9.28	6.18	5.23	6.32	5.10	4.30	3.53	3.04	2.30
7	8.25	6.05	4.55	6.42	6.97	4.98	4.85	2.24	1.58
8	7.55	6.13	4.25	6.49	6.13	5.75	4.89	2.59	2.23
9	7.94	6.87	4.07	5.33	4.33	3.73	3.32	2.28	2.70
10	7.19	6.06	4.27	6.20	3.56	4.65	4.55	4.35	3.23
11	9.68	6.56	5.78	6.75	6.92	4.21	4.33	4.31	3.40
12	7.80	6.73	4.80	6.28	6.08	4.82	4.02	4.38	4.36
13	8.44	5.57	4.08	5.81	5.17	4.25	4.89	3.50	2.26
14	8.77	7.80	5.53	5.50	5.75	4.58	4.60	4.84	3.00
15	7.29	6.19	4.04	5.48	5.53	3.83	4.45	3.45	3.54
16	8.73	6.08	4.20	5.00	4.77	3.34	3.75	3.97	2.45
17	7.22	6.32	4.21	6.07	5.38	4.98	4.70	3.45	3.20
18	8.41	7.12	5.81	6.52	6.23	4.25	4.55	4.90	3.35
19	7.45	6.21	4.88	5.54	5.28	4.82	4.40	4.17	3.60
20	7.76	6.91	4.36	6.10	5.55	4.65	4.12	4.18	3.85
21	7.55	6.82	4.32	6.31	5.35	3.40	4.46	4.25	3.60
22	8.03	7.82	4.28	6.59	5.27	4.91	NA	NA	NA
23	7.08	6.28	4.32	5.70	5.00	4.02	NA	NA	NA
24	7.32	6.28	4.25	6.20	5.58	3.30	NA	NA	NA
25	8.16	6.56	4.46	6.02	6.20	4.34	NA	NA	NA
26	8.67	6.14	4.38	6.03	5.00	3.40	NA	NA	NA
27	8.23	6.23	7.76	6.23	5.20	4.05	NA	NA	NA
28	8.15	6.69	4.43	6.90	6.28	4.68	NA	NA	NA
29	7.45	6.32	4.47	6.61	6.98	5.89	NA	NA	NA
30	9.40	6.70	5.86	6.20	5.95	3.35	NA	NA	NA
31	7.39	5.62	6.35	6.69	5.33	3.60	NA	NA	NA
32	7.28	6.46	5.77	6.10	6.97	4.30	NA	NA	NA
33	8.87	6.93	5.65	6.12	5.52	4.75	NA	NA	NA
34	9.22	6.38	4.39	6.05	5.90	4.83	NA	NA	NA
35	9.98	7.76	4.30	6.12	5.65	4.63	NA	NA	NA
36	7.85	5.47	4.20	6.35	6.39	4.21	NA	NA	NA
37	7.24	6.08	4.12	5.38	4.45	4.57	NA	NA	NA
38	7.05	5.46	3.26	6.65	5.26	4.00	NA	NA	NA
39	8.68	7.72	5.00	5.28	4.17	4.80	NA	NA	NA

40	7.02	5.05	4.36	6.90	5.83	4.82	NA	NA	NA
41	8.46	6.48	4.37	6.19	5.03	3.56	NA	NA	NA
42	7.29	6.23	4.23	6.30	4.42	4.13	NA	NA	NA
43	8.81	7.79	4.29	6.60	5.76	3.68	NA	NA	NA
44	8.92	6.23	4.38	6.22	5.43	4.08	NA	NA	NA
45	7.49	6.16	4.40	5.42	5.28	4.97	NA	NA	NA
46	7.56	7.86	4.34	5.55	5.07	4.92	NA	NA	NA
47	8.70	6.37	4.46	6.22	5.39	4.26	NA	NA	NA
48	8.86	6.36	4.55	6.00	4.60	7.73	NA	NA	NA
49	7.31	6.42	5.75	6.75	5.25	4.75	NA	NA	NA
50	7.48	5.77	4.03	5.48	5.00	4.17	NA	NA	NA
Mean	8.06	6.49	4.64	6.11	5.47	4.43	4.37	3.84	3.04
Geometric mean		6.40			3.24			3.75	
Standard deviation	0.76	0.64	0.76	0.47	0.72	0.76	0.45	0.79	0.69
Stad. Dev. of Geo. Mean		1.71			0.85			0.67	

