# DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF LINSEED THRESHER

**M.Tech. (Agril. Engg.) Thesis**

**By**


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**FACULTY OF AGRICULTURAL ENGINEERING**

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# DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF LINSEED THRESHER

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**by**

**Geeta Patel**

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**in**

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**(Farm Machinery and Power Engineering)**

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# CERTIFICATE-I

This is to certify that the thesis entitled "**Design, development and performance evaluation of linseed thresher**" submitted in partial fulfilment of the requirements for the degree of the **Master of Technology in Agricultural Engineering** of Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of bonafide research work carried out by **Geeta Patel** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigation have been duly acknowledged.

22/7/2024

**Chairman**

Date: 22/07/2024

**THESIS APPROVED BY STUDENT'S ADVISORY COMMITTEE**

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## CERTIFICATE-II

This is to certify that the thesis entitled "**Design, development and performance evaluation of linseed thresher**" submitted by **Geeta Patel** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfilment of the requirement for the degree of **Master of Technology in Agricultural Engineering** in the Department of **Farm Machinery and Power Engineering** has been approved by the external examiner and Student's Advisory Committee after oral examination.

Signature ~~of Head~~ of Department/
Dean (in case of outcampii)

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**Head of Department** ________

**Dean, SVCAET&RS, FAE** ________ 20/09/2017

**Approved/Not approved**

**Director of Instruction** ________

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*Place: Raipur*
*Date:* 22/07/2021

Patel
***(Geeta Patel)***

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURE

# LIST OF NOTATION

| Notations | Description |
|---|---|
| % | Percent |
| & | and |
| @ | at the rate of |
| cm | centimetre |
| mm | millimetre |
| dia. | diameter |
| g | gram |
| h | hour |
| kg | kilogram |
| kg/h | kilogram per hour |
| kg/min | kilogram per minute |
| kg/ha | kilogram per hectare |
| kcal | kilo calorie |
| $kg/m^3$ | kilogram per cubic meter |
| m/s | meter per second |
| M.C. | Moisture Content |
| MS | Mild Steel |
| $m^2$ | square meter |
| $mm^2$ | Square millimetre |
| $mm^3$ | Cubic millimetre |
| rpm | revolution per minute |
| N-mm | Newton millimetre |
| ml | millilitre |
| viz. | namely |
| wb | wet basis |
| db | dry basis |
| I | Interest |
| hp | horse power |

| Notations | Description |
|---|---|
| kW | kilo Watt |
| kW- h | kilo watt hour |
| $cm^2$ | square centimetre |
| S | speed of operation |
| N | Newton |
| Kgf | kilogram force |
| MJ | Mega Joule |
| ϴ | theta |
| + | Plus |
| × | Multiplication |
| η | Efficiency |
| º | degree |
| Rs | Rupees |
| Rs/h | Rupees per hour |
| t/h | Tonne per hour |
| kW.h/ton | kilo Watt hour per tonne |
| h/year | hour per year |
| W | Weight |
| Rs/year | Rupees per year |
| P | Power |
| A | Area |

# LIST OF ABBREVIATIONS

| Abbreviations | Full name |
|---|---|
| FAE | Faculty of Agricultural Engineering |
| Agril. | Agriculture |
| Agril. Engg. | Agricultural Engineering |
| C.G. | Chhattisgarh |
| *et al*. | Et alibi( and co-workers/other) |
| etc. | Et cetera |
| Fig. | Figure |
| ICAR | Indian Council of Agricultural Research |
| IGKV | Indira Gandhi Krishi Vishwavidyalaya |
| B. Tech. | Bachelor of Technology |
| Er. | Engineer |
| Dr. | Doctor |
| M.Tech. | Master of Technology |
| S.No. | Serial Numbers |
| FMPE | Farm Machinery and Power Engineering |
| Max. | Maximum |
| Min. | Minimum |
| Deptt. | Department |
| IS | Indian Standard |
| Avg. | Average |
| Dia. | Diameter |
| i.e. | that is |
| d.f. | Degree of freedom |
| S.S. | Sum of squares |
| MSS | Mean sum of square |
| CD | Critical difference |
| CV | Coefficient of variation |
| SD | Standard deviation |
| ANOVA | Analysis of variance |

# THESIS ABSTRACT

| | | | |
|---|---|---|---|
| a) | Title of the thesis | : | Design, development and performance evaluation of linseed thresher |
| b) | Full name of the student | : | Geeta Patel |
| c) | Major subject | : | Farm Machinery and Power Engineering |
| d) | Name and address of the Major Advisor | : | Dr. R. K. Naik<br>Associate Professor<br>Department of Farm Machinery and Power Engineering, SVCAET&RS,FAE, I.G.K.V., Raipur(C.G.) |
| e) | Degree to be awarded | : | Master of Technology in Agricultural Engineering |

Signature of the student

Signature of Major Advisor

Date: 24/07/2019

Signature of head of the department


## ABSTRACT

Linseed (*Linum usitatissimum* L) has many health benefits, every part of linseed were utilized. Traditional method of linseed threshing involved manual hand beating, foot trampling that is time consuming operation. The present studies main aim is to design and develop the mechanical linseed thresher and to test the performance of developed linseed thresher.

The engineering properties of linseed were investigated for three varieties i.e. Neelam, Shekhar, and Sheela within the moisture content range of 8 to 14% (d.b). Based on the studied engineering properties, the major components of linseed thresher was designed. According to the design dimension, the conceptual design and drawing was built with the help of SOLIDWORKS software. The principle of stripping and threshing operation were first strip the linseed capsule from crop by wire loop and then thresh the striped linseed capsule by impact and friction force by series of peg tooth and canvas strip fitted alternatively on the surface of threshing cylinder respectively. The linseed thresher with threshing

cylinder, concave, aspirator blower, and oscillating sieve was developed at SVCAET and RS FMPE workshop in year 2020-21.

The performance of the machine was tested for the effect of six independent parameters like no of pegs, no of loops, moisture content, feed rate, cylinder peripheral speed and concave clearance on different dependent parameters like threshing capacity, stripping efficiency, threshing efficiency, cleaning efficiency and seed damage.

The linear dimensions i.e. length, width, thickness and geometric mean diameter (GMD) of linseed seed increased with increase in moisture content for all three varieties. However, the highest length, width and thickness were observed for the Neelam variety of linseed as 5.53mm, 2.92mm 0.90 mm and 2.56 mm respectively. The mean value of rupture force for linseed seed, linseed capsule, linseed stalk tip were observed 46.25 N, 5.99 N and 8.08 N respectively.

The stripping efficiency, threshing capacity, threshing efficiency and cleaning efficiency of developed linseed thresher was found highest 99.29%, 178.62 kg/h, 99.31%, 90.5% respectively at moisture content of 8%, concave clearance of 10 mm, and cylinder peripheral speed of 14.5 m/s. The highest value of seed damage was observed at higher speed, low moisture content and lower concave clearance. It was observed highest as 2.46 and 1.91 per cent respectively. Increase in feed rate increases the damage percentage. Total operational cost of operating linseed thresher was found Rs 89.17 /h. and total cost of threshing one kilogram linseed was observed as Rs 0.75 per kg., which is much cheaper than traditional method of threshing linseed (Rs. 7.5/kg). The developed machine have output of 17.8 times more than the traditional method with profit of more than 5.63 times.

# शोध सारांश

| | | |
|---|---|---|
| अ) शोध का शीर्षक | : | अलसी थ्रेशर का डिजाइन, विकास और प्रदर्शन मूल्यांकन |
| ब) छात्र का पूरा नाम | : | गीता पटेल |
| स) प्रमुख विषय | : | कृषि यंत्र एवं शक्ति अभियांत्रिकी |
| द) प्रमुख सलाहकार का नाम और पता | : | डॉ. आर. के. नायक<br>प्राध्यापक कृषि यंत्र एवं शक्ति अभियांत्रिकी विभाग, कृषि अभियांत्रिकी संकाय, आई. जी. के. वी., रायपुर (छ.ग.) |
| ई) सम्मानित उपाधि | : | कृषि अभियांत्रिकी मे मास्टर ऑफ टेक्नोलॉजी |

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प्रमुख सलाहकार के हस्ताक्षर

दिनांक 22/7/2021.

विभागाध्यक्ष के हस्ताक्षर

## सारांश


अलसी के कई स्वास्थ्य लाभ हैं, अलसी के हर हिस्से का उपयोग किया किया जाता है । अलसी की मिंजाई की पारंपरिक विधि में हाथ से हाथ मारना, पैरों से रौंदना शामिल है, जिसमें समय लगता है। वर्तमान अध्ययन का मुख्य उद्देश्य यांत्रिक अलसी थ्रेशर को डिजाइन और विकसित करना और विकसित अलसी थ्रेशर का परीक्षण करना ळें

अलसी के इंजीनियरिंग गुणों की जांच तीन किस्मों यानी नीलम, शेखर और शीला के लिए की गई थी, जिसमें नमी की मात्रा 8 से 14% (d.b) थी। अध्ययन किए गए इंजीनियरिंग गुणों के आधार पर, अलसी थ्रेशर के प्रमुख भागों को डिजाइन किया गया । डिजाइन आयाम के अनुसार, सॉलिडवर्क्स सॉफ्टवेयर की मदद से वैचारिक डिजाइन और ड्राइंग का निर्माण किया गया। स्ट्रिपिंग और थ्रेसिंग ऑपरेशन के प्रिंसिपल थे – पहले अलसी के कैप्सूल को वायर लूप द्वारा फसल से अलग करना और फिर अलग हुवे अलसी के कैप्सूल को थ्रेसिंग सिलेंडर की सतह पर एकांतर रूप से लगे पेग टूथ और कैनवास स्ट्रिप की श्रृंखला द्वारा टक्कर बल और घर्षण बल की सहायता से मिंजाई करना है। वर्ष

2020–21 में SVCAET और RS FMPE कार्यशाला में थ्रेशिंग सिलेंडर, अवतल, एस्पिरेटर ब्लोअर और ऑसिलेटिंग चलनी के साथ अलसी थ्रेशर विकसित किया गया था।

मशीन के प्रदर्शन का परीक्षण छह स्वतंत्र मापदंडों जैसे खूंटे की संख्या, लूप की संख्या, नमी, फ़ीड दर, सिलेंडर परिधीय गति और अवतल निकासी जैसे विभिन्न निर्भर मापदंडों जैसे थ्रेसिंग क्षमता, स्ट्रिपिंग दक्षता, थ्रेशिंग दक्षता, सफाई दक्षता और बीज क्षति के प्रभाव के लिए किया गया था।

अलसी के बीज के रैखिक आयाम यानी लंबाई, चौड़ाई, मोटाई और ज्यामितीय माध्य व्यास (जीएमडी) तीनों किस्मों में नमी की मात्रा में वृद्धि के साथ बढ़े। हालांकि, नीलम किस्म की अलसी की लंबाई, चौड़ाई और मोटाई सबसे अधिक क्रमशः 5.53 मिमी, 2.92 मिमी 0.90 मिमी और 2.56 मिमी देखी गई। अलसी बीज, अलसी कैप्सूल, अलसी डंठल टिप के लिए टूटना बल का माध्य मान क्रमशः 46.25 N 5.99 N और 8.08 N देखा गया।

विकसित अलसी थ्रेशर की स्ट्रिपिंग दक्षता, थ्रेसिंग क्षमता, थ्रेसिंग दक्षता और सफाई दक्षता क्रमशः 8% की नमी, 10 मिमी की अवतल निकासी और 14.5 मी/से. सिलेंडर परिधीय गति पर उच्चतम 99.29:, 178.62 किग्रा / घंटा, 99.31:, 90.5: पाई गई। बीज क्षति का उच्चतम मूल्य उच्च गति, कम नमी सामग्री और कम अवतल निकासी पर देखा गया था। यह उच्चतम क्रमशः 2.46 और 1.91 प्रतिशत के रूप में देखा गया। फ़ीड दर में वृद्धि से क्षति प्रतिशत बढ़ जाता है। अलसी थ्रेशर के संचालन की कुल परिचालन लागत 89.17 रुपये / घंटा पाई गई। और एक किलोग्राम अलसी की थ्रेसिंग की कुल लागत 0.75 रुपये प्रति किलोग्राम देखी गई, जो अलसी की थ्रेसिंग की पारंपरिक विधि (7.5 रुपये प्रति किलोग्राम) की तुलना में काफी सस्ता है। विकसित मशीन का उत्पादन पारंपरिक पद्धति की तुलना में 17.8 गुना अधिक है और लाभ 5.63 गुना से अधिक है।

# CHAPTER-I
# INTRODUCTION

Linseed (*Linum usitatissimum* L) is a major oilseed crop grown in central India. It is locally known as Jawas, *Alashi* or *Alsi*. It has been cultivated since ancient time for flax (fibre) and seed production. Every portion of the linseed plant is used economically, either directly or after processing. Linseed has received a lot of attention in recent years due to its nutritional content, which has a good effect on disease prevention by giving health-promoting components like alfa linolenic acid, lignin, and polysaccharides essential amino acids, carbohydrates, vitamins, minerals, crude fiber and this is the best herbal source of ω-3 and ω -6 fatty acids. Diets high in dietary fiber can lower the risk of heart disease, diabetes, colorectal, cancer, obesity, and inflammation (Bozan and Temelli, 2008).

Linseed is cultivated in more than 50 different countries. Canada is leading producer of flax followed by China, the United State and India. India is one of the world's major producers of linseed. India contributed about 10.81% and 5.31 % to world area and production. Linseed is currently grown on approximately 2.63 million hectares adding 1.26 million tones to the country's annual oilseed production. The average productivity of linseed is 477 kg/ha (2018-19). Madhya Pradesh, Uttar Pradesh, Chhattisgarh, Bihar, Rajasthan, Orissa and Karnataka are the major linseed growing state in India.

In terms of area and production of linseed, India ranks third in the globe. Linseed is the most important oilseed crop cultivated in Chhattisgarh under rainfed conditions. It occupies 17% share in total oilseeds production in India and 34% in Chhattisgarh. The total area of linseed is 271 thousand ha with a production of 79 thousand tones and the productivity was reported as 292 kg/ ha. Major linseed growing districts of Chhattisgarh are Raipur, Durg, Rajnadgaon, Raigarh, Sarguja, Bastar, Bilaspur. (Agashe, 2018).

### 1.1 Cultivation of linseed crop

Linseed is a cold season crop and is grown in both northern and southern regions of India. In Chhattisgarh linseed is grown under rainfed, utera and irrigated condition. Linseed is purely a rabi crop in India, sowing from October to mid-

November. Its seed is very small, flat, oval, brown, fawn or yellow colored, glossy in appearance. The crop is well suited to deep black clay soil having soil pH 5-7;annual rainfall is ranges from 45-75cm, soil temperature 20-21℃.When the leaves are dry, capsules have turned brown and the seeds have become shiny the crop is ready to harvest. If the fiber is also desired, harvesting should be done at the physiological maturity, when the crop is still green. The crop is, generally, harvested in March-April by cutting the plants close to the ground with sickle or by pulling the plants. Harvested crop is left in the field for few days for sun drying. Threshing is done by beating the dried plants with sticks or by trampling them under cattle's feet. The seed is separated from chaff by winnowing. The average crop yield range from 210-450 kg/ha.

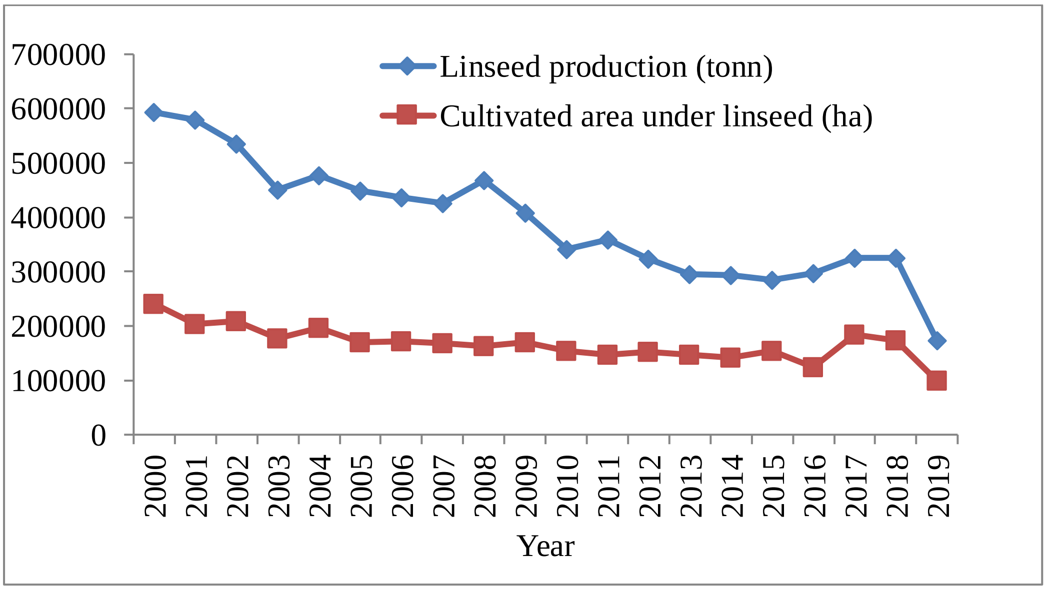



Fig. 1.1: Linseed production and cultivation area in India

### 1.2 Conventional method of linseed threshing

The conventional linseed threshing method is done manually by beating the crop with sticks or over stones or even trampling by bullocks or passing the tractor several times over the plants. Then, flaxseeds are winnowed using manually operated stationery cleaning machine. The aim of the threshing operation is to remove the capsule from the plant, then separate the seeds from the capsule, and then clean the seed from the remaining capsule. Szarszunow *et al.* (1998) concluded that ineffective threshing and threshing damage are the main causes of flax seed losses.

a. Linseed crop b. Seed plant at maturity c. Linseed

Fig 1.2 Pictorial view of linseed crop, crop at maturity and seed

The traditional linseed threshing and cleaning procedure was labour intensive, time consuming, resulted in substantial crop losses and damage from seeds and stalks, and was expensive. It also results in some losses owing to grain being damaged or buried in the ground. This is a time-consuming and energy-intensive procedure. Because of the presence of contaminants such as stone, dust, and chaff, this indigenous technique of processing the crop frequently results in low quality output.

As a result mechanical threshing is a method of overcoming the above mentioned problem. In mechanical threshing variety, moisture content of harvesting crops and some design factor such as feed rate, cylinder diameter, cylinder speed and concave clearance are some of the critical characteristics that affect threshing efficiency, mechanical damage, and seed germination.

## 1.3 Justification

Linseed has many health benefits, every part of linseed were utilized. The traditional method is a very labour intensive and time consuming process. In traditional method of threshing high seed and grain damage occur. This reducing the quality and quantity of linseed seed and it's by product utilization as fiber. Some multi crop thresher are currently available that are suitable for linseed but it is not specific to this crop. The fiber is also a useful part of the plant and it could be harvested if stem will be in full length. The present threshers will not prove to earn more income through the extraction of fiber. Hence, there is need of a thresher which will provide both threshing operation as well as stem separation simultaneously. Mechanized threshing of linseed may reduce the dependency on high labor requirement and time of operation and also save the energy requirement, and cost of operation to increase the net benefits to the farmers of state. Keeping above mentioned fact in mind, a research on design and development of a mechanical linseed thresher has been planned with following objectives:

1. To study the physical and engineering properties of linseed.
2. To design and develop linseed thresher.
3. To test and evaluate the performance of developed linseed thresher.

# CHAPTER-II
# REVIEW OF LITERATURE

This chapter deals with a review of various research aspects related to the design criteria for the development of linseed thresher. In addition to study the physical and engineering properties of linseed crop and performance evaluation of the thresher.

## 2.1Study of Engineering Properties of Linseed

The engineering properties of linseed are one of the major criteria for designing of the components. Some physical properties of this seed and comparison with other seeds are considered to be necessary for the proper design of equipment for handling, conveying, separation, dehulling, drying, mechanical expression of oil, storage and other processes (Kachru *et al.*, 1993).

### 2.1.1 Study of physical properties

The knowledge of the physical properties of crops is critical for designing different types of equipment various field operations like harvesting, threshing, handling, conveying, cleaning, separation, packaging, storing, and drying on agriculture commodities (Baryeh, 2002).

Sahay and Singh (1994) detailed that the physical and mechanical qualities of grain are critical in the design of grain handling machines, storage structures, and design procedures.

Selvi *et al.* (2006) studied some of the physical properties of linseed. The change in moisture content was from 8.25 to 22.25% (d.b.), the average length, width, thickness, and the geometric mean diameter increased from 4.57 to 4.86, 2.40 to 2.59, 1.03 to 1.13, and 2.24 to 2.43 mm respectively. Studies done in the same moisture range on rewetted linseed showed that sphericity, surface area, seed mass of one thousand seeds, and true density increased from 49.09% to 49.94%, 15.83mm$^2$ to 18.56mm$^2$ and 6 g to 6.7, 1010.1 to 1020.4kg/m$^3$, respectively.As the moisture content increased from 825 to 2225% d.b.. bulk density was decreased from 6905 to 545 kg/m$^3$ whereas the angle of repose, terminal velocity and porosity were found to increase from 21.59° to 26.85° and 2.46 to 3.82 m/s , 31.64% to 46.59%, respectively.

Coskuner and Karababa (2007) reported that the physical properties of flaxseeds as a function of seed moisture content, varying from 6.09% to 16.81% (d.b.). In this moisture range seed length, width, thickness, arithmetic mean diameter, and geometric mean diameter increased linearly from 4.27 to 4.64 mm, 2.22 to 2.38 mm, 0.85 to 0.88 mm, 2.45 to 2.63 mm, and 2.00 to 2.12 mm respectively with an increase in its moisture content. One thousand seed weight increased linearly from 4.79 to 5.32 g. The true density increased with an increase in moisture content from 1000 to 1111 kg/m$^3$ while the bulk density decreased from 726.6 to 555.6 kg/m$^3$ in the range of moisture content between 6.09% and 16.81%, (d.b). In addition, the porosity values of flaxseeds increased from 27.34 to 57.44%. Plywood surface had the highest static coefficient of friction. The static coefficient of friction increased from 0.537 to 1.073, 0.515 to 0.933, 0.472 to 0.975, 0.499 to 0.877, 0.544 to 0.862, and 0.472 to 0.824 for plywood, aluminium, stainless steel, galvanized iron, and polypropylene knitted bag and Craft paper surfaces, respectively. The angle of repose increased linearly from 21.6° to 33.4° with the increase in moisture content.

Wang *et al.* (2007) studied the physical properties of fibered flaxseed within moisture content varying between the ranges of 6.21 to 16.29%. The length, width, thickness, and geometric mean diameter increased from 4.20 to 4.44mm, 1.99 to 2.13mm, 0.91 to 0.95mm, and 1.95 to 2.06mm, respectively in that range of moisture content. One thousand seed weight increased linearly from 4.22 to 4.62g. The bulk density decreased from 726.783 to 611.872kg/m$^3$, while the true density increased from 1165.265 to 1289.341kg/m$^3$ in that range of moisture content. The porosity values of flaxseed increased linearly from 37.67 to 52.54%. The highest static coefficient of friction was found on the plywood surface, while the lowest on the stainless steel surface. The static coefficient of friction increased from 0.467 to 0.972, 0.442 to 0.864, 0.492 to 0.927, and 0.490 to 0.845 for plywood, stainless steel, aluminium sheet, and galvanized iron, respectively. The angle of repose increased linearly from 25.7° to 33.8° in the moisture content range.

Arafa et al. (2009) conducted an investigation about the different physical and mechanical properties of linseed. They found that the seed's length, width, thickness were4.38, 2.2 0.72 mm respectively. The volume of linseed was 3.631

mm$^3$, geometric mean diameter, arithmetic diameter, bulk density, sphericity of linseed were 1.906 mm, 2.44 mm, 0.640kg/m$^3$, 43.52% respectively. The flat surface area of 7.56 mm$^2$, the transverse surface area of 1.24 mm$^2$, the mass of thousand seeds was 10g and optimum moisture content of 12.5 % for flax seeds. The mechanical properties of linseed were the friction angle between stainless steel, metal, and the wood surface was22°, 34°, and 40° respectively, the angle of repose was 30°, the terminal velocity value to suspended flax grain (Sakha 2 – variety) was 2.2m/s and hardness of linseeds was 11.02 N.

Bhise *et al.* (2013) evaluated the Engineering properties of flaxseeds as a function of moisture content. In the moisture range from 10-18% d.b., the length, width, thickness of flaxseed were in the range of4.698 to 4.758 mm, 2.400 to 2.360 mm, 0.999 to 2.157 mm respectively, geometric mean diameter (GMD) between 2.240 to 2.893 mm, sphericity from 0.477 to 0.478. The thousand-kernel weight increased from 7.195 to 7.403 g, bulk density decreased from 613.818 to 547.1744 kg/ m$^3$ bulk, true density increased from 1105.326 to 1183.200 kg /m$^3$, porosity increased from 44.467 to 49.954 %, hardness decreased from 74.411 to 40.828 N, initial cracking force decreased from 52.470 to 34.019 N and area ranged between 6.140 to 6.406 N-mm. In the same moisture range, the static coefficient of friction varied from 0.320 to 0.420 for different surfaces, while the angle of repose varied from 16.969° to 24.699° for seed. Lightness (L), a value (red-green axis), and b value (yellow-blue axis) of seed decreased from 42.94 to 40.360, 7.22 to 4.96, and 10.70 to 8.30, respectively, with an increase in moisture content of seed from 10 to 18 %, db.

Sharma and Prasad (2013) studied twelve linseed varieties and reported that the dimensional parameters such as length, width, thickness, geometric mean diameter, surface area, and aspect ratio varied from 4.35 to 5.58mm, 2.10 to 2.86mm, 0.74to 1.03mm, 2.33 to 5.45mm, 17.08 to 93.43mm$^2$ and 46.36 to 51.85, respectively. While the bulk density, true density, porosity, and thousand kernel weight found to be varying in the range of 1006.37 to 1198.33kg/m$^3$, 571.32 to761.59 kg/m$^3$, 29.29 to 47.99%, and 5.421 to 10.967 g, respectively. The static coefficient of friction found to vary from 0.30 to 0.43 and the angle of repose from 10.06° to 24.45°

Singh *et al.* (2013) conducted an investigation on some selected engineering and biochemical properties of eleven flaxseed varieties. The average length, breadth, and thickness were found in the range of 4.59 to 5.73mm, 2.30 to 2.93mm, and 0.35 to 1.06 mm respectively. Neelam variety had the highest surface area, geometric mean diameter volume, and thousand-grain weight, whereas LC-2023 had the least value among these eleven varieties of flaxseed. The angle of repose varied from 19.3-23.5°and rupture force ranged between 30.57 to 46.87 N. The Alfa linolenic acid content was found to be between 37.05% to 54.59 %( on fat basis) and protein was found between 17.78% to 24.62%.

Zanwar (2016) observed and found that the physical properties i.e. length, breadth, and thickness of linseed were 5.106mm, 2.382mm, and 0.914mm respectively. The l(95.517),a(0.764) and b(1.416) value were reported for different colour of linseed. Bulk density, true density, thousand kernel weight, porosity, and angle of repose were found to be 644 kg/m³, 1066 kg/m³,7.7g, 37.566%, and 20.19° respectively. The moisture, fat, protein, crude fibre, ash, and carbohydrate in linseed were 5.353, 32.22, 18.04 6.14, 3.14, and 35.11 % respectively.

Bhatt and Prasad (2018) reported on engineering properties of whole and dehulled flaxseed. They discovered that the length was 5.500.23, mm. 2.680.18 mm in width, 1.170.24 mm in thickness, and 2.580.18 mm in geometric mean diameter. The 1000 seed mass 7.380.14 g sphericity 42.310.49% bulk density1025.332.89 kg/m3 true density, 696.671.15 kg/m3, bulk density 26.290.46 degree angle of repose Deformation 0.370.13mm, Rupture force 41.970.38 N The reported values are the averages and standard deviations of the data.

### 2.1.2 Study of mechanical properties

Mohsenin (1986) stated that the mechanical properties of grain were influenced by several factors such as drying temperature, moisture content, rigidity and region of the grain where the force is applied**.**

Chattopadhyay *et al.* (1999) investigated the shear, compression, and bending characteristics of sorghum stalk at the seed and forage stages. In addition, they discovered that the maximum shear strength and specific cutting energy increased from 3.74-8.18MPa and 34.1-101.1 mJ/mm$^2$respectively. When the bevel angle was increased from 30 to 70° at a rate of 10 mm/min, the forage stage measured 4.68-9.02 MPa and the seed stage measured 36.5-142.7 mJ/mm$^2$. The compressive strength and the energy absorbed in compression increased as the bevel angle was increased and both decreased as the rate of loading was increased from 10 to 100 mm/min.

Henry *et al.* (2000) conducted compression studies in soybean grains with four moisture contents on three orthogonal axes and confirmed that the compressive force, perpendicular to cotyledon division was the highest, causing rupture while resistance and deformation decreased with increasing moisture content.

Ebubekir and Mehmat (2007) determined the mechanical property of faba bean in terms of average rupture force, specific deformation and rupture energy along X, Y and Z-axis. Four moisture content values ranging from 9.89% to 25.08% d.b (dry basis) were employed. Faba bean grains loaded along the Z-axis exhibited the maximum rupture force, specific deformation, and rupture energy at all moisture content values.

Goneli (2008) reported that the force-deformation data of a compression test indicate the parameters that predict the response of material when subjected to a certain load which are otherwise indispensable to reduce possible damage and maintain product quality until the processing.

Gabrielly *et al.* (2019) reported that the force needed to rupture sorghum grains increased as moisture content decreased. with values ranging from 47.17 to 78.44 N, 61.81 to 69.66 N, and 52.07 to 70.89 N at temperatures ranging from 60 to 100 °C. The compression force required to distort grain sorghum reduced as moisture content increased, whereas the proportional deformation modulus increased as moisture content dropped.

Sabar (2020) studied different mechanical properties of sorghum and reported that the tensile strength of stalk, grain tip and pedicel were increased from 38.18 to 69.69 N, 2.99 to 6.07 N, and 15.87 to 27.01 N respectively by increasing the moisture content from 8.7 to 21.8 % at test speed of 50 mm/min. At the end, the rupture force of grain increased from 37.15 to 72.90 N by decreasing the moisture content from 21.8 to 8.7 % at 5 mm/min of test speed. The rupture force of sorghum grain decreased from 65.25 to 28.90 N by increasing the moisture content at 10 mm/min of test speed. Rupture force for grain of sorghum was lowered from 37.15 to 14.83 N by increasing the speed of test by 5 to 20 mm/min at a moisture content of 21.85 %. As the diameter of stalk increased, the cutting strength of stalk was also increased. When stalks were put in a vertical orientation as the diameter of stalks increased from 9.5 ± 0.5 to 12.5 ± 0.5 mm, the cutting strength was varied from 115.54 to 155.76 N. In addition, in case of horizontal orientation and 45° orientation of the stalk the cutting strength varied from 122.54 to 175.380 N and 306.42 to 398.34 N respectively as the stalk diameter varied from 9.5 ± 0.5 to 12.5 ± 0.5 mm.

## 2.2 Development of Thresher

Threshing is one of the most important post-harvest operations that were carried out after all crops have been gathered from the field; it is the step in grain preparation just after reaping. Mechanical threshing involves the use of high-end technology and machinery which are very expensive and though. It helps in maintaining a high quality of the finished product and saves a considerable amount of time. It eliminates high labour associated with the traditional and local threshing system and reduces the various threshing losses (Olaoye, 2011).

Kepner *et al.* (1978) mentioned that threshing can be done as follow: (a) impact of a fast-moving element upon the material, (b) rubbing or abrasion, (c) squeezing the pods, (d) combination of two or more of above actions or (e) some other methods to apply the required forces.

Bainer *et al.* (1982) stated that flax crops can be threshed by passing the crop between one rubber-covered roll and one steel roll. To give rubbing action in addition to the squeezing effect, the upper roll is spring-loaded and the lower roll was driven about 10 per cent slower than the upper roll. Adjustable stops on the spring-loaded roll were used to provide a minimum clearance, sufficient for the passage of seeds without damage.

Sharma and Sirohi (1982) found out regression equation for power requirement of different component of thresher. The regression equation of these component were found to be

Y (Beater) = $0.08+0.02\times10^{-2}X$

Y (Shaker) = $0.22+0.01\times10^{-2}X$

Y (Blower) = $0.04+0.05\times10^{-2}X$

Where,

Y= horse power; and

X= cylinder speed rpm.

Klenin *et al.* (1985) indicated that the flaxseed was removed from their pods by crushing and grinding them between three husking rolls of different diameters, rotating in the opposite direction. Springs keep the smaller pressed against the larger roll. The pods delivered from the hopper to the gap between the rollers and during their rotation it sequel the pods, flatten them, and strip their shell. The surface speeds of the two rollers are different, where the smaller and larger rollers have a speed of 2 to 2.5 and 3.0 to 3.5 m/s, respectively.

Abd El-Mageed (1989) evaluated three different machines for threshing the flax to select the best to produce seed and fibre. A stationary threshing machine (ML 2.8 PA), a flax harvester (LKB4A) for harvesting flax in the period of early yellow or yellow ripeness stage, and a Japanese rice harvester (Yanamer). They found that using the Yanamer harvester at 400rpm, the drum speed gave a striping efficiency of about 100% the threshing efficiency of about 92.2% while stalk losses reached 3.3%.

Badawy (2002) developed a feeding system for the threshing of flax. The main parts of the feeding system consisted of two conveyor flat belts of 15cm width, 125cm length, and 2cm thickness and feeding pulleys. The ratio of feeding system to drum speed was approximately 1.8-1.9 m/s to give the stems enough time for beating. The feeding operation was performed by putting the stalks on the feed system by the worker while the other worker was passing only the head parts of stalks through the conveyor belt in the deseeding chamber The clearance between the upper and the lower flat belts was about 20– 40 mm. The head parts of stalks were fixed with a feeding system so that the rotation speed to the deseeding drum was almost constant, therefore the deseeding operation was stable.

Majumdar (2002) suggested certain design considerations for threshing equipment and recommended that the thresher's output capacity not be less than 85kg of wheat per kWh. The threshing efficiency should not be less than 96 per cent, with a total grain loss of not more than 5%.The influence of cylinder speed on threshing performance was found to be quite significant across all machine designs. Power consumption and broken grain rise as cylinder speed increases, whereas un-threshed grain decreases.

Ramteke and Sirohi (2003) investigated the design requirements for the development of a linseed thresher by experimenting with two different types of threshing cylinders (rasp bar and spike tooth), three different moisture contents( 8.10,10.75, 13.80 %), three different cylinder speeds (22.56, 16.96,13.56 m/s) and three varying concave clearance (5.0,7.5, 10.0 mm). they gave the conclusion that threshing efficiency was maximum ( 97.18 per cent) at 22.56 m/s cylinder speed and lowest (84.12 per cent) at 13.56 m/s. Grain damage was maximum (6.82 per cent) at 22.56 m/s cylinder speed and no damage was recorded at 13.56 m/s Energy consumption for threshing while using a rasp bar thresher was 40.8 KWh and for spike tooth type 35.2 KWh. The recommended range of values for cylinder speed, moisture content, and concave clearance were 15-20 m/s, 8-10%, 5-7.5mm respectively. Among the two different threshing mechanisms used, the rasp bar mechanism was found to be more effective.

Kamble *et al.* (2003) designed a pearl millet thresher. based on its design and operating characteristics, assessing it at various cylinder speeds (450,700,850 rpm), concave clearance (5,10,15mm), moisture content (10.2,14.5,17.2%), and feed rate (300,400,500kg/h).The highest threshing efficiency obtained was 96.8 per cent, the lowest grain damage was 2.75 per cent, the grain loss was 2.10 per cent, and the maximum germination was 87 per cent, with a minimum energy consumption of 0.3MJ and an operating cost of Rs 8.50 per quintal.

Zakaria (2006) developed the threshing drum with the help of a local stationary thresher for the separation of flax capsules. The machine was tested with feed rates of 8.57, 12.86, 17.14, and 21.43 kg/min with drum speeds of 24.25, 25.81, 27.33, and 28.85 m/s. The findings revealed that the best performance was obtained at a drum speed of 28.85 m/s, a feed rate of 8.57 kg/min, 12 drum fingers, and a separation time of 15 seconds, with a threshing efficiency of 96.925 per cent.

Abouegela *et al.* (2007) manufactured a new machine from local materials for deseeding of flax crop. The main idea was to deseed flax capsules by rubbing and squeezing them between two movable flat belts (40 cm width each). The two belts were kept in contact with each other by using pair compression and concentric helical springs fitted to cylindrical rollers with the same width of belts. PTO of tractor operated the machine through pulleys with different diameters. The performance of the belt of the machine was tested under three different driving speeds 200, 300, and 400 rpm (1.047, 1.57, and 2.094 m/s). three different speed ratios between the two movable deseeding flat belts of 1:1, 1:1.5 and 1:2, three different feeding rates of 10, 15 and 20 kg/min at a constant moisture content of about 12.5% for capsules and 15% for stalks. The final results indicated that for deseeding (stripping and threshing) flax capsules the optimum performance of the machine was achieved at a driving speed of 300 rpm, feeding rate of 20 kg/min, and the speed ratio between belts was 1:2. The highest stripping efficiency, threshing efficiency and stalks losses recorded were 99.05, 98.1, and 0.75% respectively at the above-mentioned conditions.

Simonyan (2009) reported that a motorized stationary sorghum thresher was developed which consisted of components like frame, hopper, threshing unit, sieve, reciprocating mechanism, blower, and collecting trays. Sorghum heads were fed to the threshing chamber and by using a combination of striping, rubbing, and impact action by the threshing elements fitted on the threshing cylinder and the concave the grains were separated from the sorghum head. The threshed, un-threshed, partially threshed heads and some grains then fall on the upper sieve for separation of grains and the lower sieve for chaffs while both are arranged horizontally and parallel, one above the other, reciprocating as a single unit. A centrifugal blower was used to blow an airstream between the two sieves with air current to aid in the lifting of straw and the grain collector collected stalk on the upper sieve, the cleaned grain passing through the sieve. Threshing efficiency was in the range of 99.94% to 99.96%, cleaning efficiency was between 94.35% and 96.14%, and the cleaning loss varied from 6.5% and 9.91% at an average moisture content of 8% (wb).

Bansal and Lohan (2009) developed an axial flow seed crop thresher with a view to minimum injury of seed. Rasp bar type threshing cylinder with stationary concave was used. The design diameter and length of cylinder was 520mm and 512mm respectively. Different cylinder speeds of 8.2, 9.5, 11.0, 12.2, 14.7 and

19.6 m/s were provided as per the threshing requirement and physical properties of different crops.

El-Fawal *et al.*(2012) worked on developing a small prototype machine for threshing and cleaning of flax capsules using a manual feeding mechanism. The performance of the machine was tested at four different peripheral tooth cylinder speeds of 4.0, 4.4, 4.8, and 5.1 m/s; different cylinder concave clearance of 2, 4, 6, and 8 mm and different air velocity of 1.5, 2.5, 3.5, and 4.5 m/s at a recommended seed moisture content of about 14 % (d.b). The performance of the modified machine was evaluated by threshing efficiency, Un-threshed capsules, seed damage (visible and invisible), seed losses, seed cleanliness, and total seed losses and seed germination ratio. The results showed that the optimum drum speed, concave clearance, and air velocity are 4.4 m/s, 2 mm, and 4.5 m/s respectively for achieving threshing efficiency of 98.45%, seed cleanliness of 92.3%, and germination ratio of 91%. Then the modified machine can be used for threshing and cleaning the flax and it can be applied to the modified machine specifications on large-scale machines.

Gbabo *et al.* (2013) research was carried out for developing and testing a thresher having parts for threshing, separation, and cleaning. The operation of threshing is achieved by using the rotational motion of the threshing cylinder which was assembled with a beater peg above a stationary grid. This causes the seeds to be removed from panicles and get separated from the bulk of the straw. After beating, the grains fall through a concave grid into a cleaning unit which contains two sieves that are in moving in a reciprocating motion. After cleaning a constant air blast is used for blowing out the materials that are lighter than the grain. The machine is designed to run on a 5 hp electric motor. It was tested to thresh, separate, and clean the millet seed.

Ahorbo (2016) designed the motorized throw-in axial flow rice thresher fitted with peg and screw threshing mechanism. A rice thresher with a threshing drum diameter of 400mm and length of 1,120mm, a threshing drum shaft diameter of 36mm, a shaft bearing (SKF self-aligning) with the identifier 1406, and a V-belt with the number B66 was discovered. For threshing long crops of length 1,282mm at feed rates up to 402kg/h, the power need was 1.4PS (1.03kW), while for threshing short crops of length 812mm at feed rates up to 429kg/hr, the power required was 1.2PS (0.88kW).

Patel *et al.* (2020) manufactured a hand-operated linseed thresher. It is overall dimension of frame (L×W×H) cm = 50×30×100, diameter of roller (cm) = 13, length of roller (cm) = 30. The result shows that the physical properties of linseed crop were determined as the average length of linseed capsule 79.4 mm, the average width of linseed capsule 70.8 mm, the average length of linseed 4.54 mm, & average width of linseed 2.27 mm. the result shows that the machine capacity, threshing efficiency & grain damage of this thresher. The machine capacity was found maximum as 7.02 kg/h. The threshing efficiency was found maximum as 98.6%. The grain damage was found to be as minimum as 0.9%.

## 2.3 Cleaning Mechanism of Thresher

Saxsena *et al.* (1971) stated that the power requirement of a blower used in local thresher vary between 35-85% of total power required for thresher corresponding to full load and no load due to irrational and unscientific designs of blower used in thresher.

Sharma and Devnani (1979) designed the cleaning arrangement while researching and developing a multicrop thresher for pulse and oilseed crops. The grain was cleaned with air blast of a blower and separated using a set of two cleaning sieves stacked one on top of the other. The blower consisted of three flats of 90×6 mm size welded on a shaft of 25mm diameter and supported by two ball bearings. The sieve and blower were powered directly by the electric motor via a v belt system.

Sharma *et al.* (1984) created a cleaning system for a multi-crop thresher that consisted of a chaffer and a chaffer extension with adjustable apertures, Sieves having round holes and a fan with four blades measuring 400 mm in diameter. The cleaning system's breadth was 675 mm, and the sieve's length was 1200 mm.

Singh *et al.* (2003) employed a centrifugal blower with four perpendicularly placed blades on a shaft of 15 mm diameter. The helical casing was used to secure the blade assembly and the gap between the blade tip and the spiral case steadily increased from 6 to 24 mm. The blower speed was set to 925 rpm. It was used to separate grains from falling chaff and clean them.

Behera *et al.* (2007) developed a black and green gram thresher. The cleaning unit consists of a blower and an oscillating sieve. Separation of the grain from the straw was accomplished by sending an air stream through the falling grain and straw from the concave side of the blower using radially placed blades. The following formula was used to calculate the quantity of air required to separate the threshed material

$H_o = Q_p / (V_w \times L_b)$

Where,

Ho = Width of blower outlet;

$Q_p$ = Air required to separate the thresh material;

$V_w$ = Velocity required to blow the straw; and

$L_b$ = Length of the blower.