APPENDIX 13

ESTIMATION OF GEOMETRIC MEAN DIAMETER USING THE 3- AXIAL DIMENSION AT 18% POD MOISTURE CONTENT

SN	BIG SIZE 7.02 - 9.82			MEDIUM SIZE 5.09 - 6.36			SMALL SIZE 3.86 - 4.90		
	A	B	C	A	B	C	A	B	C
1	8.17	6.54	4.65	6.67	5.58	4.29	4.86	4.61	3.20
2	7.36	6.90	4.14	6.80	5.94	4.27	4.15	4.80	4.37
3	8.31	6.23	4.14	6.92	5.15	4.05	4.88	4.56	3.09
4	8.14	6.35	4.82	6.70	6.24	4.61	4.22	4.56	3.47
5	8.13	5.83	5.05	6.47	5.39	3.74	4.88	4.74	3.75
6	8.00	6.45	4.75	6.87	4.96	3.32	4.90	4.81	3.68
7	8.35	6.72	4.60	6.63	5.77	4.20	4.67	4.94	3.80
8	7.93	6.70	4.80	6.16	5.00	4.15	4.90	4.83	3.42
9	8.39	6.28	5.00	6.84	6.12	4.97	4.75	3.65	3.10
10	8.12	6.47	5.10	6.57	6.05	4.30	4.20	3.88	2.70
11	7.80	5.98	4.57	6.85	6.34	4.06	3.83	3.86	3.17
12	8.06	6.60	5.01	6.85	6.20	4.63	4.80	4.53	3.10
13	8.09	6.00	4.03	6.14	5.10	3.65	4.84	4.27	3.75
14	7.95	6.57	4.61	6.70	5.47	4.70	4.70	4.90	4.48
15	7.21	5.96	6.04	6.90	6.34	4.11	4.80	4.07	3.12
16	7.73	6.64	4.98	6.36	6.24	4.45	4.90	4.83	2.81
17	9.15	6.10	5.78	6.47	5.41	3.55	4.83	5.03	3.27
18	7.30	6.22	4.86	6.28	6.17	4.60	4.90	4.84	3.53
19	8.25	5.55	4.39	6.92	5.80	4.00	4.82	5.03	3.27
20	8.03	6.14	4.38	6.30	5.73	4.68	4.90	4.84	3.53
21	9.02	6.36	4.89	6.85	6.15	4.62	4.82	4.86	3.45
22	9.08	6.65	4.48	6.70	6.20	4.15	NA	NA	NA
23	8.82	6.55	4.67	6.71	5.73	4.75	NA	NA	NA
24	8.53	6.35	4.70	6.82	6.23	3.91	NA	NA	NA
25	7.57	6.04	4.03	6.93	5.05	4.81	NA	NA	NA
26	8.50	6.65	4.72	5.82	5.71	4.33	NA	NA	NA
27	7.32	5.82	4.35	6.91	5.92	4.18	NA	NA	NA
28	7.58	6.46	4.80	6.93	6.25	4.00	NA	NA	NA
29	7.02	5.61	3.60	6.80	6.08	4.35	NA	NA	NA
30	8.02	5.55	4.25	6.50	5.70	4.07	NA	NA	NA
31	7.88	6.46	4.53	6.96	6.35	3.55	NA	NA	NA
32	7.55	6.55	4.35	7.88	6.46	4.53	NA	NA	NA
33	8.35	6.10	4.65	7.55	6.55	4.35	NA	NA	NA
34	8.15	6.78	4.64	8.35	6.10	4.65	NA	NA	NA
35	8.37	6.29	4.37	8.15	6.78	4.64	NA	NA	NA
36	8.24	6.41	4.00	8.37	6.29	4.37	NA	NA	NA
37	7.75	6.47	4.54	8.24	6.41	4.00	NA	NA	NA
38	8.03	6.38	4.21	7.75	6.47	4.54	NA	NA	NA
39	9.14	6.07	4.54	8.03	6.38	4.21	NA	NA	NA

40	8.59	6.04	4.45	9.14	6.07	4.54	NA	NA	NA
41	7.65	6.75	4.68	8.59	6.04	4.45	NA	NA	NA
42	7.84	6.54	4.55	7.65	6.75	4.68	NA	NA	NA
43	7.89	6.75	4.75	7.84	6.54	4.55	NA	NA	NA
44	8.37	6.44	4.35	7.89	6.75	4.75	NA	NA	NA
45	7.10	6.19	4.19	8.37	6.44	4.35	NA	NA	NA
46	7.71	6.05	4.65	7.10	6.19	4.19	NA	NA	NA
47	8.06	6.42	4.73	7.71	6.05	4.65	NA	NA	NA
48	7.65	6.48	4.58	8.06	6.42	4.73	NA	NA	NA
49	8.51	6.89	5.07	7.65	6.48	4.58	NA	NA	NA
50	7.32	6.23	4.41	8.51	6.89	5.07	NA	NA	NA
mean	8.04	6.33	4.61	7.18	6.05	4.35	4.69	4.59	3.43
Geometric mean		6.33			5.86			4.24	
Standard deviation	0.51	0.33	0.41	0.77	0.48	0.36	0.31	0.41	0.44
Stad. Dev. of Geo. Mean		1.72			1.42			0.70	

APPENDIX 14

ESTIMATION OF GEOMETRIC MEAN DIAMETER USING THE 3- AXIAL

DIMENSION AT 22% POD MOISTURE CONTENT

SN	BIG SIZE 7.02 - 9.82			MEDIUM SIZE 5.09 - 6.36			SMALL SIZE 3.86 - 4.90		
	A	B	C	A	B	C	A	B	C
1	8.19	6.78	4.23	6.02	6.90	5.24	4.85	3.65	3.19
2	8.18	6.59	4.77	6.24	6.09	4.39	4.42	3.88	2.99
3	8.05	6.93	4.36	6.06	6.06	3.70	3.93	3.86	3.78
4	8.83	6.57	4.79	6.29	6.35	4.27	4.90	4.53	3.56
5	7.75	6.65	4.44	6.25	6.17	4.15	4.89	4.27	3.75
6	7.62	6.57	4.24	6.13	5.88	3.84	4.60	4.90	4.90
7	8.93	6.50	4.35	6.16	5.34	3.62	4.90	4.07	3.12
8	7.82	6.43	4.30	6.03	6.30	4.25	4.90	4.83	3.65
10	8.10	6.50	4.25	6.30	5.36	4.48	4.88	5.03	3.27
11	7.30	6.65	4.50	6.33	5.50	3.45	4.90	4.84	3.57
12	7.12	6.39	4.54	6.28	5.70	3.37	4.89	5.03	3.36
13	7.66	6.06	3.97	6.29	6.38	3.36	4.90	4.84	3.53
14	7.05	6.67	4.64	5.21	4.89	4.85	4.86	4.87	2.79
15	7.95	6.07	3.62	6.13	5.07	3.47	NA	NA	NA
16	7.23	6.50	4.85	6.30	4.89	3.51	NA	NA	NA
17	7.56	6.48	4.36	6.00	5.90	4.27	NA	NA	NA
18	7.35	5.95	4.35	5.51	4.33	3.98	NA	NA	NA
19	8.00	6.14	4.27	5.42	4.39	4.05	NA	NA	NA
20	8.52	6.59	3.04	6.36	4.89	3.78	NA	NA	NA
21	7.22	6.24	4.04	5.56	5.64	5.25	NA	NA	NA
22	7.75	6.14	4.22	6.15	5.47	4.15	NA	NA	NA
23	7.77	6.26	4.74	6.24	6.19	4.13	NA	NA	NA
24	8.36	6.82	4.15	6.29	6.15	3.93	NA	NA	NA
25	8.59	6.56	4.00	6.37	6.14	3.86	NA	NA	NA
26	7.17	5.46	4.13	5.95	5.22	3.35	NA	NA	NA
27	7.91	6.64	4.63	6.34	5.60	3.26	NA	NA	NA
28	7.92	6.68	4.44	6.35	5.35	3.51	NA	NA	NA
29	7.02	5.25	4.44	6.15	5.35	3.51	NA	NA	NA
30	7.65	6.26	4.57	6.15	5.08	3.10	NA	NA	NA
31	7.42	5.95	4.35	6.34	5.50	3.82	NA	NA	NA
32	8.60	6.55	4.05	6.15	6.30	3.90	NA	NA	NA
33	7.20	6.27	4.18	6.05	5.43	3.50	NA	NA	NA
34	7.14	6.84	4.30	6.18	6.06	4.19	NA	NA	NA
35	7.68	6.48	4.30	6.09	6.50	4.07	NA	NA	NA
36	7.38	5.95	7.36	5.74	5.45	4.37	NA	NA	NA
37	8.00	6.27	4.77	6.10	6.01	4.80	NA	NA	NA
38	7.51	6.26	4.43	6.30	5.81	4.08	NA	NA	NA
39	7.20	6.52	4.92	6.33	5.16	3.45	NA	NA	NA