Simonyan and Yiljep (2008) studied the cleaning efficiency and grain separation along the sieve length. The influence of feed rate, sieve oscillation frequency and airspeed on cleaning efficiency was observed. The result show that cleaning efficiency decreased with an increase in feed rate and sieve oscillation frequency. Cleaning loss increased with increase in feed rate, sieve oscillation frequency and air speed.

Bansal and Lohan (2009) developed a cleaning unit for seed crop thresher. It consists of oscillating sieve, blower, and aspirator. To lift the light material from the top sieve, an aspirator with four blades measuring 320 mm in length and 250 mm in breadth was constructed. A blower with four fins on the flywheel of 600 mm diameter was designed to remove the chaff and dirt from main seed outlet.

Dhananchezhiyan (2013) developed a cleaning system for multi crop threshers. The centrifugal blower was built and installed under the threshing cylinder, with a drum diameter of 350 mm, breadth of 240 mm, and an air outlet of 240 150 mm. The direction and rate of airflow must be adjusted. A blower was made up of four wings connected by a common shaft, and a mild steel cover was attached to the main frame using bearings in the proper location. One end of the shaft was connected with a stepped V pulley to allow power to be drawn from the engine at varied speeds through a V-belt and winnowing velocity was changed between 2 and 12 m/sec. The blower speed was kept at 900 rpm.

Parmanand and Verma (2014) developed a cleaning system for minor millet thresher. Aspirator blower with sieve shaker was provided. The bower fan consists of four blade of the size of 140×115mm made of 2 mm thick MS plates. Sieve assembly consists of three sieves with separate outlet and was suspended below the cylinder concave on the main frame through hangers.

Win *et al.* (2014) designed and developed the DKC-685 combine's threshing unit. It has a threshing cylinder, comb tooth, peg-tooth with wire loop design, and reinforced tooth. In the main threshing cylinder, comb tooth, reinforced tooth, threshing tooth and impact board are arranged. The comb tooth is positioned at the entrance of the thresher and its activity is to grab the paddy and lead it into the cylinder so that it may be combed and threshed gradually. Following the comb tooth, the reinforced tooth can increase grain threshing performance and prevent straw from flowing through the tooth. The machine equipped with a 42 cm diameter and length of 80.1 cm threshing unit.

Sale *et al.* (2017) studied the performance of the cleaning system of sorghum thresher. It includes the modification of the sieve shaking mechanism and the number of sieves that was increased from one to three and the connecting rod for shaking mechanism was changed from horizontal to vertical orientation. The result revealed that the cleaning efficiency, scattering losses and output capacity of 99.95%, 5.45% and 250 kg/h were recorded respectively.

Pandey (2018) developed a sieve and blower assembly based on the physical properties of fenugreek seed in order to create a thresher with improved cleaning efficiency. At one end of the counter shaft, the aspirator had to be installed parallel to the threshing cylinder. The circular casing with a total diameter of 230mm and the impeller blade of the aspirator blower were built of MS sheet. Aspirator blower was provided with 4 radial blades, the shape of blade was a combination of rectangular and triangular shape. Three reciprocating sieves were employed. The top sieve dimensions was 990×355mm, has a hole size of 5 mm, and is inclined at 30 degrees. The middle and bottom sieves have 4 mm and 2 mm hole sizes, respectively, and have 840×355mm dimensions. With the help of an appropriate belt and pulley system having stroke length of 40mm, the sieve assembly was able to reciprocate at 350 strokes per minute.

## 2.4 Study of Performance Evaluation of Thresher

According to Kepner *et al.* (1972), the performance of a thresher depends upon the parameters like the moisture content of the crop, the peripheral speed of the cylinder, the clearance between concave and cylinder, and the feed rate of the machine.

According to Huynh *et al.* (1982), the separation of seeds from stalk and passage of seeds through the concave gate was affected by variables such as feed rate, threshing speed, concave length, cylinder diameter, and concave clearance. These factors also have an impact on threshing losses and seed separation efficiency.

Klenin *et al.* (1985) reported that threshing performance was mainly dependent on design factors such as concave length, diameter, cylinder speed, feed rate, and moisture content of the crop to be harvested.

Kaul *et al.* (1985) stated that an optimum speed is required to get the desirable performance of the thresher as cracking of grains takes place at excessive speed, and low speed increases the amount of un-threshed heads in the final product**.**

El-Behairy *et al.* (1997) stated that the feeding rate is linearly dependent on drum speed. The rate of feeding is dependent on the skill of labour employed for the thresher. An increase in the drum speed causes a decrease in the volume reduction as well as the grain losses.

Nave *et al.*(1980) observed that by decreasing feed rate and increasing the drum speed threshing efficiency can be maximized. The threshing efficiency of 99.76 % was achieved at a drum speed of 21.25 m/s (1400 rpm), and a feed rate of 15 kg/min. The grain damage was found to be 0.90 % of visible grains under the above operating conditions.

Afify (1998) fabricated and constructed a simple flax thresher that can remove the capsule while keeping the stalk damage to a minimum. For that, he made use of three different drum shapes (peg tooth, beater, and peg tooth with a beater). The result showed that the drum with beater gave a threshing efficiency of

96.52%, separation efficiency of 98.21%, cleaning efficiency of 95.79%, stripping efficiency of 99.35%, the threshing capacity of 1.01t/h, the energy consumption of 2.79kW-h/ton and less criterion cost of 10.29 L.E/Ton under the drum speed of 5.23 m/s and capsule moisture content of 14.205%.

El-Nono and Mohammed (2000) studied the machine power requirement; drum speed, moisture content, and grain damage. The research stated that the machine and drum speed were directly proportional to each other. Also, the power requirement was highly affected by the moisture content and grain damage. The experiment found that the threshing effectiveness and damage of wheat were affected by using different cylinders such as swinging hammers, spike tooth, and rasp bar cylinders. In addition, the cylinder speed and concave clearance are important variables for the unthreshed grain and damage model. Variation in cylinder speed and concave clearance varies the volume of unthreshed grain. Power requirement increases with the increase in cylinder speed and a decrease in clearance. The overall result of the experiment shows that the rasp type is more effective than the swing arm type.

Mamdouh *et al.* (2000) Stated the relationship between different threshing parameters like the concave clearance, cylinder speed, feed rate of crops, the number of rows of concave teeth used with spike tooth cylinder, and the type of crop and threshing effectiveness.

Olaoye and Oni (2001) investigated the effect of crop parameters on the threshing efficiency of a thresher in Nigeria. The results showed that different parameters like the mechanical properties of grains, grain size, and geometrical dimensions of grains are important and can increase the separation of grains from the plant residue.

Lamp and Buchele (1960) mathematically modelled the relation between different parameters like the concave clearance, threshing forces, and cylinder speed and concluded that the threshing force was proportional to the square of peripheral cylinder speed and is inversely proportional to concave clearance. This shows that peripheral speed has more effect on the threshing effectiveness as compared to concave clearance.

$$F = KV_c^2/X$$

Where,

F = average threshing force, N

$V_c$ = Peripheral cylinder speed, m/s

X = average concave clearance

Which is proportional to the distance travelled because of the accelerations caused by the impact, cm

K= constant

Concave clearance and its adjustment is an important factor for the quality of threshing. From the above model, we can see that the threshing force is inversely proportional to concave clearance. This implies that for low concave clearance the grain damage will be greater but the un-threshed grain will be less.

The feed rate of the crop is also an important factor that affects the threshing efficiency (Simonyan and Oni, 2001). If the feed rate is in excess blockage in the thresher and separation system can happen which can even result in the breakdown of the whole system whereas a low feed rate would result in wastage of time and money. A feed rate higher than the optimal feed rate increases the total grain loss. An increase in cylinder speed and spike length results in an increased feed rate (Joshi and Singh, 1980). An increase in cylinder speed increases grain damage and an increase in concave clearance, feed rate, and moisture content results in decreasing the grain damage (Ghaly, 1985). There is an increase in grain loss with the increasing of cylinder and blower speed (Kashyap and Pathak, 1976)

El Behery*et al.* (2000) tested the feasibility El-Shams rice thresher by using it as a dual-purpose machine to separate seeds and stalks from flax (*Linumusit atissimum L*). The threshing was performed using a range of varying parameters such as drum speeds, feed crop rates, and the different lengths of conveyor chain tension at four different levels of capsule moisture contents. He concluded in his experiment that for obtaining optimum performance, the speed of the threshing drum, feed rate, and the length of conveyor tension should be approximately 31.43 m/s, 20 kg/min, and 48 mm, respectively, and the moisture content of capsules should be 18.45%. Seed damage was minuscule and not of an economically important level (1.78%). The values of optimum fuel consumption were 3.70

litter/h and 3.08 litter/tones at a drum speed of 31.43 m/s and a feed rate of 20 kg/minute. The flax threshing resulted in an average cost of 16.23 L.E/t as compared to 50 L.E/t for manual threshing.

El-Haddad (2000) stated that increasing the drum speed and decreasing feed rate increases the threshing efficiency.

Dauda (2001) reported that the percentage of damage seed, blown seed, and seed loss get reduced with high moisture content and low cylinder speed while low moisture content and high speed leads to an increase in the percentage of damage seed, blown seed, and seed loss. Two important factors in determining crop mechanical damage are moisture content and impact during threshing.

Badawy (2002) reported that at the optimum performance of flax deseeding machine the highest threshing efficiency achieved was 97.17%. If the drum speed was increased from 9.28 to 15.33 m/s the capacity wound increase from 1800 to 2400 kg/h.

El-Ashry *et al.* (2003) studied the effect of seed moisture content on different flax threshing systems- partially mechanized, completely mechanized, and conventional at seed moisture content 18.15, 16.85, 14.32, and 12.05%. The result showed that the un-threshed seed losses are decreased with the decrease in the seed moisture content and the lower values of losses were obtained at seed moisture contents of 12.05%. The values of un-threshed seed losses were 6.62,8.35, and 1.05% for complete mechanized, partial mechanized, and conventional systems respectively.

Vejasit and Salokhe (2004) studied the machine crop factor of an axial flow thresher to thresh soybean. A peg tooth drum was tested with four readings of drum speed, three feed rate and three-moisture content. The results of the tests revealed that the threshing efficiency varied from 98 to 100 per cent. Grain crackage and grain loss were less than 1% and 1.5 %, respectively, at 600-700 rpm drum speed and 540-720kg/h feed rate, while seed moisture content ranged from 14.34 per cent to 22.77 per cent (w.b). At 14.34 per cent moisture content, the best combination of feed rate and drum speed for increased output capacity, threshing efficacy, decreased grain crackage, and grain losses was 600-700 rpm drum speed at 720 kg/h feed rate.

Zakaria (2006) used a local stationary thresher and modified its threshing drum to separate flax seed and minimize the stalk damage. An automatic device for determining the separating time and giving signal after separating the seeds has been designed and fabricated. The testing of the thresher was done under four different feed rates of 8.57, 12.86, 17.14, and 21.43 kg/min, and four different drum speeds of 24.25, 25.81,27.33 and 28.85 m/s, two different threshing drum having 8 and 12 fingers arranged in five sets each, and having three different separating times of 10, 15, 20 seconds. Machine productivity, stalk damage, energy requirements, and seed losses were determined. The developed thresher gave the optimum performance while separating flax seed at drum speed of 28.85 m/s. feed rate of 8.57kg/min, drum fingers of 12, and separating the time of 15 seconds. A maximum threshing efficiency of 96.92% was recorded and 1.33%, 3.48%, 3.26%, and 1.262kw were the minimum seed losses, seed and stalk damage, and energy requirement respectively.

Zaky (2006) recommended that to reduce the seed damage and total losses of black seed with an acceptable level of cleaning efficiency the optimum conditions were the drum speed in the range of 3.3 to 4.4 m/s clearance range from 2.5-3 mm and the air velocity should be 2 m/s, the energy consumption was 25.12 kWh/ton and criterion cost was 752 L.E/ton.

Afify *et al.*(2007) evaluated the performance of a developed small thresher in threshing of black seed at a different varying condition such as drum speed of 4.19 (200), 5.23(250), 6.28 (300), and 7.32(350) m/s(rpm), feed rate of 600,700,800,900 kg/h and moisture contents of 11.82,13.63, 15.72 and 17.61%(w.b). The minimum seed loss of 2.63%, stripping efficiency of99.31%, threshing efficiency of 98.74%, cleaning efficiency of 95.88% required energy of 2.85kw.h/ton were observed in the final result.

Singh *et al.* (2008**)** designed and developed pedal-operated paddy thresher. Machine’s performance was assessed for optimal design parameters, which included wire loop spacing of 39.1 mm, wire loop tip height of 60.6 mm, and threshing drum speed of 339.46 m min-1.h. The corresponding threshing capacity and efficiency were 64.6 kg h-1 against predicted 66.8 kg h-1 and 96.4% against predicted 98.3%, respectively, It was concluded that wire loop shape and drum speed had a significant impact on the threshing performances of paddy threshers.

Fakrany *et al.* (2014) modified and tested a rubbing thresher for flax and sunflower. The thresher was tested at four different drum speeds: 4.2, 5.5, 6.4, and 7.3 m/sec, four different belt speeds: 0.42, 0.67, 0.96, and 1.25 m/sec, and three concave clearances: 1.5, 2.5, 4.0 cm with flax crop and 2.5, 4.0, 5.5 cm with sunflower crop. And reported that thresher performs best when the drum speed is around 7.3 m/sec, the belt speed is about 0.42 m/sec, and the concave clearance is about 1.5 cm. Whereas the ideal parameters for threshing sunflower crop by modified thresher are drum speed of approximately 7.3 m/sec, belt speed of approximately 0.42 m/sec, and concave clearance of about 2.5 cm.

Amare *et al.* (2015) reported that the threshing capacity of pedal operated paddy thresher depends on Paddy rice holding capacity of the operator at once with hand, feeding rate of the operator, threshing unit rpm and the variety of the rice.

Tiwari and Chauhan (2018) studied the effect of round spiked threshing cylinder geometry on the threshing performance of wheat crop. The tip diameter of the threshing cylinder, spike thickness, and feed rate were considered as independent factors in this study. The dependent parameters included were total power consumption, broken grain loss, total grain loss, threshing efficiency, and cleaning efficiency, straw length of wheat, splitting of wheat straw, output capacity and specific power consumption. The round spiked plain pegs of 6, 8 and 10 mm diameters with 75, 100 and 125 mm length were used for study. The results show that for wheat crop threshing, a threshing cylinder with round spikes produced the highest output capacity and threshing efficiency, which were 369.3 kg/h and 99.87 per cent at tip diameter of 600 mm and spike thickness of 6 mm, respectively, corresponding to a maximum feed rate of 780 kg/h. In the instance of a round spiked threshing cylinder, the wheat straw size for optimum output capacity and threshing efficiency was 22.67 mm at a tip diameter of 600 mm and a spike thickness of 6 mm, equivalent to a maximum feed rate of 780 kg/h.. For greater threshing efficiency, fine straw quality, and low specific power consumption, a round spiked threshing cylinder with a tip diameter of 600 mm and a spike thickness of 6 mm produced the best results, with total grain loss within the allowable limit. A 6 mm spike thickness resulted in little broken grain loss and good straw quality.

An investigation was carried out by Tiwari and Chauhan (2018) on effect of cylinder configuration of rectangular spiked tooth thresher on threshing performance of wheat crop. The independent parameters of tip diameter of threshing cylinder, thickness of the spike and feed rate were selected for the study and The dependent parameters were total power consumption, broken grain loss, total grain loss, threshing efficiency, cleaning efficiency, straw length of wheat, splitting of wheat straw, output capacity and specific power consumption. Result revealed that for higher threshing efficiency, fine straw quality and minimum specific power consumption and output capacity, rectangular spiked threshing cylinder of diameter having 600 mm tip diameter and spikes of 6 mm thickness and 125 mm in length gave best performance results with total grain loss within permissible limit.

Khayer *et al.* (2019) investigated the most important design parameters of a pedal-operated paddy thresher (POPT), such as loop spacing, tip height, drum peripheral speed, and the number of strips on the drum's periphery. Response surface methodology (RSM).was used to optimize the design parameters. Among the four independent factors, a linear term of loop spacing (A) and tip height (B), a quadratic term of spacing ($A^2$) and drum speed ($C^2$), and an interaction term of drum peripheral speed and number of strips all had a significant impact on threshing capacity (CD)The investigation revealed that the key parameters impacting the threshing capacity studied were loop spacing = 3.99 cm, tip height = 5.09 cm, peripheral drum speed = 398.215 r min-1, and number of strips on the perimeter of the revolving drum =13.9421(≈14). At optimum condition of machine parameters, the threshing capacity was found approximately 53.0127 kg h-1 with minimal worker’s discomfort.

### 2.4.1 Effect of moisture content of crop on performance of thresher

The moisture content of the grain has a significant impact on machine efficiency. If the crop's moisture level was high, the grains were not separated from the crop, which reduces efficiency. Again, if the moisture content is low, mechanical damage is increased. To achieve the greatest results, we must select a crop with the optimal moisture content.

Chhabra and Singh (1977) reported that the extent of seed damage is inversely proportional to the seed moisture content.

Kamble *et al.* (2003) evaluated a pearl millet thresher and reported that threshing efficiency was reduced with increase of moisture content because high moisture content increased the plasticity of grain.

El-Ashry *et al.*(2003) reported that the unthreshed sesame seed losses decreased by reducing the seed moisture content. The reduction of sesame seed moisture content from 18.15 to 12.05 per cent increases threshing capacity from 2.23 to 3.06t/h. The energy needs were also reduced by lowering the seed moisture content.

Sinha *et al.* (2009) studied the influence of moisture content, concave clearing, and cylinder speed on visual damage, internal damage, germination percentage, and threshing efficiency of chickpea seed crop with three levels of moisture content (8, 10%, and 12%), three levels of cylinder peripheral speed (8.05, 8.94, and 13.42 ms-1). The results indicate that the cylinder speed is the most important factor in determining the amount of visual and internal injuries. Moisture content had a negative impact on internal damage levels in threshed seed. The cylinder speed of 8.94 ms-1, concave clearance of 14 mm, and moisture level of 10% resulted in excellent quality seed with little visual and internal harm and optimal threshing efficiency.

Prasanna and Naveen (2012) tested the ragi MR1 and HR911 variates. At 9.8 per cent grain moisture content, the cultivar MR1 had the maximum threshing efficiency of 79.6 per cent. The best threshing efficiency of 79.0 per cent was attained for variety HR911 at a grain moisture level of 10.1 per cent. It was discovered that threshing of ragi crop is more efficient at 10% to 13% grain moisture level. Despite the fact that mechanical damage to grain was significant and seed germination was reduced when threshed at a lower (10%) grain moisture level.

Singh *et al.* (2015) determine the greatest threshing efficiency (99.5%) and cleaning efficiency (88.5%) at 7.79% moisture content. Also found that threshing efficiency was decreased with increase of moisture content. It can be shown that at a feed rate of 75 kgh-1, threshing efficiency steadily increased within 5 to 7 percent, then reached a maximum within 7 to 8 per cent, and then gradually decreased.

**2.4.2 Effect of cylinder speed on performance of thresher**

Cylinder speed was key component for good threshing because threshing was done by impact force acting on the crop or grain. If the speed is too high, the grain will be broken, which is not desirable. On the other side, if the speed was too slow, appropriate crop threshing will not occur. So we have to take the optimum speed which is help in increasing the efficiency.

Ige (1978) reported that a 500-rpm cylinder speed proved to be optimal for achieving maximum threshing efficiency with minimum damaged cowpea seeds.

Modi and Kamble's (1980) research on the threshing properties of barley seed crop revealed that threshing losses, visible mechanical damage, and seed cleaning varied with cylinder speed, however invisible damage seed remained constant.

Alizadeh and Khodabakhshipour (2010) studied the impacts of axial-flow threshing drum speed at five levels of 450, 550, 650, 750, and 850 rpm on broken and cracked grains, as well as paddy moisture content at three levels of 17.0, 20.0, and 23.0 per cent (w.b.).The results revealed that the most broken grains (0.677) were obtained at drum speeds of 850 rpm and paddy moisture contents of 17%, while the least value was obtained at drum speeds of 450 and 550 rpm and paddy moisture contents of 23.0%.The cracked grains increased from 7.0 to 37.0 %, 6.67 to 25.0 % and 14.0 to 17.30 % at paddy moisture contents of 17.0, 20.0 and 23.0 %, respectively as the drum speed increased from 450 to 850 rpm. The highest grain damage was seen at a moisture level of 17.0 per cent, while the least was observed at a moisture content of 23.0 per cent.

According to Singh *et al.* (2015), the optimal values of the independent variables for maximum threshing efficiency (99.5 per cent) and cleaning efficiency (88.5 per cent) were reached at 105.31 kgh-1 feed rate and 626.9 rpm cylinder speed. Chhabra and Singh (1977) reported that the extent of seed damage is directly proportional to the impact energy.

Olaye *et al.*(2016) investigate an axial flow spike tooth thresher with four cylinder speed 600,800,1000 and 1200 rpm and three sample of paddy weight 40,50and 60kg. result showed that the mean threshing capacity ranged from 1326-2013 kg/h, threshing efficiency was 100% and mechanical seed damage ranged from 2.63 to 16.45%.the cleaning efficiency of 95.57 to 96.79 % while the seed loss from 0.88to 4.23% for the four speed.