40	7.91	6.18	4.15	6.09	5.71	4.06	NA	NA	NA
41	7.20	6.27	4.70	NA	NA	NA	NA	NA	NA
42	7.78	5.89	4.91	NA	NA	NA	NA	NA	NA
43	7.85	5.89	4.91	NA	NA	NA	NA	NA	NA
44	7.98	7.20	4.75	NA	NA	NA	NA	NA	NA
45	7.78	6.21	4.21	NA	NA	NA	NA	NA	NA
46	7.95	6.63	4.35	NA	NA	NA	NA	NA	NA
47	7.27	6.72	3.97	NA	NA	NA	NA	NA	NA
48	7.57	6.57	4.31	NA	NA	NA	NA	NA	NA
49	8.10	6.60	4.41	NA	NA	NA	NA	NA	NA
50	8.13	6.46	4.62	NA	NA	NA	NA	NA	NA
Mean	7.76	6.39	4.43	6.11	5.65	3.96	4.76	4.51	3.50
Geometric mean		6.19			5.24			4.25	
Standard deviation	0.47	0.36	0.55	0.27	0.58	0.51	0.29	0.50	0.52
Stad. Dev.of Geo. Mean		1.67			1.13			0.67	

APPENDIX 15
MEAN CONVEYOR AND THRESHING EFFICIENCIES OF THE
EQUIPMENT

A. Conveyor Efficiency (%)

PMC	Range	Mean
14.0	66.9 – 74.1	64.8
18.0	55.2 – 73.9	67.2
22.0	60.1 – 79.1	67.4

B. Threshing Efficiency (%)

PMC	Range	Mean
14.0	67.5 – 97.7	86.7
18.0	77.1 – 92.4	86.7
22.0	77.7 – 97.0	85.6

APPENDIX 16

ANOVA TABLE FOR CONVEYOR AND THRESHING EFFICIENCIES (%) AT VARIOUS POD MOISTURE CONTENT

A: Anova Table for Conveyor Efficiency (%) at various Pod Moisture Content

SUMMARY					
Groups	Count	Sum	Average	Variance	
Column 1	6	387	64.575	52.6	
Column 2	3	202	67.197	108.1	
Column 3	4	270	67.415	69.98	

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Pod Moisture Content	24.45099	2	12.225	0.177	0.84	4.103
Error	689.1309	10	68.913			
Total	713.5819	12				

B: Anova Table for Threshing Efficiency (%) at various Pod Moisture Content

SUMMARY					
Groups	Count	Sum	Average	Variance	
Column 1	6	500	83.393	120.4	
Column 2	3	260	86.69	77.93	
Column 3	4	342	85.623	67	

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Pod Moisture Content	25.27379	2	12.637	0.132	0.878	4.103
Error	958.6436	10	95.864			
Total	983.9174	12				

MATERIAL SPREAD IN THE CLEANING CHAMBER

Table 1: Mean Material distribution at PMC = 14.0%, GMC =15.3%,
O = 90⁰, V_r = 900 rpm

SN	Materials	1	2	3	4	5	6	7	Total
1	Big seeds	5.9	4.0	2.4	0.7	0.1	0.0	0.0	13.1
	Medium								
2	seeds	0.4	1.1	0.4	0.2	0.0	0.0	0.0	2.1
	Small								
3	seeds	0.0	0.2	0.0	0.3	0.1	0.0	0.0	0.7
	Damaged								
4	seeds	6.5	3.6	2.1	1.6	0.1	0.0	0.0	14.0
5	Whole pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Medium pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Small pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unthreshed								
8	pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	Total	12.9	8.9	4.9	2.9	0.4	0.0	0.0	29.9

Table 2: Mean Material distribution at PMC = 18.0%, GMC =17.2%,
O = 90⁰, V_r = 900 rpm

SN	Materials	1	2	3	4	5	6	7	Total
1	Big seeds	6.4	7.9	4.1	1.8	0.2	0.1	0.1	20.7
	Medium								
2	seeds	0.8	0.7	0.3	0.1	0.0	0.0	0.0	2.0
	Small								
3	seeds	0.4	0.1	0.1	0.3	0.0	0.0	0.0	0.9
	Damaged								
4	seeds	2.1	2.1	2.2	0.1	0.3	0.0	0.0	6.9
5	Whole pods	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
6	Medium pods	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
7	Small pods	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
	Unthreshed								
8	pods	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
	Total	9.7	10.8	7.7	2.3	0.6	0.1	0.1	31.4

**Table 3: Mean Material distribution at PMC = 22.0%, GMC = 18.8%,
O = 90°, V_f = 900 rpm**

SN	Materials	1	2	3	4	5	6	7	Total
1	Big seeds	3.3	4.7	2.3	1.4	0.3	0.0	0.0	12.1
	Medium								
2	seeds	0.3	0.2	0.2	0.0	0.0	0.0	0.0	0.6
	Small								
3	seeds	0.3	0.8	0.3	0.2	0.1	0.0	0.0	1.6
	Damaged								
4	seeds	0.6	1.0	0.3	0.1	0.0	0.0	0.0	2.1
5	Whole pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Medium pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Small pods	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
	Unthreshed								
8	Pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	4.4	6.8	3.1	1.7	0.4	0.0	0.0	16.5