Olayanju *et al.* (2019) tested the proposed threshing machine at three different paddy straws MC levels (25.10, 18.10, and 14.5 per cent) concurrently with three different threshing drum speeds (398, 487, 565 rpm).They employed the response surface method to investigate the impact of independent factors on dependent parameters. To fit experimental data for each response, a polynomial regression model for the dependent variables was constructed, as indicated in equation:

$$y_i = a_0 + \sum_{i=1}^{b} a_i X_i + \sum_{i=1}^{b} a_{ii} X_{I^2} + \sum_{i=1}^{b} \sum_{i=1}^{b} a_{ij} X_I i X_j$$

Where, $x_i$ (i = 1, 2) were the independent variables (MC and TDS) and $a_0$, $a_i$, $a_{ii}$ and $a_{ij}$ are coefficient for intercept, linear, quadratic and interactive effect, respectively The cleaning efficiency, threshing recovery, threshing efficiency, percentage loss and percentage blown grain are some of the parameters that determine the performance efficiency of the tangential paddy thresher. They determined that the influence of MC of the input was found to have the largest impact on the performance efficiency of the produced thresher MC on TR, TE, and PL were linear, while for CE and PBG it was quadratic. The optimum operating condition was to be 19.16% MC wet basis and 446 rpm TDS.

Many researchers have investigated the effect of fan speed, cylinder speed, and concave clearance on the threshing efficiency of a mechanical thresher (Joshi *et al.*, 1981; Ghaly, 1985; Behera *et al.*, 1990).

### 2.4.3 Effect of concave clearance on performance of thresher

Fakrany *et al.* (2014) stated that the ideal concave clearance for threshing flaxseed was about 1.5 cm.

Ramteke and sirohi (2003) studied the design parameter for threshing linseed and found that concave clearance of 5-7.5 mm was best suited for maximum threshing efficiency, minimum grain damage and energy consumption.

El-Fawal *et al.* (2012) tested a modified machine for flax threshing at four different concave clearances of 2, 4, 6, 8 mm and reported that 2mm concave clearance was suitable to obtain the best threshing efficiency of 98.45%, cleaning efficiency of 92.3% and germination ratio of 91%.

Zaky (2006) recommended that the concave clearance ranged from 2.5-3mm was optimum to reduce the seed damage and total losses of black seed with acceptable level of cleaning efficiency.

Prasanna and Naveen (2012), found the maximum threshing efficiency when threshing at 5 mm concave clearance for ragi. Sharma and Devnani (1980) reported that threshing efficiency decreased with the increase of feed rate and concave clearance. In addition, they reported energy consumption was directly proportional feed rate and remained constant at selected concave clearance.

Salari *et al.* (2013) evaluated a laboratory peg-tooth thresher for chickpea threshing. The effects of various cylinder speeds (9, 12, 15 m s-1), concave clearance (12, 14, 16 mm), feed rate (80, 160, 240 kg h-1) and seed moisture content (5, 10, 15% wb) on percentage of grain damage, threshing efficiency, and percentage of germination were investigated. The experimental plan for optimization was prepared using response surface methodology technique with composite experimental design. With increasing cylinder speed grain damage and threshing efficiency increased whereas seed germination decreased and grain damage and threshing efficiency dropped as moisture level rose, while seed germination increased. Grain damage and threshing efficiency dropped as feed rate and concave clearance rose, whereas seed germination increased. The optimum point was obtained at a cylinder speed of 10.63 m s-1, a concave clearance of 13.74 mm, a feed rate of 240 kg h-1, and a moisture content of 12%. (w.b). The optimal values for grain damage, threshing efficiency, and seed germination in this setting were 3, 98.3, and 84.29 per cent, respectively.

Kumar *et al.*(2016)studied the effect of front to rear clearance ratios of 3:1 to 1:1 and found very little difference in cylinder loss, visible damage and germination of wheat for any given mean clearance. The modified thresher was evaluated at three different levels each of cylinder concave clearance (10, 20, 30 mm), seed moisture content (12.5, 14.0. 17.0%), two levels of cylinder speed (580,600 rpm peripheral speed 4.2m/s and 4.4m/s ), and feed rate 10kg/hr of dried wheat. Performance parameters for the study were threshing efficiency, cleaning efficiency, total loss of seed and germination. The test results indicated a maximum of 97% threshing efficiency and 97.7% cleaning efficiency, a minimum of 3.3% total seed loss and a maximum germination of 85%. The average output capacity of machine was 6.3kg/h of seed. The performance was found to be influenced by all the study variables.

## 2.5 Study of Seed Damage in Thresher

Reddy *et al.*(1995) reported that mechanical damage to soybean during threshing leads in a lower storage life of the seeds. It indicated that threshing methods affect seed quality in terms of germination and vigour.

Szarszunow *et al.* (1998) concluded that the flax seed losses were mainly caused by threshing damage and ineffective threshing. Experiments by improving the precision of their separation during threshing were carried out to reduce the loss and damage to flaxseed

Fakrany *et al.* (2014) reported that during the performance evaluation of rubbing thresher neither visible nor invisible seed damage was occurred with flax crop.

Sinha and Pandita (2002) investigated the effect of different threshing methods on seed damage. In addition, it was discovered that seed harvested by tractor treading had the lowest germination rate (78%), but manual threshing had a much greater germination rate (92%).Germination percentage and vigour index in Pullman thresher had an 87 per cent and a 23.34 per cent respectively, whereas De-awner thresher had an 88 per cent and a 24.45 percent.

Ramteke and Sirohi (2003) reported that cylinder mechanism and the cylinder speed were the most important variables, which influenced the invisible seed damage. The rasp bar mechanism resulted in 81.31% to 95.33%germination count while spike toot gave lower germination ranging from 79.66% to 92.66%. Average seed germination was highest (90.16%) at lowest speed (13.57m/s). and highest concave clearance (10mm) was best suited for maximum germination.

Vejasit and Salokhe (2004) stated that the percentage of grain damage increased slightly with anincrease in drum speed at 32.88% (w.b.), grain moisture content for feed rates of 360 to 720 kg/h. The grain damage slightly decreased with an increase in feed rate. The grain damage increased as the grain moisture content increased from 14.34 to 32.88% (w.b.). However, the grain damage was less than 1.5% at all moisture contents feed rates and drum speeds combination.

Bansal and Lohan (2009) reported that the concave clearance, cylinder speed, and seed moisture content all had a substantial impact on seed germination and seed damage. The maximum germination rates of 90, 92, 92, 96, and 92 per cent were found in threshing of green gram, black gram, soybean, chickpea, and sunflower crops while lower seed damage of 1.10, 1.48, 0.15, 0.27, and 0.25 per cent in green gram, black gram, soybean, chickpea, and sunflower crops respectively were found at lower cylinder speed, higher concave clearance, and greater seed moisture content. The germination percentages were higher than the minimum seed criteria recommended by ISTA (1999).

The important parameters affecting the threshing operation and seed quality is the moisture content of the ear-head. The traditional methods implied in threshing are labour-intensive, time-consuming, and have low efficiency in operation. Mechanical damage, moisture content, threshing cylinder speed, feeding rate, and concave clearance are some of the important parameters that influence the threshing efficiency (Naveen Kumar *et al*.2013).

Senthil *et al.*(2021) reported that the manual beating method had the highest seed recovery (67.8 per cent), germination (81 per cent), seedling growth characters, and vigour index (1512), followed by mechanical threshing which had 65.2% seed recovery, 80% germination, and (1466) vigour index. Furthermore, it was indicated that mechanical threshing was a viable way for obtaining excellent quality seeds with maximum threshing efficiency for large-scale seed production of little millet.

## 2.6 Studies on Cost Economics

Ghaly (1985) stated that threshing process that requires four day using local practice may be accomplished in less than two hour using mechanically operated stationary thresher.

Ahuja *et al*. (1987) during performance evaluation of IRRI PAK axial flow thresher on paddy found that, this machine thresh paddy with labour savings of about 120 man hr/ha and low grain losses i. e. 1.53 % to 2.73 %.

Behera *et al.* (1990) estimated net unit threshing cost of wheat using the developed thresher was Rs. 13.63 / quintal, where as it was Rs. 14.94 /quintal when threshed by conventional methods.

Kamble *et al.* (2003) evaluated the developed pearl millet thresher and compared the cost of operation of prototype thresher with traditional method of threshing and found that threshing by mechanical thresher, animal trampling and manual beating were Rs. 8.50, Rs. 31.25 and Rs. 165.00 per quintal of input crop respectively. Thus, the mechanical thresher was observed to be most economical and efficient method of pearl millet threshing.

Singh *et al.* (2003) reported that there is 80% saving in labour requirements and 74% saving in cost of threshing operation with motorized wire loop paddy thresher as compared to pedal type paddy thresher.

Naik *et al.* (2010) reported that threshing is recognized to be very labour intensive operation and involved considerable human drudgery. Further delay in threshing operation result in delay in sowing of the next crop and hence it reduced the yield. Studies on the effect of moisture content, feed rate, and cylinder speed on the performance of thresher were done for different make threshers.

Dhananchezhiyan *et al.* (2013) studied the comparative performance of mechanical and traditional threshing method of paddy crop. And reported that The saving in cost and time of the portable power paddy thresher were 86.5% and 95%, respectively as compared to manual threshing. The break-even point for the developed portable power paddy thresher was 205 hours of use per year.

Chaturvedi and Rathor (2018) evaluate the performance of developed thresher and compared with traditional method of threshing, and reported that the costs of operation of manually hand beating method was 8.25rs/kg for 5 men, in tractor operation it was 14.65 rs/kg and in developed millet thresher it was 4.34rs/kg.

Sial (2018) tested economic evaluation of the newly developed ragi thresher cum pearler and compares the cost of operation with the traditional method like manual hand beating and foot trampling, and reported that 65 to 70 % reduction of the operational cost as compare to the conventional method. The operating cost for threshing one kg of ragi by the developed ragi thresher was calculated as Rs 1.44/kg the total operating cost of machine was Rs. 76.56 per hour and 0.88 per kg of ragi grain. In case of traditional method, it was coming around Rs. 26.65 per hour and Rs. 5.24 per kg for hand beating method but in case of foot trampling method it was about Rs. 4.20 that is costlier as compare to the developed thresher cum pearler.

## 2.7 Concluding Remarks

The review of studies done on the engineering properties of linseed indicated that the parameters like length, width, thickness, geometric mean diameter, bulk density, angle of repose, coefficient of friction and terminal velocity had significant relation with moisture content and these parameters are to be considered for design of the linseed thresher.

The review of works done on development of threshers indicated that the speed of operation of the threshing cylinder should be 15-22 m/s, concave clearance be 5-10 mm at moisture content of 8-14 per cent.

The performance indicators such as striping efficiency, threshing efficiency, threshing capacity and cleaning efficiency of the thresher developed earlier were found to be affected by cylinder speed, concave clearance, feed rate and moisture content.

CHAPTER-III

# MATERIALS AND METHODS

This chapter deals with the materials and methods required for, conducting the experiments to study the physical and engineering properties of linseed crop and development of linseed thresher, its performance valuation and study of cost economics of developed of linseed thresher.

## 3.1The Study Area

The fabrication and performance evaluation of thresher were conducted in the FMPE workshop of Swami Vivekananda College of Agricultural Engineering and Research Station, Faculty of Agricultural Engineering, IGKV, Raipur (C. G.). It is located at 21º 14’ 02” N latitude and 81º 43’ 11” E longitude. To determination of physical and engineering properties of linseed experiments were conducted in the laboratories of the department of Agricultural Processing and Food Engineering, SVCAET & RS, IGKV, Raipur (C.G.).

## 3.2 Physical Properties of Linseed Capsule

The properties include, no of capsule per plant, no of seed per capsule, length, width, thickness and geometric mean diameter. For determination of physical properties of linseed capsule, sample was procured from agronomy department IGKV Raipur. The length, width and thickness of the linseed capsule was measured by digital Vernier Caliper (Fig 3.1).


Fig 3.1 Measurement of linear dimension of linseed capsule

## 3.3 Physical Properties of Linseed

Some physical properties like moisture content, linear dimension, GMD, thousand grain weight, bulk density, true density, porosity, volume, surface area were selected for the study.

### 3.3.1 Moisture content

The linseed of three popular variety were collected in adequate quantity from Agronomy department IGKV Raipur, Chhattisgarh, India. Seeds were cleaned manually to remove all foreign materials such as dust, dirt and broken and immature seeds. The initial moisture content of seed was determined (Fig 3.2) by using the standard hot air oven method using the following formula (AACC, 2000).

$$\mathrm{MC}(\%) = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \qquad \ldots (3.1)$$

Where,

MC= Moisture content on dry basis, %;

$W_1$= Initial weight of the bowl, g;

$W_2$ = sample weight before drying +bowl weight, g;

$W_3$ = sample weight after drying + bowl weight, g

Seed sample of desired moisture content levels were prepared by adding calculated amount of distilled water by using following equation and mixed thoroughly. (Sacilink *et al.*, 2002)

$$Q = W_i \times \frac{m_f - m_i}{100 - m_f} \qquad \ldots (3.2)$$

Where,

Q = Weight of water to be added, g;

$W_i$ = Initial weight of seed sample, g;

$m_i$ = Initial moisture content of seed sample (% db); and

$m_f$= Final moisture content of seed sample (% db).

### 3.3.2 Linear dimension of seed

To determine the size and shape of linseed, length, breadth and thickness of randomly selected 10 seeds of each variety were measured by using a digital Vernier Caliper with least count reading 0.01 mm and its average was recorded. (Fig 3.3)

### 3.3.3 Grain size

The arithmetic mean diameters (AMD), geometric mean diameter (GMD), square mean diameter (SMD), an equivalent diameter (EQD), of seeds were calculated by using the following relationships (Mohsenin, 1986).

$$AMD = \frac{(L + B + T)}{3} \qquad \text{... (3.3)}$$

$$GMD = (LBT)^{\frac{1}{3}} \qquad \text{... (3.4)}$$

$$\mathrm{SMD} = \sqrt{(\mathrm{LB} + \mathrm{BT} + \mathrm{TL})} \qquad \text{... (3.5)}$$

$$\mathrm{EQD} = \frac{(\mathrm{AMD} + \mathrm{GMD} + \mathrm{SMD})}{3} \qquad \text{... (3.6)}$$

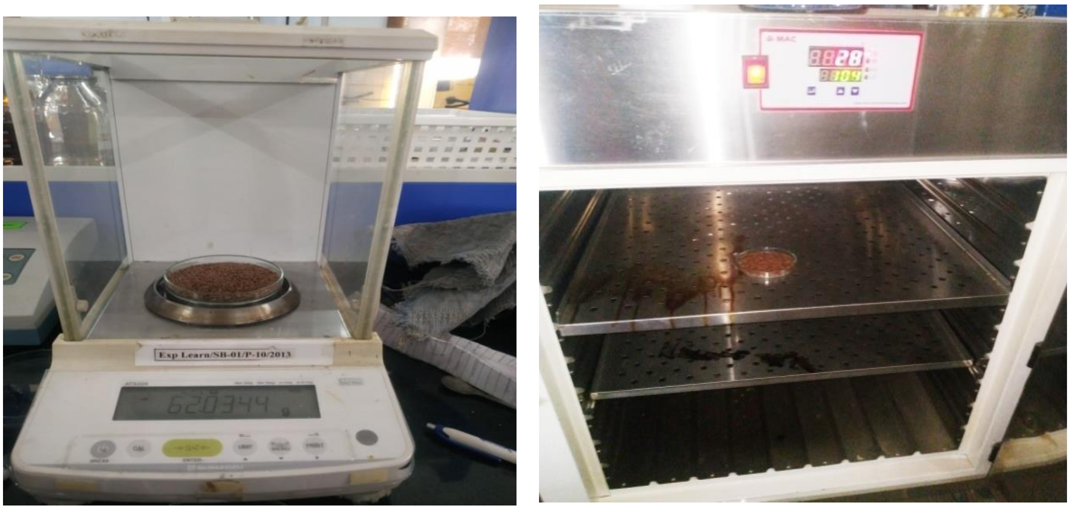


Fig. 3.2: Moisture content determination


Fig: 3.3 Measurement of linier dimension

### 3.3.4 Surface area (S)

The surface area (S) was calculated by using the expression given by (Singh *et al.*, 2010).

$$S = \pi(GMD)^2 \qquad \text{... (3.7)}$$

### 3.3.5 Sphericity (ϕ)

Sphericity is defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area of the grain and it was determined using following formula (Mohsenin, 1986).

$$\phi = \frac{(LBT)^{\frac{1}{3}}}{L} \qquad \text{... (3.8)}$$

Where,

L=Length of seed, mm;

B= Breadth of seed, mm; and

T= Thickness of seed, mm.

### 3.3.6 Volume(V)

The volume of the grain was determined by taking the dimensions of seed of three axes length, width and thickness and then volume was estimated using the following relationship as described by Mohsenin (1986)

$$V = \frac{\pi LBT}{6} \qquad \text{... (3.9)}$$

Where,

V = Volume, $mm^3$;

L= Length of seed, mm;

B= Breadth of seed, mm;

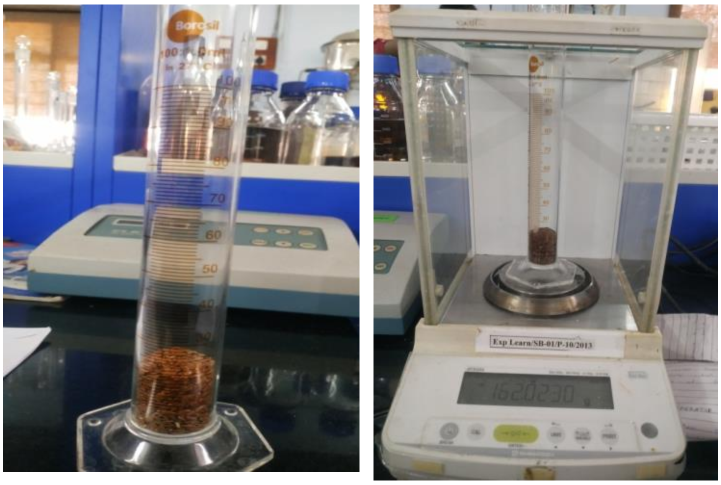
T= Thickness of seed, mm; and

π = constant (22/7).

### 3.3.7 Thousand grain weight(M1000)

One thousand randomly selected grains of test samples at various moisture levels were collected and weighed on electronic balance having a least count of 0.01 g. This magnitude is termed as the thousand-grain weight specific to the grain. The procedure described in IS: 4333 (part IV)-1986 was adopted. Average of ten replications have been considered and reported as a 1000 grain weight of sample (Fig 3.4).

Fig.3.4: Weighing thousand grain weight



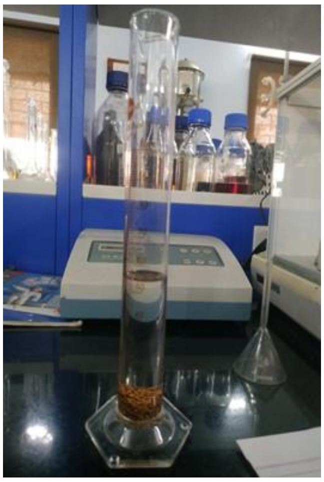


Fig.3.5: Measurement of bulk density

Fig.3.6: Measurement of true density

### 3.3.8 Bulk density (BD)

The bulk density of seed is the ratio of its mass to total volume. It was determined by using standard test weight procedure by filling a 500ml container with seeds from a height of about 15cm at constant rate (Fig 3.5), striking the top level and weighing the contents (IS:4333 part III). Bulk density was then calculated as the ratio between the kernels weight and the volume of the cylinder (Akaaimo and Raji, 2006; Mwithiga and Sifuna, 2006).

$$BD = \frac{W_s}{V_s} \qquad \text{... (3.10)}$$

Where,

BD = Bulk density in kg/m$^3$;

$W_s$=Weight of the sample in kg; and

$V_s$ =Volume occupied by the sample, m$^3$.

### 3.3.9 True density

The true density defined as the ratio of mass of the sample to its true volume, was determined using the toluene ($C_7H_8$) displacement method (Fig 3.6). Toluene was used in place of water because it is absorbed by seeds to a lesser extent. 50 millilitres of toluene were placed in a 100ml graduated measuring cylinder and 5g seeds were immersed in the toluene (Mwithiga and Sifuna, 2006; Ovelade *et al*., 2005). The amount of displaced toluene was recorded from the graduated scale of the cylinder. The ratio of weight of seeds to the volume of displaced toluene gave the true density.

True volume of seeds (ml) = (initial toluene level in measuring jar) – (final moisture level in measuring jar)

$$\mathrm{TD} = \frac{\mathrm{W_s}}{\mathrm{T_{vs}}} \qquad \text{... (3.11)}$$

Where,

TD = True density, kg/m$^3$;

Ws= Weight of seed, kg; and

$T_{vs}$= True volume of seed, m$^3$.

### 3.3.10 Porosity(ϵ)

The porosity is the fraction of the space in the bulk grain which is not occupied by the grain. The porosity of the bulk seed was calculated from the values of true density and bulk density using the equation:

$$\varepsilon = \frac{\mathrm{TD} - \mathrm{BD}}{\mathrm{TD}} \times 100 \qquad \text{... (3.12)}$$

Where,

ε = Porosity;

TD = True density, kg/m$^3$; and

BD = Bulk density, kg/m$^3$.

## 3.4 Mechanical Properties

Some mechanical properties like coefficient of friction, angle of repose, terminal velocity, rupture force, tensile force were selected for the study.

### 3.4.1 Coefficient of static friction

The static coefficient of friction may be defined as the friction force acting between surfaces of contact at rest with respect to each other. The coefficient of static friction apparatus consists of a horizontal plane and bottomless open container and the container was tied with a cord passing over a frictionless pulley attached to a pan. Static coefficient of friction was determined with respect to four surfaces: plywood, stainless steel, glass, and galvanized iron. Known weight of linseed was taken in the container. The weights were added in the pan and at the instant at which the pan weight exceed the sample weight and friction; the container start to slide on selected surface the static coefficient of friction was calculated using the equation suggested by Sahay and Singh,1994; Niveditha 2001; Bahnasawy,2007.Fig 3.7 (a) and Fig 3.7(b)

$$\mu = \frac{F}{N} \qquad \text{... (3.13)}$$

Where,

μ = Coefficient of friction;

F = Friction force (force applied); and

N = Normal force (weight of the linseed sample).

### 3.4.2 Terminal velocity

The terminal velocity is defined as the velocity of air at which the grain is neither blown upward nor fallen downward; rather remains in the suspended state. The terminal velocities of linseed at different moisture contents were measured using an air column device. For each experiment, a sample was dropped into an air stream from the top of the air column. Then airflow rate was gradually increased until the seed became suspended in the air stream. The air velocity which kept the seed in suspension was measured using a pivot tube in conjunction with a micro manometer. Each sample consisted of 20 seeds selected randomly at the same moisture content of the seed. Three replications were taken for each sample (Gupta and Das, 1997 and Sacilink *et al*.2003). Fig 3.8 and Fig 3.9.

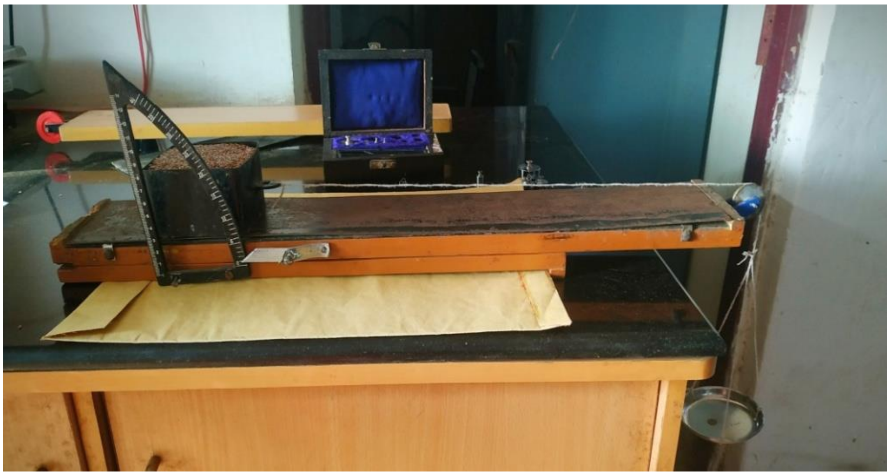


Fig.3.7 (a) : Measurement of coefficient of static friction

Fig.3.7 (b): Measurement of coefficient of static friction

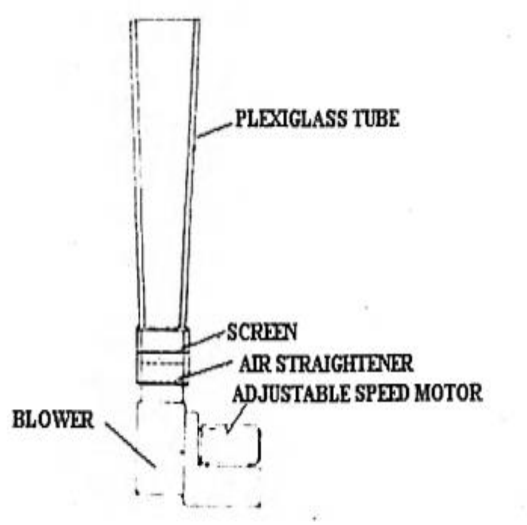



Fig 3.8 Vertical air tunnel for measurement of terminal velocity of linseed (Sacilink *et al*.2003

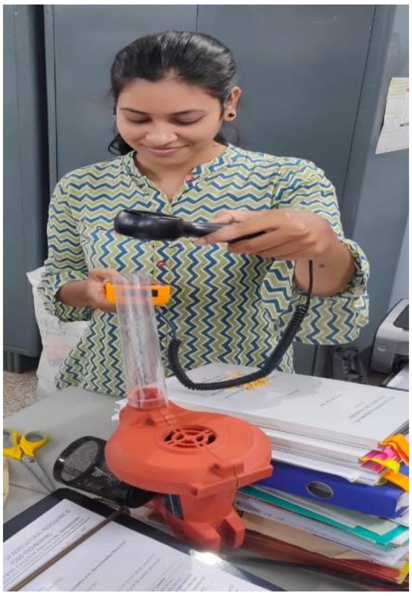


Fig 3.9 Taking reading of terminal velocity with help of anemometer

### 3.4.3 Angle of repose

The angle of repose is the angle with horizontal at which the material will stand when piled. To determine angle of repose, a box measuring 950mm×100mm×150mm, having an open ended cylinder of 70mm diameter and 45mm height of cone with removable front panel was used (Fig 3.10). The box was filled with the linseeds from until the cone was formed on circular plate and the front panel was quickly removed, allowing the seeds to flow to their natural slope. The height of the cone was recorded by using scale of 0-1 cm precision. The angle of repose (ɵ) was calculated using the following formula

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \qquad \ldots(3.14)$$

Where,

H = Height of the cone, cm; and

D = Diameter of cone, cm.

### 3.4.4 Rupture force

The experiment was carried out to find the rupture force of linseed seed, linseed capsule and stalk. The texture analyzer (TW+Di) of APFE laboratory was used for determination of force (Fig. 3.11a). The texture analyzer consisted of two primary components: hardware (load cell with a platform to hold sample and moving head for holding probe) and software (Texture Expert) for recording & calculating the test results. Before performing the tests, the machine was calibrated for load and distance for each type of test. The load calibration was done to check whether the load cell was accurate in sensing the force imposed over the sample of seed, capsule and stalk. Calibrating 50 g were suspended on the crosshead and selected the desired option under T.A. settings. Similarly, calibrated the movement of the cross ensure the compliance of the set deformation (strain) of the sample. After calibrating the texture analyzer, a sample of linseed capsule was placed on the platform. Different probes were used for different tests as per settings to generate the force-time curves. The force required to rupture or deform was abstracted from the graph shown and procedure repeated for 5 times to get the average mean value. Similar process was carried out for seed and stalk. (Kingsly *et al.*, 2006).

Fig. 3.10: Measurement of angle of repose


Fig. 3.11 Texture analyzer (TW+Di) (1), rupture force testing of linseed seed sample(2), rupture force testing of linseed capsule (3), ruptured linseed capsule(4)and ruptured linseed(5)

## 3.5 Significance of Properties of Linseed for Designing Thresher

The study of physical and mechanical properties of grain such as linear dimension, volume, surface area, density, porosity and hardness are important in many problems associated with design of a specific machine. The theoretical performance of machine and mechanisms used in mechanical handling and processing of material cannot be fully appreciated without knowledge of the physical property of material (Mohsenin 1986).

### 3.5.1 Dimension

What shape is to be assumed for the material and which dimension is to be employed in calculation are two first questions which one must answer before understanding the problems of separation of seed and grain from undesirable materials. Therefore, the dimensions of the linseed can be used to choose the appropriate fan that can separate the linseed seeds from the undesirable material also the efficiency of sieving and hence, the removal of chaff is affected by the seed parameters of each seed. However, sieve parameters- size shape and spacing of screen openings, angle of inclination and vibration amplitude and frequency of screens can also be determined by using the dimension of the linseed (Mohsenin, 1986 and Datta, 2003).

### 3.5.2 Geometric mean diameter

The geometric mean diameter is essential in the determination of terminal velocity and drag coefficient. The knowledge of the geometric mean diameter can also be used in the determination of cylinder concave clearance of the threshing unit of thresher.

### 3.5.3 Bulk and true density

The knowledge of density of agricultural product is needed in separating the product from undesirable material, thus the design of fan. Density of grains decides the size of screening surface. It also used in determination of purity of grain.

### 3.5.4 Terminal velocity

Terminal velocity is necessary to decide about the winnowing velocity of air blast for separation of lighter material.

### 3.5.5 Angle of repose

The angle of repose of linseed is used in the determination of the angle at which the hopper of the thresher will be slanted so it has free flow of the linseed seed in the hopper.

### 3.5.6 Coefficient of friction

The knowledge of coefficient of friction of the food grain s on various surfaces is necessary in analysis and design of post-harvest grain handling, processing and storage equipment such as grain bin conveyors flow of food grain from bins by gravity or loaded auger. A machine can only be started or stopped if forces of static coefficient of friction or dynamic friction are overcome by the power source. Therefore, information on both static and dynamic coefficient of friction is vital in estimating the power requirement of machines.

### 3.5.7 Porosity

The percent of voids of unconsolidated materials such as grains and other porous materials is often needed in the design of air flow mechanisms (Mohsenin, 1986).

### 3.5.8 Weight

The weight of linseed can be used to determine the type o fan and sieve that can be used to separate the linseed seed from the undesirable materials.

### 3.5.9 Mechanical property

Mechanical properties such as cracking force, hardness, and compressive strength are important and, in some cases, necessary engineering data in studying size reduction of cereals grain as well as seed resistance to cracking under harvesting and handling condition (Mohsenin, 1986). Therefore, the mechanical properties of linseed seed can be used to determine the type of materials to be used in selecting cylinder beaters, and construction materials (metal type) of the thresher.

## 3.6 Determination of Straw Grain Ratio

Straw grain ratio of linseed was determined by selecting five sample of only tip portion of linseed crop because in this thresher only tip portion of linseed crop is subjected while threshing. Each sample was weigh 5 kg (IS: 1985). The weight of the grain and straw were determined separately for each sample after separating them from each other and their ratio was calculated. The average of five sample were considered as the straw grain ratio for the test purpose

$$\delta = \frac{W_S}{W_g} \qquad ... (3.15)$$

Where,

$\delta$ = Straw grain ratio;

Ws = Weight of straw, kg; and

Wg = Weight of grain, kg.

## 3.7 Design of Linseed Thresher

### 3.7.1. Design considerations for the developed thresher

a) The capacity of the thresher should be more than 150 kg/h.
b) The machine should be suitable for removing of capsules only.
c) The machine should be capable of threshing of the capsules.
d) It should clean the linseed seed from the chaff.
e) The machine should be operated by a single phase electric motor so that it could be easily available at farmer's field / threshing yard.

### 3.7.2 Design of threshing cylinder

In developed machine the threshing cylinder is one of the major component. The machine cylinder plays two role viz. stripping of capsules from the plant as well as threshing of the capsule by impact as well as vide frictional force. Before designing of the cylinder the following assumptions are taken into consideration:

#### 3.7.2.1 Calculation of power requirement for thresher

Power required to thresh linseed from capsule is expressed as (Gbabo *et al.* 2013)

$$P = T \times \omega \qquad \ldots (3.16)$$

$$\omega = 2\pi N / 60 \qquad \ldots (3.17)$$

$$T = F \times r \qquad \ldots (3.18)$$

Where,

P= Power required, watt;

T= Torque of the drum, Nm

ω = Angular velocity, rad/sec

N= Speed, rpm

F= The impact force required to thresh linseed, N (as selected from Table 3.1)

r = The distance of point of force application from axis of rotation, m

Table 3.1 Rupture force for different variety of linseed

| S No | Variety | Rupture force(N) |
|---|---|---|
| 1 | Sheela | 35.35 |
| 2 | Garima | 33.22 |
| 3 | Shikha | 45..94 |
| 4 | Shekhar | 37.07 |
| 5 | Neelam | 46.87 |
| | Mean | 39.69 |

Source: Singh *et al*. 2013

Hence,

$\omega = 2\times\pi\times712/60 = 74.52$ rad/sec

T= 39.69×0.085 = 3.37 Nm

Therefore,

P = 3.37×74.52 = 251.13 W = 0.25113 kW=0.34 hp

As per availability in market and taking factor of safety of 1.47 times a 0.5 hp single phase electric motor was selected for the thresher.

**3.7.2.2 Determination of feed rate**

The feed rate was calculated using following formulae.

$$\mathrm{Fr} = \frac{75(1-\mu) \times p}{v^2} \quad \text{... (3.19)}$$

Where,

Fr = Feed rate, kg/sec;

v = Speed of cylinder, m/s;

p = Power, HP; and

μ = Co-efficient of material rubbing.

$$\mathrm{Fr} = \frac{75(1-0.48) \times 0.5}{14.5^2} = 0.0927\,\frac{\mathrm{kg}}{sec} = 333\mathrm{kg/h}$$

Considering factor of safety 1.66 the feed rate is calculated as

m= 200kg/h

**3.7.2.3 Determination of threshing cylinder diameter**

The threshing cylinder diameter can be determined by using following formulae

$$\mathrm{Dc} = \frac{\mathrm{C_{pv}}}{\pi \times \mathrm{N_c}} \quad \text{... (3.20)}$$

Where,

Dc = Diameter of cylinder;

$C_{pv}$ = Peripheral velocity of cylinder, m/s; (v = 14.5 m/s Ramteke and Sirohi 2003)

$N_c$ = Speed of cylinder, rpm.

Hence, cylinder diameter is:

$$\mathrm{Dc} = \frac{14.5\times60}{3.14\times712} = 0.3891\mathrm{m} \approx 0.389\mathrm{m} = 389\mathrm{mm}$$

**3.7.2.4 Determination of threshing cylinder length**

Length of drum ($L_d$) of thresher is determined by using Winkler formula which is given by

$$\mathrm{L_d} = \frac{\mathrm{F_r} \times (1 + \delta')}{0.25 \times \mathrm{n} \times \mathrm{N} \times \mathrm{k}} \quad \text{... (3.21)}$$

$$L_d = 0.7m$$

Where,

$L_d$= Length of drum

$F_r$ = Feed rate of thresher, kg/sec; 0.054

n = No of bars on threshing cylinder;

N = Revolution of threshing drum /sec;

k =0.17-0.32 kg per meter length of drum;

$\delta'$=1/$\delta$; and= 1.34

$\delta$ = Straw grain ratio.

**3.7.2.5 Determination of no. of peg**

$$Np = \left[\frac{L_d}{a} + 1\right] P \quad \text{... (3.22)}$$

Where,

Np= No of peg,

$L_d$ = Drum length,

a= Constant (Recommended value 25-37.50mm, IS: 3327-1982.)

p = No of pitch of the helix over which peg are located = $C_b$/2

where, $C_b$ = no of cross bar

i.e. 4/2 = 2

Np = 2(400/37+1)

Np = 23.6 ≈(selected 24)



Fig 3.12 Selected threshing element

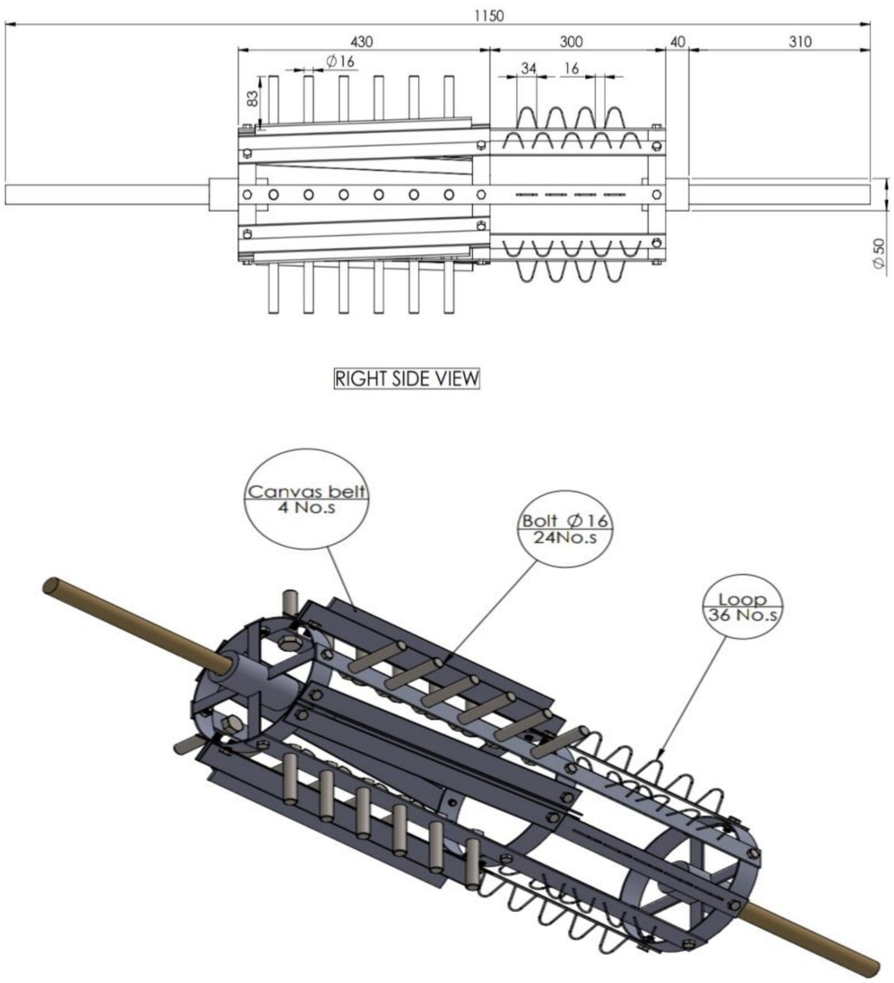



Fig 3.13 Diagram and isometric view of threshing cylinder

### 3.7.3 Design of concave

The following parameters were considered for the designing of the concave for the developed thresher. The different sources and its specification was depicted in the Table 3.2.

Table 3.2 The parameters and specification and material selected for the concave

| Parameters | Specification | Selected | Reference |
|---|---|---|---|
| Concave clearance for linseed crop | 5-15 mm | 10 mm | Ramteke and Sirohi 2003 |
| Clearance between concave bars | 3-5 mm | 3.5mm | |
| Cross section of concave bar | 6×6 $mm^2$ | 6×6 $mm^2$ | CIAE Data book |
| Wrap angle | 120°-160° | 140° | |

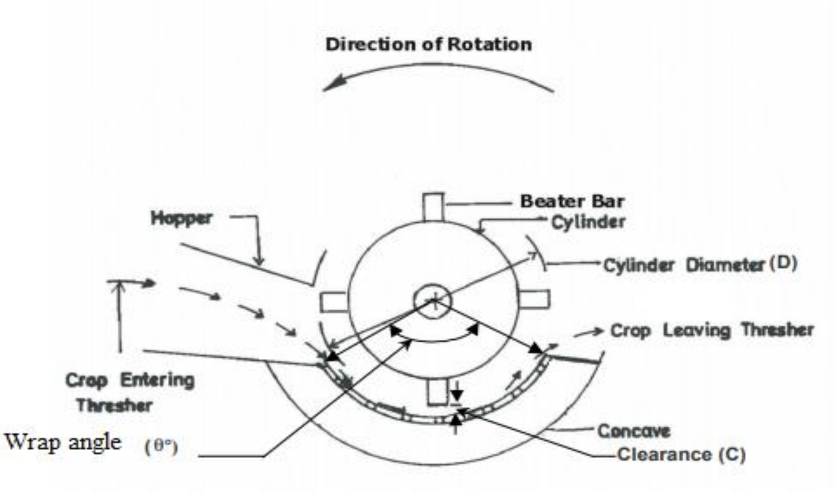



Fig 3.14 Cylinder-concave arrangement of the spike tooth thresher.

Radius of the concave = (Radius of the cylinder + Concave clearance)

= (195+10) = 205 mm

Wrap angle of concave = Length of the concave arc / Radius of the concave

= 140°× (π/180)

= length of the concave arc /205

Length of concave arc = 659.79 mm≈660 mm

Length of concave arc = (Clearance between axial slits + Width of the axial slit) ×Total number of slits

660 = (3.5+6) ×total number of slits

Total number of slits =69.47 ≈68

Length of concave ($L_c$) = $0.57\times L_d$ …(3.23)

Where,

$L_d$= Length of drum,

Lc= Length of concave,

Lc = 0.57 ×700

Lc = 399mm≈ 400mm

After calculating the size of the concave its drawing was made through SOLIDWORKS (Fig 3.12.). For collection of capsules after detachment from plant the first side of the cylinder was packed with a MS sheet concave whereas in second part it was opened though square bars for easy threshing (Fig 3.15 (d)).