**Table 4: Mean Material distribution at PMC = 18.0%, GMC = 17.2%,
O = 105°, V_f = 900 rpm**

SN	Materials	1	2	3	4	5	6	7	Total
1	Big seeds	2.3	5.1	0.9	0.9	0.0	0.0	0.0	9.3
	Medium								
2	seeds	0.4	0.5	0.0	0.5	0.0	0.0	0.0	1.4
	Small								
3	seeds	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.5
	Damaged								
4	seeds	1.4	2.0	1.3	0.1	0.0	0.0	0.0	4.8
5	Whole pods	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.4
6	Medium pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Small pods	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2
	Unthreshed								
8	Pods	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	Total	4.6	8.1	2.6	1.6	0.0	0.0	0.0	16.9

**Table 5: Mean Material distribution at PMC = 14.0%, GMC = 15.3%,
O = 105°, V_f = 900 rpm**

SN	Materials	1	2	3	4	5	6	7	Total
1	Big seeds	9.1	5.7	3.4	2.4	1.3	0.0	0.0	21.8
	Medium								
2	seeds	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
	Small								
3	seeds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Damaged								
4	seeds	1.7	3.0	1.3	0.3	0.0	0.0	0.0	6.4
5	Whole pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Medium pods	0.3	1.7	1.0	0.0	0.0	0.0	0.0	3.0
7	Small pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unthreshed								
8	Pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	11.1	10.4	5.7	3.7	1.3	0.0	0.0	32.3

**Table 6: Mean Material distribution at PMC = 22.0%, GMC = 18.8%,
O = 105°, V_f = 900 rpm**

SN	Materials	1	2	3	4	5	6	7	Total
1	Big seeds	5.6	5.4	3.7	0.7	0.0	0.0	0.0	15.4
	Medium								
2	seeds	0.7	0.5	0.5	0.0	0.0	0.0	0.0	1.7
	Small								
3	seeds	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.5
	Damaged								
4	seeds	3.2	3.4	1.5	0.2	0.0	0.0	0.0	8.3
5	Whole pods	0.0	1.5	0.7	0.0	0.0	0.0	0.0	2.2
6	Medium pods	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2
7	Small pods	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2
	Unthreshed								
8	Pods	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.5
	Total	9.5	12.0	6.6	1.0	0.0	0.0	0.0	29.0

**Table 7: Mean Material distribution at PMC = 14.0%, GMC = 15.3%,
O = 120°, V_r = 1,500 rpm**

SN	Materials	1	2	3	4	5	6	7	Total
1	Big seeds	0.6	1.7	0.6	1.9	3.9	3.6	2.6	14.9
	Medium								
2	seeds	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.7
	Small								
3	seeds	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2
	Damaged								
4	seeds	0.0	0.0	0.1	0.3	0.2	0.8	1.5	3.0
5	Whole pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Medium pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Small pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unthreshed								
8	pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	0.6	1.7	0.7	2.4	4.8	4.4	4.2	18.8

**Table 8: Mean Material distribution at PMC = 18.0%, GMC = 17.2 %,
O=120°, V_r = 1,500 rpm**

SN	Materials	1	2	3	4	5	6	7	Total
1	Big seeds	0.1	0.1	0.3	0.5	0.9	1.5	1.1	4.5
	Medium								
2	seeds	0.2	0.1	0.7	0.3	0.8	0.7	0.8	3.8
	Small								
3	seeds	0.0	0.2	0.0	0.4	0.1	0.0	0.3	1.1
	Damaged								
4	seeds	0.0	0.1	0.1	0.6	0.7	0.8	1.5	3.9
5	Whole pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Medium pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Small pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unthreshed								
8	pods	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
	Total	0.3	0.5	1.2	1.9	2.6	3.0	3.8	13.3

Table 9:

SN	M Materials	1	2	3	4	5	6	7	Total	Outside Tray
1	Big seeds ^a	0.0	0.2	0.7	2.5	1.4	1.5	0.8	7.1	1.0
2	Medium seeds ^a	0.1	0.4	0.4	0.8	0.6	0.0	0.2	2.5	0.1
3	Small seeds ^M	0.2	0.0	0.1	0.3	0.1	0.3	0.1	1.1	0.0
4	Damaged seeds ^a	0.1	0.0	0.1	0.0	1.0	1.3	1.2	3.7	6.0
5	Whole pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Medium pods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
7	Small pods	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
8	Unthreshed pods ^a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total^f	0.4	0.6	1.3	3.6	3.1	3.1	2.4	14.5	7.3

distribution at PMC = 22.0%, GMC = 18.8%,
O = 120°, V_f = 1,500 rpm

Table 10: Mean Material distribution at PMC = 14.0%, GMC = 15.3%,
O = 105°, V_f = 1,500 rpm

0.1	1.9	2.9	2.2	2.4	1.6	0.7	11.9
0.0	0.4	0.6	1.0	0.7	0.3	0.1	3.2
0.0	0.3	0.1	0.0	0.0	0.4	0.0	0.9
0.0	0.2	0.0	0.0	0.0	0.1	0.6	0.9
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	2.8	3.7	3.3	3.1	2.5	1.5	17.0

Table 11: Mean Material distribution at PMC = 22.0%, GMC = 18.8%,
O = 90°, V_f = 1,500 rpm

0.5	1.4	3.9	3.7	3.8	1.8	1.2	16.2
0.0	0.0	0.2	0.9	0.9	0.9	0.2	3.2
0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.3
0.0	0.0	0.0	0.0	0.2	0.2	0.6	1.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	1.4	4.3	4.6	4.9	3.0	2.0	20.6

**Table 12: Mean Material distribution at PMC = 14.0%, GMC = 15.3%,
O = 120°, V_r = 1,500 rpm**

0.0	0.9	1.8	3.3	3.0	1.3	1.6	11.9
0.0	0.8	0.2	1.5	1.5	0.2	0.8	3.8
0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	1.7	1.9	4.9	4.5	2.0	2.4	16.2

**Table 13: Mean Material distribution at PMC = 18.0%, GMC = 17.2%,
O = 120°, V_r = 1,500 rpm**

0.0	0.2	1.2	2.0	2.2	3.4	1.3	10.5
0.0	0.0	0.0	0.3	0.3	0.2	0.0	1.4
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.2	1.2	2.3	2.5	3.6	2.0	12.8

**Table 14: Mean Material distribution at PMC = 22.0%, GMC = 18.8%,
O = 120°, V_r = 1,500 rpm**

0.2	0.2	1.5	1.9	3.4	1.3	0.8	8.5
0.0	0.2	0.0	0.0	0.2	0.0	0.2	0.6
0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2
0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.6
0.2	0.0	0.2	0.0	0.0	0.0	0.2	0.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.4	1.9	1.9	3.6	1.5	1.5	10.4