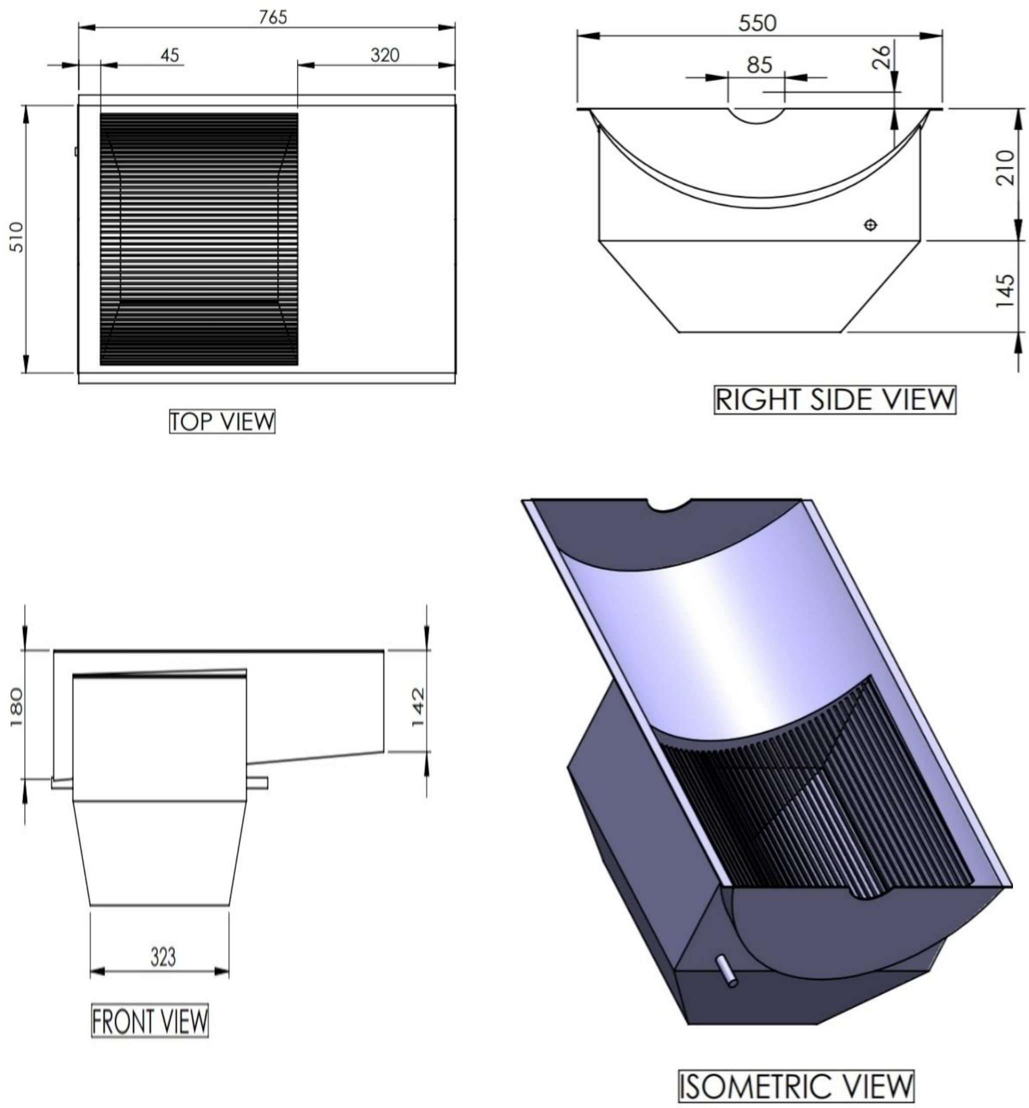



Fig 3.15 Diagram and isometric view of concave

### 3.7.4 Design of shaft

Since the shaft material was selected as mild steel so the maximum shear stress theory also known as guest's theory was used to design the shaft. According to maximum shear stress theory, the maximum stress in the shaft (Khurmi *et al.* 2005).

$$\tau_{max} = \frac{1}{2}\sqrt{{\sigma_b}^2 + 4\tau^2} \quad \text{... ( 3.24 )}$$

Shaft of cylinder subjected to

1. Torsional stress (τ): Due to tangential force acting on shaft.
2. Bending stress (σb): Due to the weight of the threshing cylinder, and the pulley

When shaft is subjected to fluctuating load then the equivalent stress is given by the equation

$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{(K_b \times M)^2 + (K_t \times T)^2} \quad \text{... ( 3.25 )}$$

$$= \frac{16}{\pi d^3}\sqrt{(1.5 \times M)^2 + (1.25 \times T)^2} \quad \text{... (3.26)}$$

$K_b$ and $K_t$ stand for combined shock and fatigue factor for bending and combined shock and fatigue factor for torsion. Respectively, 1.5-2.0 and 1.0 – 1.5 for suddenly applied minor shock.

Torque acting on cylinder shaft can be determined by-

Power transmitted through belt = 0.5 hp

$$\mathrm{P} = \frac{2\pi \mathrm{NT}}{4500} \quad \text{... (3.27)}$$

Where,

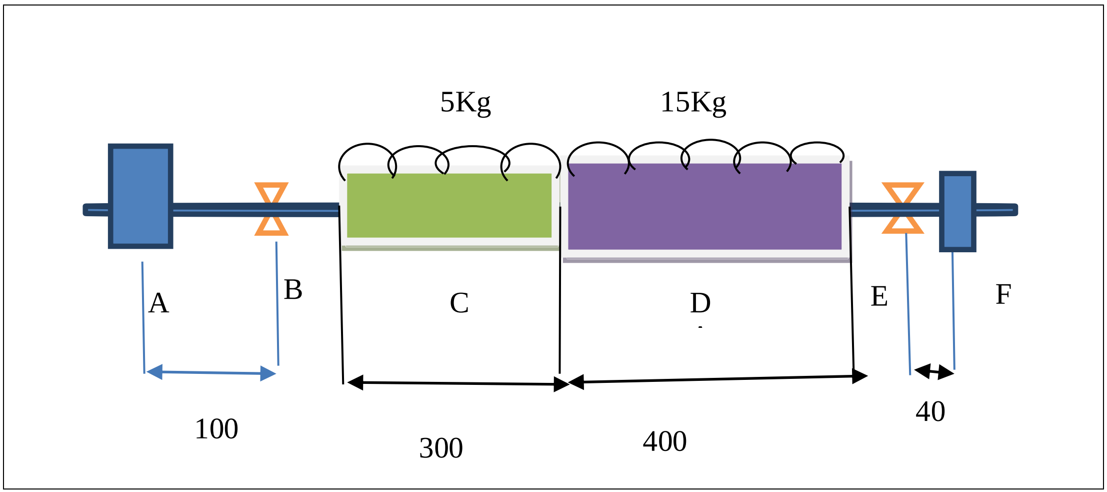
P = Power, hp;

N = Speed, rpm;

T = Torque, kg-m

$$0.5 = \frac{2\pi \times 712 \times \mathrm{T}}{4500}$$

$$\mathrm{T} = 0.503\mathrm{kgm} \ \text{ or } 5.03\mathrm{Nm}$$




Frig. 3.16 Free body diagram of the developed machine shaft

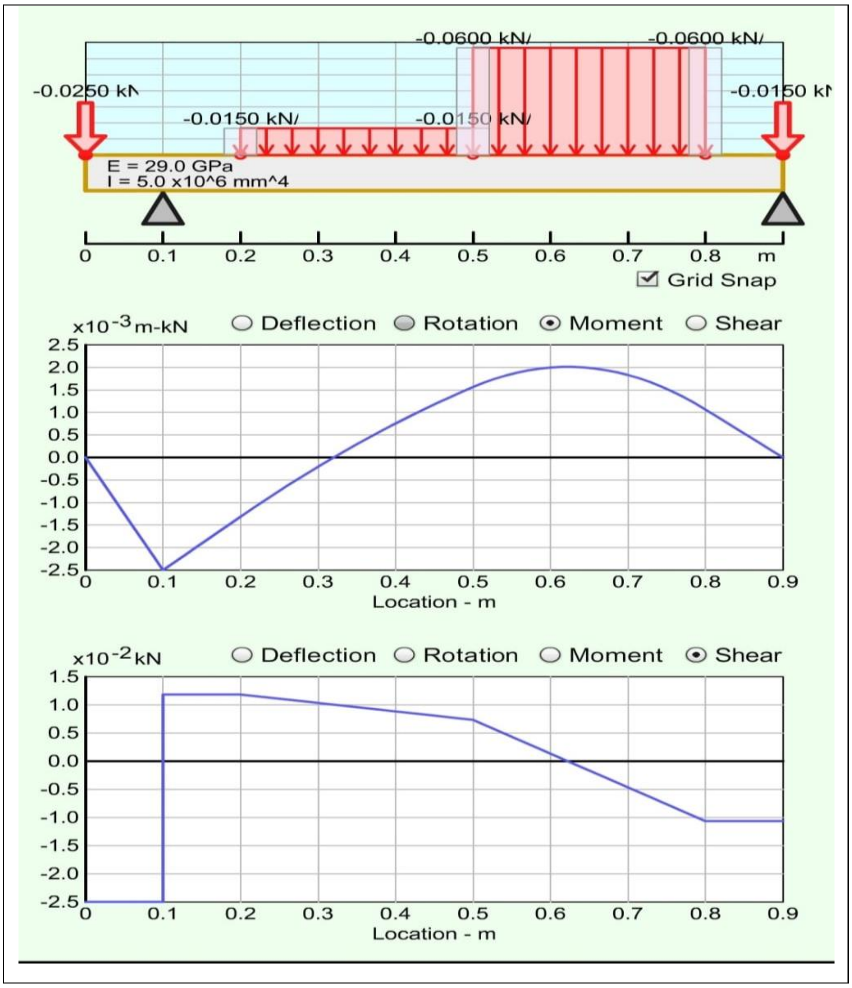



Fig 3.17 Bending moment and shear force diagram (Beam HPC Mobile APP)

Bending moment at different point of the shaft

i. Bending moment at length C due to weight of the wire loop cylinder(UDL)

$M_{BC}= (W_C \times L_C)/8$ …(3.28)

= 5×9.81×0.3/8 = 1.84Nm

ii. Bending moment at length D due to weight of the spike tooth cylinder(UDL

15×9.81×0.4/8 = 7.36Nm

iii. Bending moment at point A due to pulley and belt tension.

$T_{max} = (T_1 - T_2)r$ ... (3.29)

T1= belt tension on tight side

T2 = belt tension on slack side

r = radius of the pulley mounted on shaft

$5.03 = (\mathrm{T}_1 - \mathrm{T}_2) \times 0.2$

T1-T2= 25.15 ….(3.30)

We know that

$\frac{T_1}{T_2} = e^{\mu\theta}$ ... (3.31)

Where,

μ= 0.3 and ɵ = angle of lap=2.966

$\frac{T_1}{T_2} = 2.43$ ... (3.32)

Solving equation 3.30 and 3.32, T1= 17.53, T2= 42.688

The net horizontal force act on the shaft of the cylinder

T=T1+T2 = 60.2183N

The bending moment at point A, $M_{AB}$= Total bending force ×Distance (AB) = 60.21×0.1= 6.03Nm

iv. Bending moment at point C due to pulley and belt tension.

From equation 3.29

$T_{max} = (T_1 - T_2)r$

T1= belt tension on tight side

T2 = belt tension on slack side

r = radius of the pulley mounted on shaft

$5.03 = (\mathrm{T}_1 - \mathrm{T}_2) \times 0.1$

T1-T2= 50.3 ……. (3.33)

We know that form equation 3.31

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

Where,

µ= 0.3 and ө = angle of lap=2.909

$$\frac{T_1}{T_2} = 2.386 \quad \text{... (3.34)}$$

Solving equation 3.33 and 3.34, T2=36.29N, T1= 86.59N

The net horizontal force act on the shaft of the cylinder

T=T1+T2 = 122.88N

The bending moment at point C, $M_{EF}$= Total bending force ×Distance (EF) = 122.88×0.04= 4.92Nm

Bending moment at point D is maximum 7.36 Nm

$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{(1.5 \times M)^2 + (1.25 \times T)^2}$$

$$35 \times 10^6 = \frac{16}{\pi d^3}\sqrt{(1.5 \times 7.36)^2 + (1.25 \times 5.03)^2}$$

d = 12.6 mm

Taking safety factor= 2

Diameter of shaft = 12.6×2 = 25.2 mm

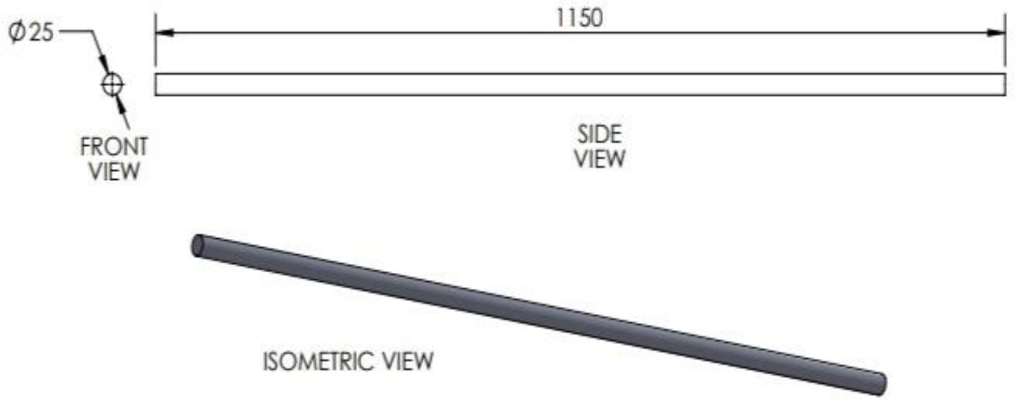



Fig. 3.18 Different view of shaft

### 3.7.5 Design of belt and pulley

#### 3.7.5.1 Determination of pulley dimension

The peripheral speed needed for threshing of linseed was suggested as 14.5

m/sec by Ramteke and Sirohi (2003). To obtain that amount of peripheral speed the following calculation are done for determination of size driving and driven pulleys the equation given by Hannah and Stephen (1984) were used as:

$$N\iota D_1 = N_2 D_2 \qquad \text{... (3.35)}$$

Where,

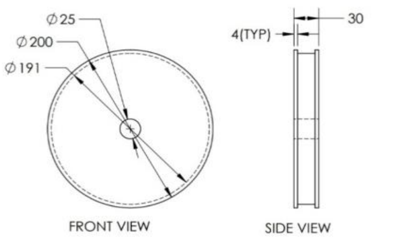
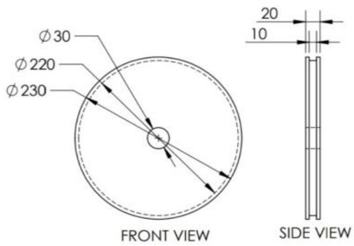
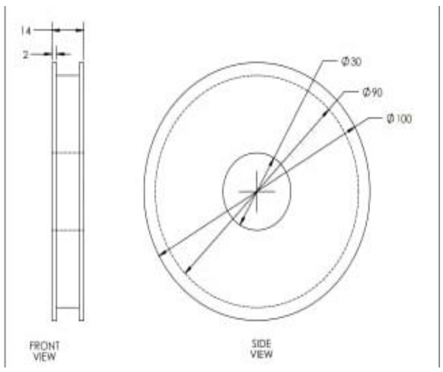
$D_1$ = Diameter of the drive pulley, mm;

$D_2$ = Diameter of the driven pulley, mm;

$N_1$ = Speed of the drive pulley, rpm; and

$N_2$ = Speed of the driven pulley, rpm.

Table 3.3 Determination of size of pulley

| Pulley between | Relation and specification | Calculation | Drawing |
|---|---|---|---|
| Cylinder shaft driven pulley | $N\iota D_1 = N_2 D_2$<br>Where,<br>N1 = 1425 rpm<br>D1 = 100 mm<br>N2 = 712 rpm | 1425×100 = D2× 712<br>**D2 = 200.14 mm** |  |
| Shaker shaft driven pulley | $N3D3 = N4D4$<br>Where,<br>N3= 712 rpm<br>D3= 100 mm<br>N4 = 310 rpm | 712×100 = 310×D4<br>**D4 = 229.7 mm ≈230 mm** |  |
| Blower shaft driven pulley | $N3D3 = N5D45$<br>Where,<br>N3= 712 rpm<br>D3= 100 mm<br>N5 = 712 rpm | 712×100 = 712×D5<br>**D5 = 100mm** |  |

To determine the value of $N_2$ the following calculation is done.

$$N2 = V/\pi D \qquad \ldots(3.36)$$

Where,

V = Peripheral velocity required for threshing of linseed = 14.5m/sec

= 14.5x60= 870 m/min

D = Diameter of threshing cylinder = 389 mm =0.389 m

Hence,

$$N_2 = \frac{870}{\pi \times 0.389} = 712$$

Five pulleys were used on thresher. There are two pulleys on the cylinder drum shaft, one pulley on motor shaft one pulley on blower shaft and another one on reciprocating sieve shaft. Looking to the requirement of the cylinder rpm as 712 the following calculation were made and depicted in Table 3.3.

**3.7.5.2 Determination of length of belt**

Length of open belt can be determined by following formula

$$L = \frac{\pi}{2}(D + d) + 2C + \frac{(D - d)^2}{4C} \qquad \ldots(3.37)$$

Length of cross belt can be determined by following formula,

$$L = \frac{\pi}{2}(D + d) + 2C + \frac{(D + d)^2}{4C} \qquad \ldots(3.38)$$

Where,

C = Distance between the drive and driven pulley, mm;

D = Diameter of drive pulley, mm; and

d = Diameter of driven pulley, mm.

Table 3.4 Determination of size of belt

| length of belt between | Relation, specification and calculation | Photograph |
|---|---|---|
| Prime mover and cylinder pulley | $L = \frac{\pi}{2}(D + d) + 2C + \frac{(D - d)^2}{4C}$<br>D = 200 mm<br>d = 100 mm<br>C = 577 mm<br>Therefore,<br>L = 1629.3 mm or **64 A** |  |
| Cylinder pulley and shaker pulley | $L = \frac{\pi}{2}(D + d) + 2C + \frac{(D - d)^2}{4C}$<br>D = 230 mm<br>d = 100 mm<br>C = 565 mm<br>Therefore,<br>L = 1655.4mm or **65 A** |  |
| Cylinder pulley and blower pulley | $L = \frac{\pi}{2}(D + d) + 2C + \frac{(D + d)^2}{4C}$<br>D = 100 mm<br>d = 100 mm<br>C = 468 mm<br>Therefore,<br>L = 1271.3mm or **50A** |  |

### 3.7.5.3 Determination of angle of lap of belts on pulley

To determine the angle of lap (θ) of the belt on pulleys the equation below as given by Khurmi and Gupta (2007) were used as:

$$\theta = (180 - 2\alpha)\frac{\pi}{180} \quad \text{... (3.39)}$$

$$\sin\alpha = \frac{D - d}{2C} \quad \text{... (3.40)}$$

$$\sin\alpha = \frac{D + d}{2C} \qquad ...(3.41)$$

Where,

D = Diameter of driver pulley, mm;

d = Diameter of driven pulley, mm; and

C = Distance between the centre of two pulleys, mm.

Both open and cross belt were used in design of the machine

**3.7.5.3.1 Determination of angle of lap of belt on pulley between cylinder pulley and prime mover pulley**

The angle of lap of belt on pulley between cylinder pulley and prime mover pulley was determined by using the Equation 3.39 and 3.40.

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

$$\sin\alpha = \frac{D - d}{2C} = 0.0866\,, \qquad \alpha = 4.96°$$

C = 577mm

D = 200 mm

d = 100 mm

$\theta$ = 2.966 rad

**3.7.5.3.2 Determination of angle of lap of belt on pulley between cylinder pulley and shaker pulley**

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

$$\text{Sin } \alpha = \frac{D - d}{2C} = 0.1150, \qquad \alpha = 6.6°$$

C = 565 mm

D = 230 mm

d = 100 mm

$\theta$ = 2.909 rad

**3.7.5.3.3 Determination of angle of lap of belt on pulley between cylinder pulley and blower pulley**

For cross belt drive

$$\theta = (180 + 2\alpha)\frac{\pi}{180}$$

$$\text{Sin}\ \alpha = \frac{D + d}{2C} = 0.2136, \qquad \alpha = 12.33°$$

C = 468` mm

D = 100 mm

d = 100 mm

$\theta$ = 3.57 rad

### 3.7.6 Design of aspirator blower

The air suction is a basic requirement for cleaning of seed and separating impurities and dust particles. Aspirator was designed to create pressure differential and suck specified amount of air volume.

#### 3.7.6.1 Determination of fan air discharge

The requirement of the air discharge through aspirator blower can be estimated in terms of velocity of air (V), depth of air stream cleaning (D) and width over which air is required for cleaning (W). Therefore actual air flow rate ($Q_A$) can be estimated as mentioned by Joshi (1981).

$$Q = V \times D \times w \qquad \dots (3.42)$$

Where,

Q = Air discharge, $m^3/s$;

V = Air velocity, m/s;

D = Depth of flow above the reference point, m; and

W= Width over which air is required, m.

The study showed that terminal velocity of the linseed grains ranges from 2.4m/s to 3.4 m/s, the aspirator blower was designed to provide air stream are less than 2.2 m/s The air velocity (V, m/s) at exit portion of the chaff outlet was considered as 2 m/s recommended . (Amer Eissa., 2009).