APPENDIX 18

REGRESSION ANALYSIS SUMMARY FOR THE SPREAD PATTERN PLOTS

Regression Fig. 7.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.931 ^a	.867	.841	7.0955

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1645.261	1	1645.261	32.679	.002 ^a
	Residual	251.731	5	50.346		
	Total	1896.992	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	45.616	6.102		7.478	.001
	Distance from the point of entr	-.628	.110	-.931	-5.717	.002

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.733 ^a	.538	.446	14.0347

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1146.648	1	1146.648	5.821	.061 ^a
	Residual	984.871	5	196.974		
	Total	2131.519	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	40.441	12.069		3.351	.020
	Distance from the point of entr	-.525	.217	-.733	-2.413	.061

a. Dependent Variable: Medium seeds

Regression

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance from the point of entr		Enter

a. All requested variables entered.

b. Dependent Variable: Small seeds

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.183 ^a	.033	-.160	21.8081

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	82.341	1	82.341	.173	.695 ^a
	Residual	2377.977	5	475.595		
	Total	2460.317	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	21.295	18.753		1.136	.308
	Distance from the point of entr	-.141	.338	-.183	-.416	.695

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.928 ^a	.861	.833	7.0648

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1540.652	1	1540.652	30.868	.003 ^a
	Residual	249.554	5	49.911		
	Total	1790.206	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	44.604	6.075		7.342	.001
	Distance from the point of entr	-.608	.109	-.928	-5.556	.003

a. Dependent Variable: Damaged seeds

Regression

Warnings

The dependent variable Whole pods has been deleted. Statistics cannot be computed.

Regression Fig. 8

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.913 ^a	.834	.801	7.0080

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1235.662	1	1235.662	25.160	.004 ^a
	Residual	245.560	5	49.112		
	Total	1481.222	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	41.438	6.028		6.876	.001
	Distance from the point of entr	-.545	.109	-.913	-5.016	.004

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.919 ^a	.844	.813	7.8473

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1670.733	1	1670.733	27.131	.003 ^a
	Residual	307.898	5	61.580		
	Total	1978.631	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	45.858	8.748		6.796	.001
	Distance from the point of entr	-.633	.122	-.919	-5.209	.003

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.729 ^a	.531	.437	13.3697

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1011.019	1	1011.019	5.656	.063 ^a
	Residual	893.742	5	178.748		
	Total	1904.762	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	38.846	11.497		3.379	.020
	Distance from the point of entr	-.493	.207	-.729	-2.378	.063

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.874 ^a	.765	.718	8.5324

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1183.195	1	1183.195	16.252	.010 ^a
	Residual	364.012	5	72.802		
	Total	1547.207	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	40.855	7.337		5.568	.003
	Distance from the point of entr	-.533	.132	-.874	-4.031	.010

a. Dependent Variable: Damaged seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.198 ^a	.039	-.153	40.5807

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	337.445	1	337.445	.205	.670 ^a
	Residual	8233.963	5	1646.797		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Whole pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	28.475	34.897		.816	.452
	Distance from the point of entr	-.285	.629	-.198	-.453	.670

a. Dependent Variable: Whole pods

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.198 ^a	.039	-.153	40.5807

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	337.445	1	337.445	.205	.670 ^a
	Residual	8233.983	5	1646.797		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	28.475	34.897		.816	.452
	Distance from the point of entr	-.285	.629	-.198	-.453	.670

a. Dependent Variable: Medium pods

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.198 ^a	.039	-.153	40.5807

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	337.445	1	337.445	.205	.670 ^a
	Residual	8233.983	5	1646.797		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	28.475	34.897		.816	.452
	Distance from the point of entr	-.285	.629	-.198	-.453	.670

a. Dependent Variable: Small pods

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.198 ^a	.039	-.153	40.5807

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	337.445	1	337.445	.205	.670 ^a
	Residual	8233.983	5	1646.797		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Unthreshed pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	28.475	34.897		.816	.452
	Distance from the point of entr	-.285	.629	-.198	-.453	.670

a. Dependent Variable: Unthreshed pods

Regression Fig. 9

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.902 ^a	.814	.777	7.1379

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1116.682	1	1116.682	21.917	.005 ^a
	Residual	254.747	5	50.949		
	Total	1371.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	40.097	6.138		6.533	.001
	Distance from the point of entr	-.518	.111	-.902	-4.682	.005

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.899 ^a	.808	.770	8.8481

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1649.376	1	1649.376	21.068	.006 ^a
	Residual	391.441	5	78.288		
	Total	2040.816	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	45.655	7.609		6.000	.002
	Distance from the point of entr	-.629	.137	-.899	-4.590	.006

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.747 ^a	.558	.470	11.8219

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	883.021	1	883.021	6.318	.054 ^a
	Residual	898.788	5	139.758		
	Total	1581.809	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	37.238	10.166		3.663	.015
	Distance from the point of entr	-.460	.183	-.747	-2.514	.054

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.819 ^a	.670	.604	12.1032

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1488.988	1	1488.988	10.165	.024 ^a
	Residual	732.440	5	146.488		
	Total	2221.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	44.091	10.408		4.236	.008
	Distance from the point of entr	-.598	.188	-.819	-3.188	.024

a. Dependent Variable: Damaged seeds

Regression

Warnings

The dependent variable Whole pods has been deleted. Statistics cannot be computed.

Regression

Warnings

The dependent variable Medium pods has been deleted. Statistics cannot be computed.

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.399 ^a	.159	-.009	37.9614

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1366.093	1	1366.093	.948	.375 ^a
	Residual	7205.335	5	1441.067		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	42.835	32.644		1.312	.246
	Distance from the point of entr	-.573	.588	-.399	-.974	.375

a. Dependent Variable: Small pods

Regression

Warnings

The dependent variable Unthreshe pods has been deleted. Statistics cannot be computed.

Regression Fig. 10

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.782 ^a	.611	.533	13.1628

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1361.236	1	1361.236	7.857	.038 ^a
	Residual	866.298	5	173.260		
	Total	2227.534	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	42.784	11.319		3.780	.013
	Distance from the point of entr	-.572	.204	-.782	-2.803	.038

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.673 ^a	.452	.343	14.5424

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	873.400	1	873.400	4.130	.096 ^a
	Residual	1057.403	5	211.481		
	Total	1930.804	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	37.113	12.505		2.968	.031
	Distance from the point of entr	-.458	.225	-.673	-2.032	.098

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.893 ^a	.797	.757	9.3826

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1731.263	1	1731.263	19.666	.007 ^a
	Residual	440.165	5	88.033		
	Total	2171.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	46.425	8.068		5.754	.002
	Distance from the point of entr	-.645	.145	-.893	-4.435	.007

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.874 ^a	.763	.716	9.2179

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1369.109	1	1369.109	16.113	.010 ^a
	Residual	424.850	5	84.970		
	Total	1793.959	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	42.866	7.927		5.408	.003
	Distance from the point of entr	-.573	.143	-.874	-4.014	.010

a. Dependent Variable: Damaged seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.331 ^a	.110	-.068	29.2972

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	529.803	1	529.803	.617	.468 ^a
	Residual	4291.626	5	858.325		
	Total	4821.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Whole pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	32.065	25.193		1.273	.259
	Distance from the point of entr	-.357	.454	-.331	-.786	.468

a. Dependent Variable: Whole pods

Regression

Warnings

The dependent variable Medium pods has been deleted. Statistics cannot be computed.

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.399 ^a	.159	-.009	37.9614

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1366.093	1	1366.093	.948	.375 ^a
	Residual	7205.335	5	1441.067		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	42.835	32.644		1.312	.246
	Distance from the point of entr	-.573	.588	-.399	-.974	.375

a. Dependent Variable: Small pods

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.625 ^a	.391	.269	32.3167

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3349.584	1	3349.584	3.207	.133 ^a
	Residual	5221.845	5	1044.369		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Unthreshed pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	58.990	27.790		2.123	.087
	Distance from the point of entr	-.897	.501	-.625	-1.791	.133

a. Dependent Variable: Unthreshed pods

Regression Fig.11

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.955 ^a	.912	.895	4.9013

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1251.717	1	1251.717	52.106	.001 ^a
	Residual	120.112	5	24.022		
	Total	1371.829	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	41.613	4.215		9.873	.000
	Distance from the point of entr	-.548	.076	-.955	-7.218	.001

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.002 ^a	.000	-.200	41.4038

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.898E-02	1	4.898E-02	.000	.996 ^a
	Residual	8571.380	5	1714.276		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	14.115	35.604		.396	.708
	Distance from the point of entr	3.429E-03	.641	.002	.005	.996

a. Dependent Variable: Medium seeds

Regression

Warnings

The dependent variable Small seeds has been deleted. Statistics cannot be computed.

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.824 ^a	.679	.615	11.3737

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1368.822	1	1368.822	10.581	.023 ^a
	Residual	646.800	5	129.360		
	Total	2015.621	6			

a. Predictors: (Constant), Distances from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	42.863	9.781		4.382	.007
	Distance from the point of entr	-.573	.176	-.824	-3.253	.023

a. Dependent Variable: Damaged seeds

Regression

Warnings

The dependent variable Whole pods has been deleted. Statistics cannot be computed.

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.600 ^a	.361	.233	19.5662

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1079.463	1	1079.463	2.820	.154 ^a
	Residual	1914.188	5	382.838		
	Total	2993.651	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	39.663	16.826		2.357	.065
	Distance from the point of entr	-.509	.303	-.600	-1.679	.154

a. Dependent Variable: Medium pods

Regression

Warnings

The dependent variable Small pods has been deleted. Statistics cannot be computed.

Regression

Warnings

The dependent variable Unthresed pods has been deleted. Statistics cannot be computed.

Regression Fig. 12

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.928 ^a	.857	.829	7.0132

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1475.278	1	1475.278	29.995	.003 ^a
	Residual	245.923	5	49.185		
	Total	1721.201	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	43.954	6.031		7.288	.001
	Distance from the point of entr	-.595	.109	-.926	-5.477	.003

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.897 ^a	.805	.786	8.8164

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1608.392	1	1608.392	20.692	.006 ^a
	Residual	388.642	5	77.728		
	Total	1997.034	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	45.263	7.581		5.970	.002
	Distance from the point of entr	-.621	.137	-.897	-4.549	.006

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.463 ^a	.214	.057	23.6899

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	765.363	1	765.363	1.364	.296 ^a
	Residual	2806.066	5	561.213		
	Total	3571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	35.655	20.372		1.750	.140
	Distance from the point of entr	-.429	.367	-.453	-1.168	.296

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.896 ^a	.804	.764	9.0137

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1662.071	1	1662.071	20.457	.006 ^a
	Residual	406.237	5	81.247		
	Total	2068.308	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	45.776	7.751		5.906	.002
	Distance from the point of entr	-.632	.140	-.896	-4.523	.006

a. Dependent Variable: Damaged seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.477 ^a	.228	.073	25.5686

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	963.816	1	963.816	1.474	.279 ^a
	Residual	3268.770	5	653.754		
	Total	4232.586	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Whole pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	38.266	21.987		1.740	.142
	Distance from the point of entr	-.481	.396	-.477	-1.214	.279

a. Dependent Variable: Whole pods

Regression**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.399 ^a	.159	-.009	37.9614

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1366.093	1	1366.093	.948	.375 ^a
	Residual	7205.335	5	1441.067		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	42.835	32.644		1.312	.246
	Distance from the point of entr	-.573	.588	-.399	-.974	.375

a. Dependent Variable: Medium pods

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.399 ^a	.159	-.009	37.9614

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1366.093	1	1366.093	.948	.375 ^a
	Residual	7205.335	5	1441.067		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	42.835	32.644		1.312	.246
	Distance from the point of entr	-.573	.588	-.399	-.974	.375

a. Dependent Variable: Small pods

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.380 ^a	.144	-.069	42.2189

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1203.587	1	1203.587	.675	.457 ^a
	Residual	7129.746	4	1782.437		
	Total	8333.333	5			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Unthreshed pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	46.250	39.914		1.159	.311
	Distance from the point of entr	-.675	.821	-.380	-.822	.457

a. Dependent Variable: Unthreshed pods

Regression Fig. 13

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.768 ^a	.591	.509	6.2038

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	277.556	1	277.556	7.212	.044 ^a
	Residual	192.436	5	38.487		
	Total	469.992	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.417	5.335		.266	.801
	Distance from the point of entr	.258	.096	.768	2.685	.044