Therefore actual air flow rate required was calculated by equation 3.15

$$Q = 2 \times 0.151 \times 0.274 = 0.083\ m^3/s$$

The efficiency of the blowers can be considered as 30 %. So, the theoretical discharge ($Q_T$) can be estimated as

$$Q_T = \frac{Q_A}{0.3} = \frac{0.083}{0.3} = 0.276 m^3/s$$

The diameter of rotating blades was taken as 370 mm as outer diameter of impeller. The blower shaft of 19 mm diameter was placed to hold blades. The four straight blades of 140mm x 105 mm (lengthx width) having dimension were designed. The overall dimensions of the blower are as shown in Fig. 3.4

**3.7.6.2 Determination of weight of fan**

The weight of fan is calculated as per the following formulae (Hannah and Stephen, 1984 and Mohammed, 2009)

$$W = \delta g v \qquad \dots(3.43)$$

Where,

g = Acceleration due to gravity, m/s;

v = Volume of the material used for the fan construction, m³; (taking as 0.140×0.105×0.002 m³)

δ = Density of fan blade material, kg/m³.

for mild steel sheet material density = 7850 kg/m³ (Khurmi and Gupta, 2007)

w= 7850

$$W = 7850 \times 9.81 \times 2.94 \times 10^{-5} = 2.264\ N$$

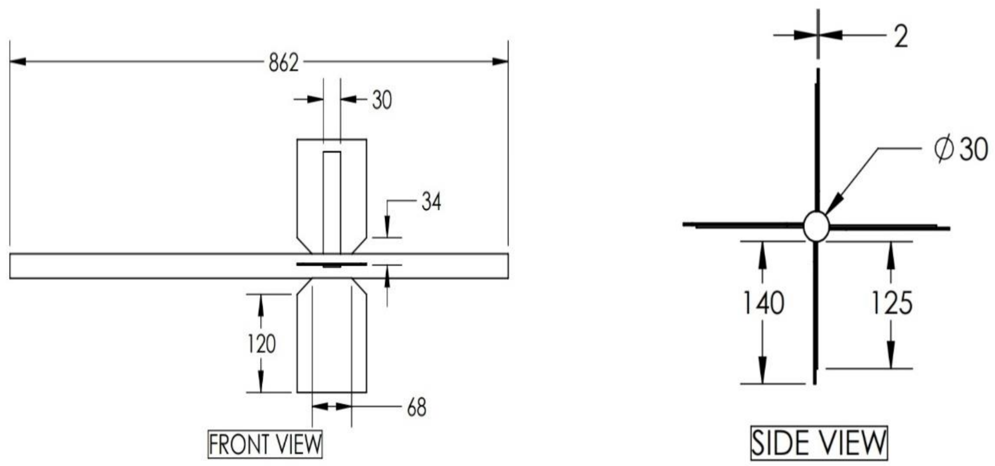
Power required for fan

Pf= 2.264×Vf …(3.44)

Vf= ΠDN/ 60= 3.14×0.30×700/60 = 10.99 m/s

Pf = 2.264×10.99 = 24.88 W

The overall dimensions of the blower are as shown in Fig. 3.4



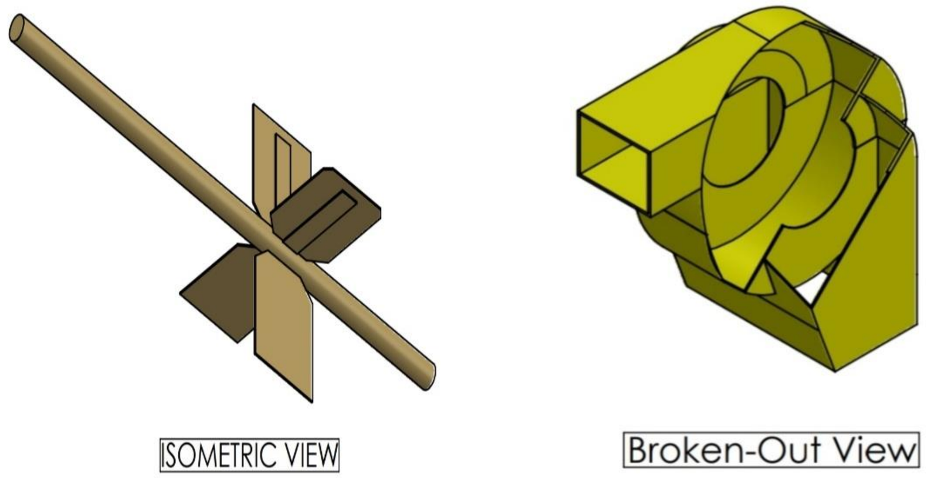



Fig 3. 19 Diagram and isometric view of fan blade

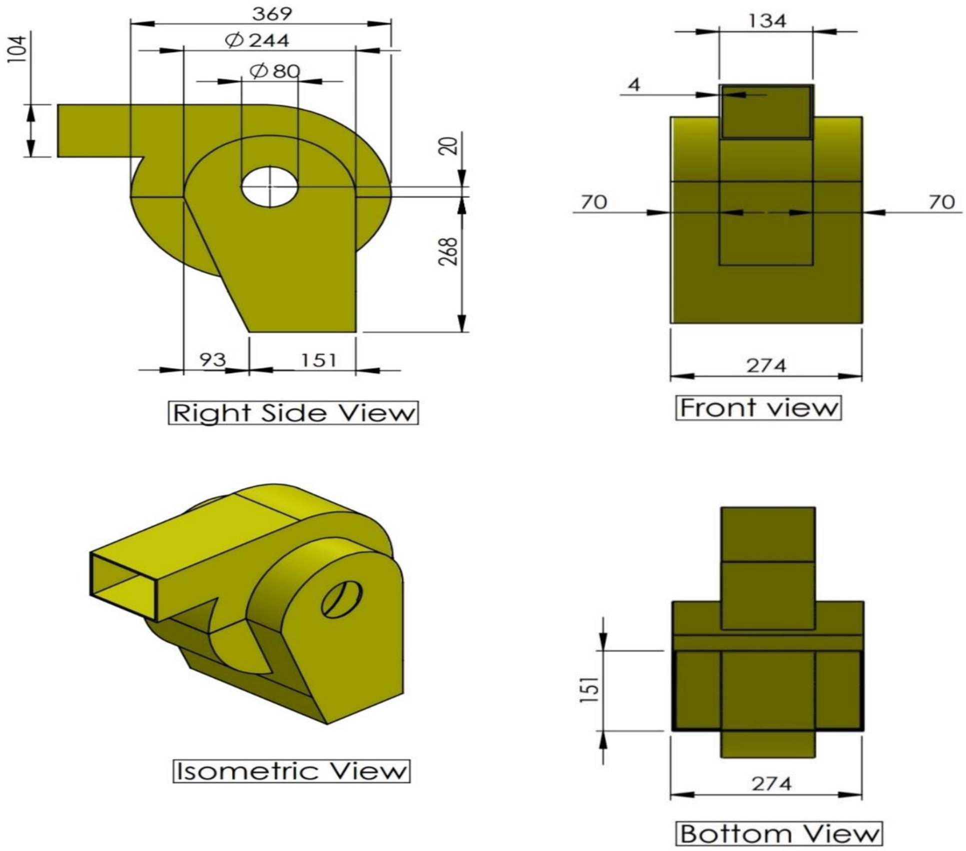



Fig 3. 20 Diagram and isometric view of aspirator blower casing

### 3.7.7 Design of sieve

According to sale *et al.*2016 power required by oscillation mechanism is calculated as:

$$P_{OC} = \frac{W_{Si} \times f \times 2y}{4500} + \frac{W_{Si} \times f \times 2\mu \times 2x}{4500} \quad \text{... (3.45)}$$

Where,

$P_{oc}$ = Power required by oscillation mechanism, kW;

$W_{si}$ =Weight of sieve component along with threshed material, N;

f = Frequency of sieve oscillation, rad/s;

µ = Coefficient of friction of moving component; and

x and y= Horizontal and Vertical component of the sieve, m

The performance of the cleaning system depends upon the scale of sieve, frequency of oscillation, feed rate of crop, slope of the sieve air flow rate, hole size of ratio amount of grain to MOG and properties of crop. (Myhan *et al.* 2016). The detail dimension and different view of sieve assembly are shown in Fig 3.21 and 3.22.

#### 3.7.7.1 Determination of hole size of sieve by Sieve analysis

A plastic container was used to collect the material ejected from the concave outlet. Collected material (straw + seed) was weighted by electronic scales and put on the sieves box. Two types of sieve box, round hole and rectangle hole are used for analysis. Sieves box consisted of four sieves used for separation of seed and straw. Their mesh numbers are 6, 5, 4 and 3. The holes of mesh were round and for rectangular hole mesh size of 5, 4, 3 and 2mm are used. to determine the perfect hole size for separation of seed and straw,, sieves box was shocked with ten minutes and materials that were on the sieves were weighted. Material into the each sieve was rated to the total material. (Yilmaz *et al.* 2008)

### 3.7.8 Design of feeding hopper

The hopper of the machine was made in such a way that the operator could view the loop thresher arrangement so that operator could place the capsule in proper position for proper detachment from the plant. The inclination angle of the hopper was kept at $36^0$, which saves the operator from any hand injury (Kumar *et al.*, 2002). The schematic view of the top cover and hopper with outlet is shown in Fig. 3.24.

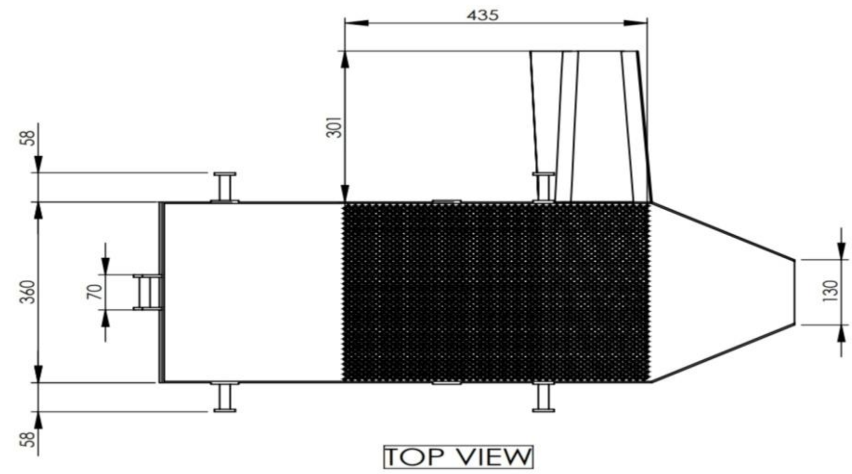
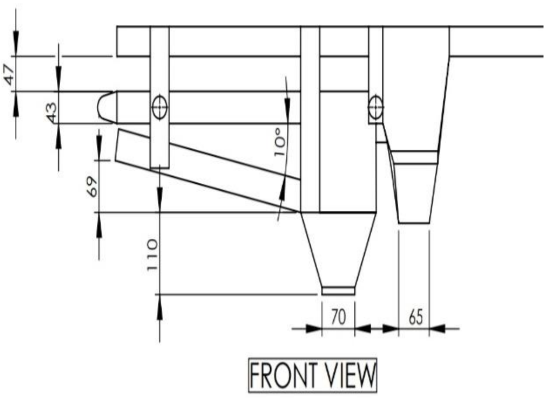
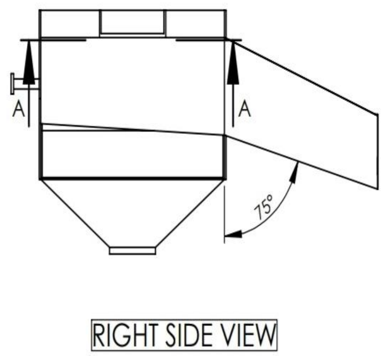
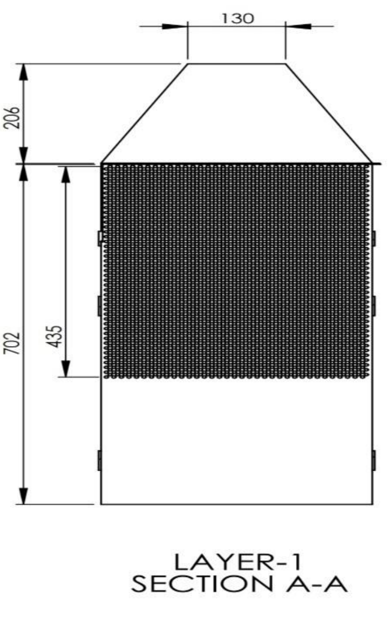
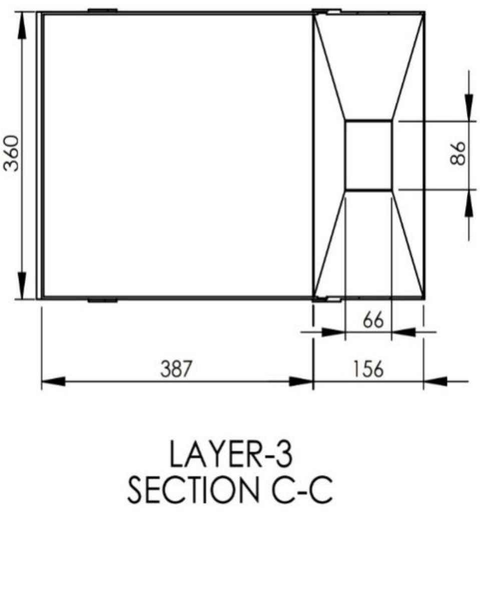



Fig. 3.21 Top view of sieve assembly



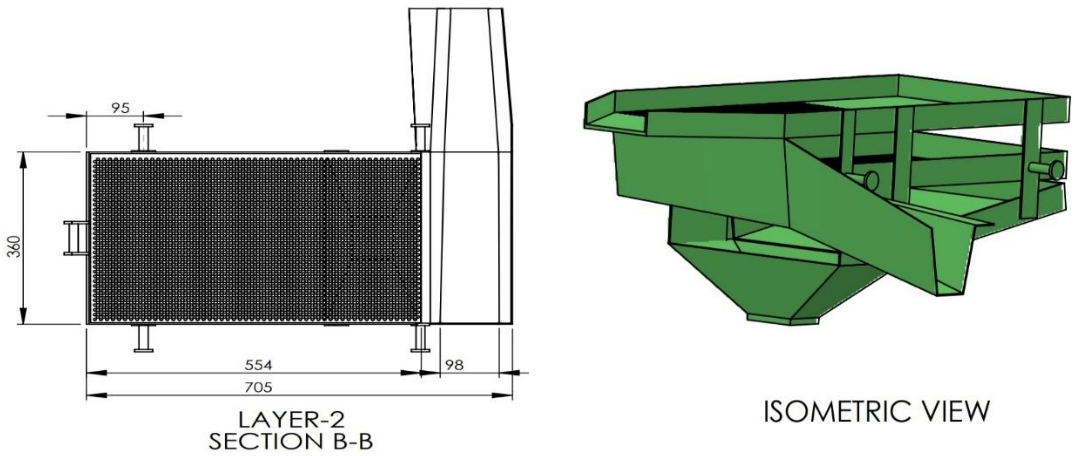



Fig 3.22 Diagram and isometric view of sieve and sieve assembly

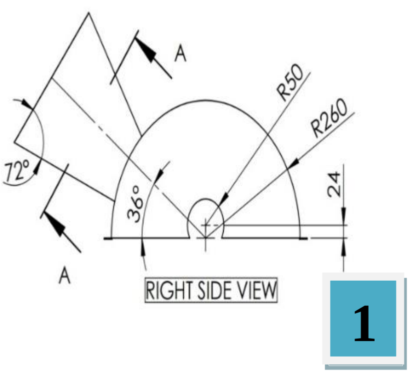
### 3.7.9 Design of frame

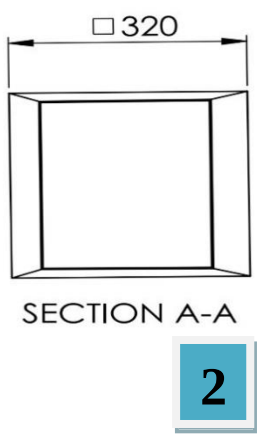
A structural frame was made for attachment threshing drum, aspirator blower and oscillating sieve. The two design factors considered in determining the material required for the frame are weight and strength. In this work MS angle of (35× 35× 3) is used to give the required rigidity. The dimension of the frame (L×W×H) of 950 ×580 ×760 mm.The other dimensions as well as isometric views taken were given in Fig 3.25.

### 3.7.10 Design and selection of bearings

The bearings were designed using the load resulting from the belt tension and the appropriate size and strength of bearing to withstand such loads selected. Single row deep grove ball bearings were employed for the shaft because they are low maintenance cost and do not require starting torque. The selected bearing are shown in Fig 3.23.

Fig. 3.23 Selected bearing for cylinder shaft



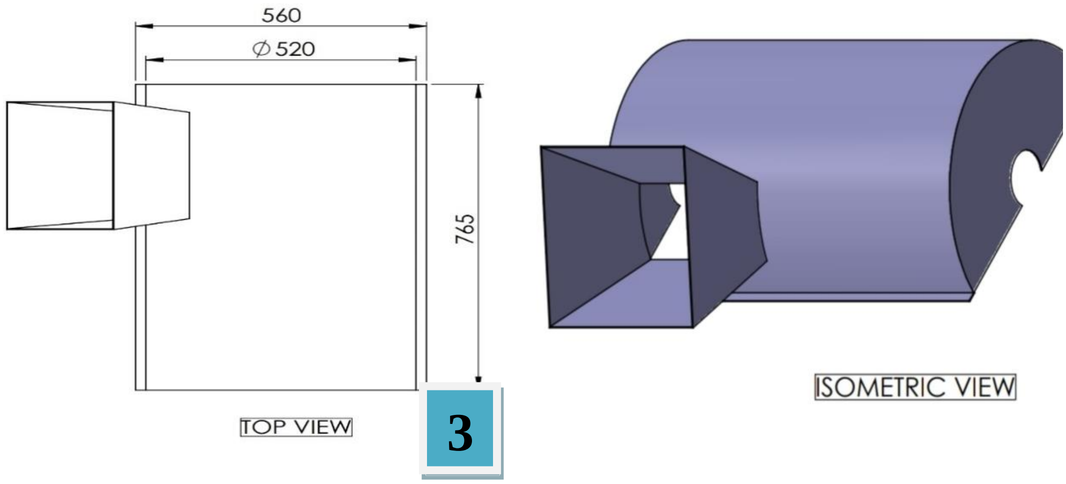



Fig 3.24 Diagram (1, 2 and 3 and isometric view of feeding hopper

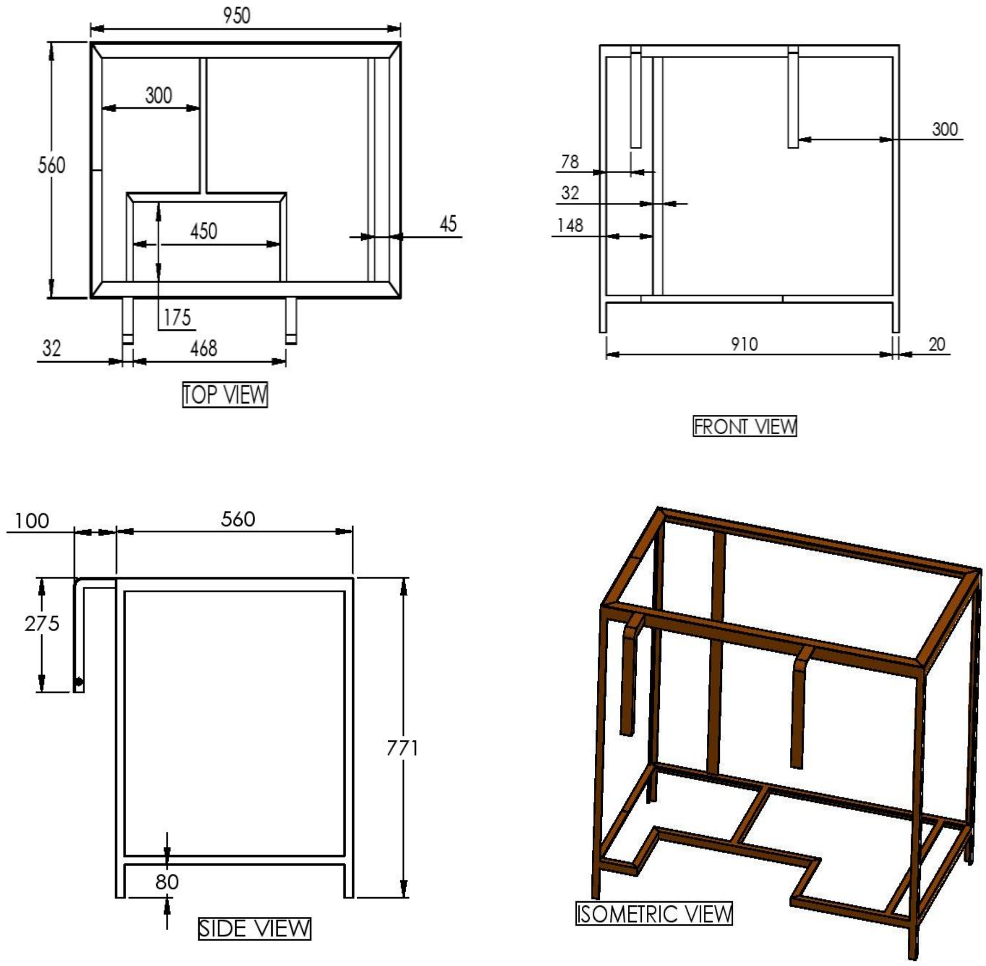
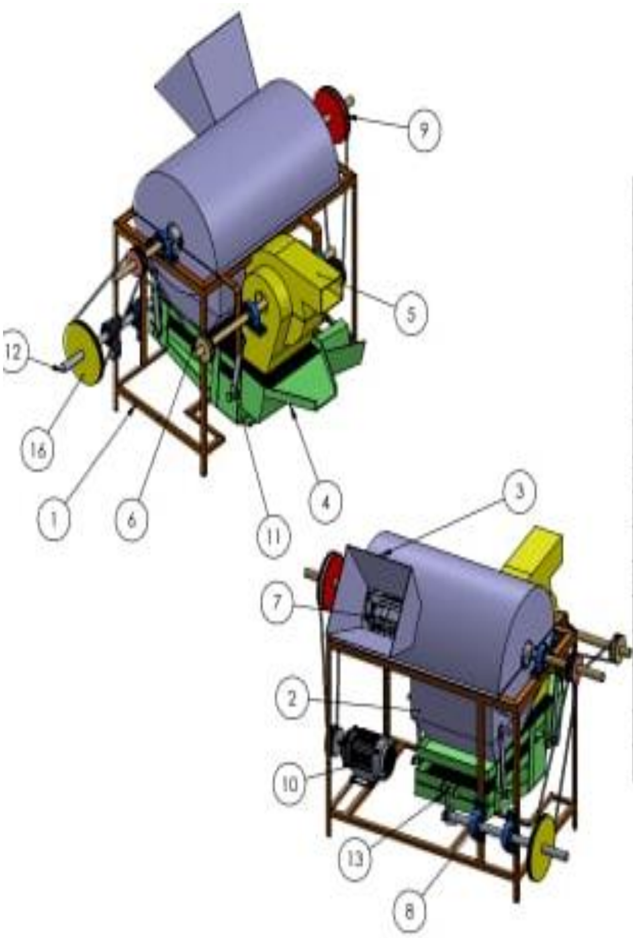



Fig 3.25 Diagram and isometric view of frame

## 3.8 Development of the Machine

The design obtained from the above was made available to the technician of the workshop of the Department of Farm Machinery and Power Engineering, SVCAET&RS, IGKV Raipur. The full view of the developed SOLIDWORKS is given in Fig 3.26.