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.203 ^a	.041	-.150	40.5402

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	353.904	1	353.904	.215	.662 ^a
	Residual	8217.525	5	1643.505		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.245	34.862		-.007	.995
	Distance from the point of entr	.291	.628	.203	.464	.662

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.470 ^a	.221	.065	23.5855

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	790.051	1	790.051	1.420	.287 ^a
	Residual	2781.378	5	556.278		
	Total	3571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-7.425	20.282		-.366	.729
	Distance from the point of entr	.435	.365	.470	1.192	.287

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.862 ^a	.743	.691	10.5806

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1614.538	1	1614.538	14.422	.013 ^a
	Residual	559.745	5	111.949		
	Total	2174.283	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-16.751	9.099		-1.841	.125
	Distance from the point of entr	.623	.164	.862	3.798	.013

a. Dependent Variable: Damaged seeds

Regression

Warnings

The dependent variable Whole pods has been deleted. Statistics cannot be computed.

Regression Fig. 14

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.917 ^a	.842	.810	5.2141

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	721.913	1	721.913	26.554	.004 ^a
	Residual	135.935	5	27.187		
	Total	857.848	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-6.468	4.484		-1.442	.209
	Distance from the point of entr	.416	.081	.917	5.153	.004

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.790 ^a	.624	.549	5.6420

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	264.120	1	264.120	8.297	.035 ^a
	Residual	159.160	5	31.832		
	Total	423.280	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.733	4.852		.357	.736
	Distance from the point of entr	.252	.087	.790	2.880	.035

a. Dependent Variable: Medium seeds

Regression**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.287 ^a	.082	-.101	16.9824

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	129.412	1	129.412	.449	.533 ^a
	Residual	1442.017	5	288.403		
	Total	1571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.499	14.604		.377	.722
	Distance from the point of entr	.176	.263	.287	.670	.533

a. Dependent Variable: Small seeds

Regression**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.939 ^a	.881	.858	5.2810

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1035.862	1	1035.862	37.142	.002 ^a
	Residual	139.444	5	27.889		
	Total	1175.306	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-10.574	4.541		-2.328	.067
	Distance from the point of entr	.499	.082	.939	6.094	.002

a. Dependent Variable: Damaged seeds

Regression

Warnings

The dependent variable Whole pods has been deleted. Statistics cannot be computed.

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.605 ^a	.366	.239	32.9729

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3135.368	1	3135.368	2.884	.150 ^a
	Residual	5436.061	5	1087.212		
	Total	8571.428	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Unthreshed pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-28.965	28.354		-1.022	.354
	Distance from the point of entr	.867	.511	.605	1.698	.150

a. Dependent Variable: Unthreshed pods

Regression Fig. 15**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.517 ^a	.267	.120	11.3500

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	234.401	1	234.401	1.820	.235 ^a
	Residual	644.110	5	128.822		
	Total	878.511	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.460	9.780		.252	.811
	Distance from the point of entr	.237	.176	.517	1.349	.235

a. Dependent Variable: Big seeds

Regression**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.076 ^a	.006	-.193	12.3208

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.421	1	4.421	.029	.871 ^a
	Residual	759.008	5	151.802		
	Total	763.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	15.910	10.595		1.502	.193
	Distance from the point of entr	-3.26E-02	.191	-.076	-.171	.871

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.201 ^a	.040	-.151	11.0611

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	25.810	1	25.810	.211	.665 ^a
	Residual	611.735	5	122.347		
	Total	637.544	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10.362	9.512		1.089	.326
	Distance from the point of entr	7.871E-02	.171	.201	.459	.665

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.864 ^a	.747	.696	9.0091

a. Predictors: (Constant), Distance from the point of entr

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1197.018	1	1197.018	14.748	.012 ^a
	Residual	405.821	5	81.164		
	Total	1602.839	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-12.438	7.747		-1.606	.169
	Distance from the point of entr	.536	.140	.864	3.840	.012

a. Dependent Variable: Damaged seeds

Regression**Warnings**

The dependent variable Whole pods has been deleted. Statistics cannot be computed.

Regression**Warnings**

The dependent variable Medium pods has been deleted. Statistics cannot be computed.

Regression**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.605 ^a	.366	.239	32.9729

a. Predictors: (Constant), Distance from the point of entr

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3135.368	1	3135.368	2.884	.150 ^a
	Residual	5438.081	5	1087.212		
	Total	8571.429	6			

a. Predictors: (Constant), Distance from the point of entr

b. Dependent Variable: Small pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-28.965	28.354		-1.022	.354
	Distance from the point of entr	.667	.511	.605	1.698	.150

a. Dependent Variable: Small pods

Regression Fig 16

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.813 ^a	.661	.593	9.9165

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	959.242	1	959.242	9.755	.026 ^a
	Residual	491.687	5	98.337		
	Total	1450.929	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	96.837	8.528		11.356	.000
	Distance from the point of entry	-.480	.154	-.813	-3.123	.026

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.219 ^a	.048	-.143	11.1199

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	31.068	1	31.068	.251	.637 ^a
	Residual	618.266	5	123.653		
	Total	649.334	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	11.323	9.562		1.184	.290
	Distance from the point of entry	8.635E-02	.172	.219	.501	.637

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.134 ^a	.018	-.179	7.6043

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.254	1	5.254	.091	.775 ^a
	Residual	289.126	5	57.825		
	Total	294.380	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.830	6.539		.433	.683
	Distance from the point of entry	3.551E-02	.118	.134	.301	.775

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.630 ^a	.397	.276	12.4324

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	508.962	1	508.962	3.293	.129 ^a
	Residual	772.818	5	154.564		
	Total	1281.780	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-10.126	10.691		-.947	.387
	Distance from the point of entry	.350	.193	.630	1.815	.129

a. Dependent Variable: Damaged seeds

Regression

Warnings

The dependent variable Small pods has been deleted. Statistics cannot be computed.

Regression Fig. 17

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000 ^a	1.000	1.000	.0000

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4166.357	1	4166.357		. ^a
	Residual	.000	5	.000		
	Total	4166.357	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.000	.000			
	Distance from the point of entry	1.000	.000	1.000		

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.973 ^a	.947	.936	4.1973

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1559.842	1	1559.842	88.540	.000 ^a
	Residual	88.087	5	17.617		
	Total	1647.929	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	111.621	3.609		30.925	.000
	Distance from the point of entry	-.812	.065	-.973	-9.410	.000

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.710 ^a	.504	.405	8.7328

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	388.062	1	388.062	5.089	.074 ^a
	Residual	381.307	5	76.261		
	Total	769.369	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3.030	7.510		-.404	.703
	Distance from the point of entry	.305	.135	.710	2.256	.074

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.063 ^a	.004	-.195	2.0049

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8.126E-02	1	8.126E-02	.020	.892 ^a
	Residual	20.099	5	4.020		
	Total	20.180	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.980	1.724		.588	.594
	Distance from the point of entry	4.416E-03	.031	.063	.142	.892

a. Dependent Variable: Damaged seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.747 ^a	.558	.470	7.6424

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	368.954	1	368.954	6.317	.054 ^a
	Residual	292.035	5	58.407		
	Total	660.989	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Whole pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-9.251	6.572		-1.408	.218
	Distance from the point of entry	.298	.118	.747	2.513	.054

a. Dependent Variable: Whole pods

Regression

Warnings

The dependent variable Medium pods has been deleted. Statistics cannot be computed.

Regression Fig. 18

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.498 ^a	.248	.097	26.9329

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1193.913	1	1193.913	1.646	.256 ^a
	Residual	3626.904	5	725.381		
	Total	4820.817	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	31.168	23.160		1.346	.236
	Distance from the point of entry	.535	.417	.498	1.283	.256

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.065 ^a	.004	-.195	18.3517

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.077	1	7.077	.021	.890 ^a
	Residual	1683.931	5	336.786		
	Total	1691.009	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	21.741	15.781		1.378	.227
	Distance from the point of entry	-4.12E-02	.284	-.065	-.145	.890

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.412 ^a	.170	.004	7.5062

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	57.721	1	57.721	1.024	.358 ^a
	Residual	281.716	5	56.343		
	Total	339.437	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3.025	6.455		-.469	.659
	Distance from the point of entry	.118	.116	.412	1.012	.358

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.605 ^a	.366	.239	9.4632

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	258.257	1	258.257	2.884	.150 ^a
	Residual	447.763	5	89.553		
	Total	706.020	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-8.313	8.138		-1.022	.354
	Distance from the point of entry	.249	.147	.605	1.698	.150

a. Dependent Variable: Damaged seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.412 ^a	.170	.004	3.1685

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.285	1	10.285	1.024	.358 ^a
	Residual	50.195	5	10.039		
	Total	60.480	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Whole pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.277	2.725		-.469	.659
	Distance from the point of entry	4.968E-02	.049	.412	1.012	.358

a. Dependent Variable: Whole pods

Regression

Warnings

The dependent variable Medium pods has been deleted. Statistics cannot be computed.

Regression Fig. 19

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.396 ^a	.157	-.012	35.8943

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1199.633	1	1199.633	.931	.379 ^a
	Residual	6442.004	5	1288.401		
	Total	7641.637	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	49.990	30.867		1.620	.166
	Distance from the point of entry	.537	.556	.396	.965	.379

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.282 ^a	.080	-.104	6.5764

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.737	1	18.737	.433	.539 ^a
	Residual	216.243	5	43.249		
	Total	234.980	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.157	5.855		.205	.846
	Distance from the point of entry	6.706E-02	.102	.282	.658	.539

a. Dependent Variable: Medium seeds

Regression

Warnings

The dependent variable Small seeds has been deleted. Statistics cannot be computed.

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.605 ^a	.368	.239	5.5724

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	89.549	1	89.549	2.884	.150 ^a
	Residual	155.259	5	31.052		
	Total	244.809	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4.895	4.792		-1.022	.354
	Distance from the point of entry	.147	.086	.605	1.698	.150

a. Dependent Variable: Damaged seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.805 ^a	.366	.239	5.2427

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	79.265	1	79.265	2.884	.150 ^a
	Residual	137.429	5	27.486		
	Total	216.694	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Whole pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4.605	4.508		-1.022	.354
	Distance from the point of entry	.138	.081	.605	1.698	.150

a. Dependent Variable: Whole pods

Regression

Warnings

The dependent variable Medium pods has been deleted. Statistics cannot be computed.

Regression Fig. 20

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.329 ^a	.108	-.070	23.2285

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	328.191	1	328.191	.608	.471 ^a
	Residual	2697.806	5	539.561		
	Total	3025.997	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Big seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	59.350	19.975		2.971	.031
	Distance from the point of entry	.281	.360	.329	.780	.471

a. Dependent Variable: Big seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.229 ^a	.053	-.137	19.6138

a. Predictors: (Constant), Distance from the point of entry

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	106.809	1	106.809	.278	.621 ^a
	Residual	1923.500	5	384.700		
	Total	2030.309	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Medium seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	17.697	16.866		1.049	.342
	Distance from the point of entry	-.160	.304	-.229	-.527	.621

a. Dependent Variable: Medium seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.787 ^a	.619	.543	4.1910

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	142.613	1	142.613	8.120	.036 ^a
	Residual	87.821	5	17.564		
	Total	230.434	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Small seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-5.596	3.604		-1.553	.181
	Distance from the point of entry	.185	.065	.787	2.849	.036

a. Dependent Variable: Small seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.384 ^a	.148	-.023	5.7047

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28.217	1	28.217	.867	.395 ^a
	Residual	162.718	5	32.544		
	Total	190.934	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Damaged seeds

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.832	4.906		-.170	.872
	Distance from the point of entry	8.230E-02	.068	.384	.931	.395

a. Dependent Variable: Damaged seeds

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.529 ^a	.280	.136	16.9949

a. Predictors: (Constant), Distance from the point of entry

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	561.742	1	561.742	1.945	.222 ^a
	Residual	1444.135	5	288.827		
	Total	2005.877	6			

a. Predictors: (Constant), Distance from the point of entry

b. Dependent Variable: Whole pods

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	28.664	14.614		1.961	.107
	Distance from the point of entry	-.367	.263	-.529	-1.395	.222

a. Dependent Variable: Whole pods

Regression**Warnings**

The dependent variable Medium pods has been deleted. Statistics cannot be computed.