BILL OF MATERIALS

| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | bottom frame_1 | 1 |
| 2 | bottom cylinder | 1 |
| 3 | hopper | 1 |
| 4 | sieve | 1 |
| 5 | aspirator blower | 1 |
| 6 | pulley | 1 |
| 7 | cylinder | 1 |
| 8 | Pillow Block Bearing | 6 |
| 9 | pulley | 1 |
| 10 | Motor 48V.step | 1 |
| 11 | hanger | 4 |
| 12 | shaft1 | 1 |
| 13 | eccentric unit | 1 |
| 14 | IS 3640 - M14 x 40 x 22-N | 2 |
| 15 | PULLEY Ø 100 | 1 |
| 16 | PULLEY Ø 230 | 1 |

Fig 3.26 Isometric view of developed machine (SOLIDWORKS)

## 3.9 Performance Evaluation of Linseed Thresher

### 3.9.1 Test at no load condition

The thresher was run at no load condition for 10 min at specific speed i.e 712 rpm connected to energy meter with thresher for measuring the power consumption at no load for one hour. It was observed that there was no rising of bearings temperature, slippage of belts, unusual wear or slackness of belt or part during the running condition (IS: 6284-1985, 1986). For testing vibration and sound of the machine sound meter and vibrometer was used.

### 3.9.2 Test at load condition

The machine was run for one hour to observe the performance of the machine i.e., threshing capacity, threshing efficiency, cleaning efficiency losses etc. with 0.5 hp motor.

## 3.10 Terminology

For the purpose of testing of power thresher, the following definitions shall apply (IS: 6284-1985, 1986).

1. Hold on type thresher- A type of thresher where the heads of the cut crops are fed into the threshing drum with lower part of the straw being manually or mechanically held.
2. Broken Grain - Wholly or partially cracked or broken grain.
    a. The percentage of broken grain is calculated by using following equation
3. $B_G = \frac{C}{A} \times 100$ ... (3.46)
4. Where,
    i. $B_G$= Broken grain, %;
    ii. C = Quantity of broken grain from all outlets per unit time; and
    iii. A = Total grain input per unit time
5. Foreign matter – It includes inorganic and organic matter-sand, gravel, dirt, pebbles, stone lumps of earth, clay mud iron chips, chaff, straw, weed seed etc.
6. Clean Grain - Threshed grain free from foreign matter and broken grain.
7. Grain mixture – The mixture of clean, broken, un-threshed grains and foreign matter coming out of the main grain outlet.
8. Concave Clearance - The clearance between beater or cylinder tip and concave.
9. Screen Slope - Inclination of screen with the horizontal plane in degrees.
10. Sieve Clearance - The vertical distance between two successive sieves.
11. Un-threshed grain – Grain collected from un-threshed heads
12. Percentage of blown grain -The clean grain lost along with chaffed straw with respect to total grain input expressed as percentage by mass.

$$Bl_g = \frac{G}{A} \times 100 \qquad \ldots (3.47)$$

Where,

$Bl_g$ = Blown grain, %;

G = quantity of clean grain obtained at straw outlet per unit time; and

A = total grain input per unit time.

13. Percentage of un-threshed grain- The un-threshed grain collected from all outlets with respect to total grain input, expressed as percentage.

$$G_{Un} = \frac{D}{A} \times 100 \qquad \ldots (3.48)$$

Where,

$G_{Un}$ = Un-threshed grain, %

D = Quantity of un-threshed grain obtained from all outlets per unit time; and

A = Total grain input per unit time.

14. Percentage of spilled grain- The clean grain dropped through the sieve and overflow from sieve along with tailing with respect to total grain input, expressed as percentage by mass.

$$G_{sp} = \frac{J}{A} \times 100 \qquad \ldots (3.49)$$

Where,

$G_{sp}$ = Spilled grain, %

J = Quantity of clean grain obtained at sieve overflow and underflow per unit time; and

A = Total grain input per unit time.

15. Total grain input per unit time-

A= B + C + D … (3.50)

Where,

A = Total grain input per unit time;

B = Quantity of (threshed, clean) grain collected from a grain outlets) per unit time;

C= Quantity of broken grain from all outlets per unit time; and

D = Quantity of un-threshed grain from all outlets per unit time.

## 3.11 Prototype Feasibility Testing of Developed Machine

To test the prototype feasibility of developed thresher following 6 independent variable and 6 dependent variables were taken

Table: 3.5 Various study parameters

| S.No. | Independent parameters | Levels | Dependent parameters |
|---|---|---|---|
| 1. | Feed rate, kg/h | F1=200kg/h<br>F2 = 250kg/h<br>F3 = 300kg/h | Threshing capacity, kg/h<br>Stripping efficiency, %<br>Threshing efficiency, %<br>Cleaning efficiency, %<br>Visible and invisible seed damage, % |
| 2. | Moisture content (% db) | M1 = 8<br>M2 = 12<br>M3 =16 | |
| 3. | Speed m/s | S1 = 13.27<br>S2 = 14.5<br>S3 =15.71 | |
| 4. | Concave clearance, mm | C1 = 8<br>C2 =10 | |
| 5. | Number of Pegs, no | Np1 = 4<br>Np2 = 6 | |
| 6. | Number of loops, no | Nl1= 6<br>Nl2 = 8 | |

### 3.11.1 Determination of efficiencies

**a) Threshing capacity or output capacity**

The output capacity was estimated by weighing the total grain (whole and damaged) received per hour at the main grain outlet of the thresher (IS: 6284-1985, 1986).

$$\text{Output capacity}\left(\frac{\text{kg}}{\text{h}}\right) = \frac{\text{Weight of grain threshed (kg)}}{\text{Time taken (h)}} \quad \ldots (3.51)$$

**b) Stripping efficiency**

$$\text{Stripping efficiency}(\%) = \frac{\text{Weight of the stripped seed} \times 100}{\text{Total weight ofcapsule on the stalk}} \quad \ldots (3.52)$$

**c) Threshing efficiency**

Threshing efficiency is the threshed grain received from all outlets with respect to total grain input expressed as percentage by mass the threshing efficiency was calculated by using the formula and expressed in percentage (IS: 6284-1985, 1986).

Threshing efficiency (%) = 100 − percentage of un-threshed grain … (3.53)

**d) Cleaning efficiency**

Cleaning efficiency is clean grain received at main grain outlet(s) with respect to the total grain mixture received at main grain outlet(s) expressed as percentage by mass. The cleaning efficiency was calculated by using the formula (IS: 6284-1985, 1986)

$$CE = \frac{Q_{CG}}{Q_T} \times 100 \quad ...(3.54)$$

Where,

CE= Cleaning efficiency, %

$Q_{CG}$ = Quantity of clean grain obtained from the sample taken at main grain outlets; and

$Q_T$ = Total quantity of the sample taken at main grain outlets.

**e) Seed damage**

- **Visible seed damage**

The damaged seeds were separated by hand and weighted, and then visible seed damage (%) was estimated as a percentage of total seed mass as follows:

$$\text{Visible seed damage}(\%) = \frac{\text{Wd}}{\text{Ws}} \times 100 \quad ...(3.55)$$

Where,

Wd = Mass of damage seeds, (g); and

Ws = Total seed mass (100 g).

- **invisible seed damage**

The germination test was used to estimate, the percentage of the invisible seed damage as follows:

$$\text{Invisible seed damage} = \frac{\text{a}}{\text{b}} \times 100 \quad ...(3.56)$$

Where,

a = Number of un-germinated seeds from the samples taken after threshing operations.

b = Total number of seeds in the sample.

## 3.12 Germination test

Germination tests were conducted in quadruplicate using 100 seeds each in the rolled paper towel method (ISTA, 1999).In a germination environment maintained at 25°C temperature and 96.2% relative humidity (RH) with diffused light during the day. The number of normal seedlings was counted on the tenth day of the germination test, and the average was represented as a percentage.

Fig. 3.27 Germination test of linseed seed

## 3.13 Statistical Analysis

The result of the experiment on physical properties, mechanical properties and performance evaluation of the linseed thresher were analysed statistically considering the dependent and independent parameters.

### 3.13.1 Analysis of results on engineering properties

The statistical analysis of the result of physical properties were conducted using the split plot design by taking variety as main plot and moisture content as sub plot with 4 replication and 4 treatment..

### 3.13.2 Analysis on results of performance evaluation of machine parameters

The statistical analysis of the result of performance evaluation of machine parameters were conducted using the OPSTAT software , a free online agriculture data analysis tool.The independent parameters were moisture content, concave clearance, cylinder speed, feed rate, no of pegs, and no of loops. The dependent parameters were threshing efficiency, stripping efficiency, threshing capacity, cleaning efficiency, visible seed damage and invisible seed damage. The design of experiment was 3 factor randomised block design (RBD) with three replication. After that 2 factor RBD with three replication at constant moisture content and concave clearance was done to find the relation between feed rate and speed on the performance evaluation of machine parameters.

## 3.14 Costs Evaluation of the Machine

Cost of threshing operation was worked out on the basis of the prevailing market price of thresher, labour charges, repair and maintenance. Cost of threshing operation was calculated on the basis of Rs/h. For calculation of cost of machine assistance was drawn from IS: 9164.the procedure for calculation of cost of operation of thresher is given below.

### 3.14.1 Fixed cost of machine

i. **Depreciation:** This cost reflects the reduction in value of a machine with use (wear) and time (obsolescence). It is the loss of value of a machine with the passing of time and calculated by the formula (IS 9164: 1979)

$$D = \frac{C - S}{L \times H} \quad \text{... (3.57)}$$

Where,

D = Depreciation per hour;

C = Initial cost of implement, Rs;

S = Salvage value @ 10 % of C, Rs.;

L = Working life of machine in years; and

H = Number of working hours per year;

ii. **Interest of investment:** Interest was calculated on the average investment of the machine, taking into consideration the value of the machine in first and last year (IS 9164: 1979)

$$I = \frac{C + S}{2} \times \frac{i}{H} \quad \text{... (3.58)}$$

Where,

I = Interest per hour; and

i = 10% per year;

iii. **Shelter/ housing cost:** Housing cost was calculated on the basis of the prevailing rate of the locality and generally taken as 1% of the initial cost of the machine per year. (IS 9164: 1979)

Therefore,

**Total fixed cost** = depreciation +interest + housing

### 3.14.2 Variable cost

i. **Electricity cost:=** electricity consumed (kWh/h)× electricity charges (Rs/kWh)

ii. **Repair maintenance cost:** Cost of repairs and maintenance varies between 5 to 10% of the initial cost of the machine per year. (IS 9164: 1979)

iii. **Labour wages:** Wages of labour was calculated on the basis of actual wages of the worker in present time. (IS 9164: 1979)

Therefore,

**Total variable cost (TVC)** = electricity cost + Repair and maintenance cost + Labour wages

Then,

**Total cost (TC)** = Total Fixed Cost (TFC) + Total Variable Cost (TVC)

**3.14.3 Break-even point.** The break-even point was calculated by following formula (Sharma and Mukesh, 2008).

$$\text{BEP} = \frac{FC_A}{\text{CH} - \text{C}} \qquad \text{... (3.59)}$$

Where,

BEP = Break-even point, h/year;

$FC_A$ = Annual fixed cost, Rs/ year;

C = Operating cost, Rs/ h; and

CH = Custom hiring charge, Rs/h;

### 3.14. 4 Pay back period

The payback period for the developed thresher was calculated to know the time required to get back the investment. The payback period was estimated by using the following formula (Reddy *et al.*, 2003).

$$\text{PBP} = \frac{\text{I}}{\text{E}} \qquad \text{... (3.60)}$$

Where,

PBP = Payback period, Years;

I = Investment, rupees;

E = Annual net return, rupees.

# CHAPTER-IV
# RESULTS& DISCUSSION

This chapter deals with the results on experiments of engineering properties of three varieties of linseed seed under different moisture contents and performance evaluation of the linseed thresher. The results on economics of use of the developed thresher along with the other methods have been discussed.

## 4.1 Physical Properties of Linseed Capsule

The parameters under physical property of linseed capsule includes, no. of capsule per plant, no of seed per capsule , length , width and thickness of capsule and geometric mean diameter(GMD). The results on the physical properties of linseed capsule have been presented in Table 4.1.

Table 4.1 Physical properties of linseed capsule (N = 05)

| Particular | No. of linseed capsule per plant | No of seed per capsule | Length, mm | Width, mm | Thickness, mm | GMD, mm |
|---|---|---|---|---|---|---|
| Mean | 37.50 | 9.59 | 7.79 | 6.57 | 6.49 | 6.91 |
| Range | 36.23-<br>38.34 | 9.23-<br>9.75 | 7.58-<br>7.94 | 5.98-<br>7.00 | 5.91-<br>6.96 | 6.48-<br>7.16 |
| SD (σ) | 0.77 | 0.21 | 0.14 | 0.38 | 0.41 | 0.27 |
| CV | 0.02 | 0.02 | 0.02 | 0.06 | 0.06 | 0.04 |

It was found that 37.5 number of capsules were found per plant. The number of seeds per capsules was observed to be 9.59 with a range of 9.23 to 9.75. Whereas, length, width and thickness of linseed were observed as 7.79, 6.57 and 6.49 mm respectively. The geometric mean diameter was ranges from 6.48 to 7.16 mm. The variations among the samples are not more. Similar type of observation were found by Maurya *et al.*2017.

## 4.2 Physical Properties of Linseed

The result on design related physical properties of three varieties of linseed seed i.e. Neelam, Shekhar and Sheela have been presented in this section. The physical properties are linear dimension**,** 1000 grain weight, bulk density, true density, and porosity,

**4.2.1Effect of varieties and moisture content on linear dimension**

The results on linear dimensions i.*e*. length, breadth and thickness of three varieties of linseed seed *i.e*. Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.

Table 4.2 Effect of varieties and moisture content on linear dimensions for linseed

| | Moisture content | Varieties | | | Mean |
|---|---|---|---|---|---|
| | | Neelam | Shekhar | Sheela | |
| Length, mm | M1(8.00) | 5.27 | 4.53 | 4.58 | 4.79 |
| | M2(10.00) | 5.38 | 4.66 | 4.73 | 4.92 |
| | M3(12.00) | 5.49 | 4.84 | 4.90 | 5.07 |
| | M4 (14.00) | 5.53 | 5.01 | 5.03 | 5.19** |
| | Mean | 5.41** | 4.76 | 4.81 | |
| Breadth, mm | M1(8.00) | 2.77 | 2.50 | 2.37 | 2.55 |
| | M2(10.00) | 2.86 | 2.59 | 2.39 | 2.61 |
| | M3(12.00) | 2.89 | 2.65 | 2.40 | 2.65 |
| | M4 (14.00) | 2.92 | 2.70 | 2.42 | 2.68** |
| | Mean | 2.86** | 2.61 | 2.40 | |
| Thickness, mm | M1(8.00) | 0.90 | 0.93 | 0.84 | 0.89 |
| | M2(10.00) | 0.92 | 0.96 | 0.88 | 0.92 |
| | M3(12.00) | 0.98 | 0.98 | 0.89 | 0.95 |
| | M4 (14.00) | 0.90 | 0.93 | 0.84 | 1.00** |
| | Mean | 0.97 | 0.97 | 0.88 | |

** = Significant at 1% level of significance

Table 4.3ANOVA Table for length

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.01 | 0.00 | | |
| Main plot (V) | 2 | 4.27 | 2.14 | 350.03 | 19.33 |
| Error (v) | 6 | 0.04 | 0.01 | | |
| Sub plot (MC) | 3 | 1.09 | 0.36 | 242.13 | 8.64 |
| VxMC | 6 | 0.07 | 0.01 | 7.43 | 3.84 |
| Error (mc) | 27 | 0.04 | 0.00 | | |
| Total | 47 | 5.52 | | | |

| | | | |
|---|---|---|---|
| CD | | CV,% | |
| Main plot(variety) | 0.10 | CV (a) | 1.56 |
| Sub plot( moisture content) | 0.04 | CV (b) | 0.78 |
| Sub plot at same level of main plot | 0.08 | | |
| Main plot at same or different level of sub plot | 0.12 | Mean | 4.99 |

Table 4.4 ANOVA Table for breadth

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.00 | 0.00 | | |
| Main plot (V) | 2 | 1.72 | 0.86 | 5112.26 | 19.33 |
| Error (v) | 6 | 0.00 | 0.00 | | |
| Sub plot (MC) | 3 | 0.12 | 0.04 | 219.61 | 8.64 |
| VxMC | 6 | 0.03 | 0.00 | 24.35 | 3.84 |
| Error (mc) | 27 | 0.01 | 0.00 | | |
| Total | 47 | 1.88 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.02 | CV (a) | 0.49 |
| Sub plot( moisture content) | 0.02 | CV (b) | 0.52 |
| Sub plot at same level of main plot | 0.03 | | |
| Main plot at same or different level of sub plot | 0.03 | Mean | 2.62 |

Table 4.5 ANOVA Table for Thickness

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.00 | 0.00 | | |
| Main plot (V) | 2 | 0.08 | 0.04 | 168.84 | 19.33 |
| Error (v) | 6 | 0.00 | 0.00 | | |
| Sub plot (MC) | 3 | 0.08 | 0.03 | 171.86 | 8.64 |
| VxMC | 6 | 0.01 | 0.00 | 15.52 | 3.84 |
| Error (mc) | 27 | 0.00 | 0.00 | | |
| Total | 47 | 0.19 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.02 | CV (a) | 1.67 |
| Sub plot( moisture content) | 0.01 | CV (b) | 1.34 |
| Sub plot at same level of main plot | 0.02 | | |
| Main plot at same or different level of sub plot | 0.03 | Mean | 0.94 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.2). The observation were analysed in ANOVA (Table 4.3, Table 4.4 and Table 4.5) It was observed that there is significant difference at 1% level in between the varieties on linear dimension (length, breadth, thickness). It was found highest length (5.41mm), breadth (2.86mm) for Neelam variety whereas highest Thickness (0.97 mm) was found for both Neelam and Shekhar variety. The lowest linear dimensions were observed in case of Sheela variety. It was also observed that moisture content also plays a vital role on linear dimension. It was observed length (5.19mm), breadth (2.68) and thickness (1.00 mm) in case of moisture content of 14% which were significantly highest ($\alpha$=0.01). The observation of an increased in linear dimension and average diameter of linseed with regards to increase in moisture content agree with the findings reported by Bhishe *et al.* 2013and Wang *et al*. 2007.

**4.2.2 Effect of varieties and moisture content on GMD for linseed**

The results on geometric mean diameter of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.

Table 4.6 Effect of varieties and moisture content on GMD for linseed

| Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 2.34 | 2.17 | 2.07 | 2.20 |
| M2(10.00) | 2.39 | 2.24 | 2.13 | 2.26 |
| M3(12.00) | 2.47 | 2.30 | 2.17 | 2.32 |
| M4 (14.00) | 2.56 | 2.39 | 2.21 | 2.39** |
| Mean | 2.44** | 2.27 | 2.15 | |

** = Significant at 1% level of significance

Table 4.7 ANOVA Table for GMD

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.00 | 0.00 | | |
| Main plot (V) | 2 | 0.69 | 0.34 | 818.79 | 19.33 |
| Error (v) | 6 | 0.00 | 0.00 | | |
| Sub plot (MC) | 3 | 0.24 | 0.08 | 740.28 | 8.64 |
| VxMC | 6 | 0.01 | 0.00 | 15.32 | 3.84 |
| Error (mc) | 27 | 0.00 | 0.00 | | |
| Total | 47 | 0.94 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.03 | CV (a) | 0.89 |
| Sub plot (moisture content) | 0.01 | CV (b) | 0.45 |
| Sub plot at same level of main plot | 0.02 | | |
| Main plot at same or different level of sub plot | 0.03 | Mean | 2.29 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.6). The observation were analysed in ANOVA Table 4.7. It was observed that there is significant difference at 1% level in between the varieties on Geometric mean diameter (GMD). It was found highest (2.44mm) for Neelam variety and lowest in case of Sheela variety. It was also observed that moisture content also plays a vital role on GMD. It was observed 2.39 mm in case of moisture content of 14% which was significantly highest ($\alpha$=0.01).

### 4.2.3 Effect of varieties and moisture content on surface area for linseed

The results on surface area of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.

Table 4.8 Effect of varieties and moisture content on surface area for linseed

| Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 17.23 | 14.84 | 13.51 | 15.19 |
| M2(10.00) | 18.00 | 15.75 | 14.34 | 16.03 |
| M3(12.00) | 19.22 | 16.62 | 14.86 | 16.90 |
| M4 (14.00) | 20.51 | 17.88 | 15.40 | 17.93** |
| Mean | 18.74** | 16.27 | 14.53 | |

** = Significant at 1% level of significance

Table 4.9 ANOVA Table for surface area

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.25 | 0.08 | | |
| Main plot (V) | 2 | 143.64 | 71.82 | 631.15 | 19.33 |
| Error (v) | 6 | 0.68 | 0.11 | | |
| Sub plot (MC) | 3 | 49.50 | 16.50 | 770.94 | 8.64 |
| VxMC | 6 | 3.04 | 0.51 | 23.65 | 3.84 |
| Error (mc) | 27 | 0.58 | 0.02 | | |
| Total | 47 | 197.69 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.44 | CV (a) | 2.04 |
| Sub plot (moisture content) | 0.17 | CV (b) | 0.89 |
| Sub plot at same level of main plot | 0.29 | | |
| Main plot at same or different level of sub plot | 0.50 | Mean | 16.51 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.8). The observation were analysed in ANOVA Table 4.9. It was observed that there is significant difference at 1% level in between the varieties on surface area. It was found highest (18.74mm$^2$) for Neelam variety and lowest in case of Sheela variety. It was also observed that moisture content also plays a vital role on surface area. It was observed 17.93 mm$^2$ in case of moisture content of 14% which was significantly highest ($\alpha$=0.01).

**4.2.4 Effect of varieties and moisture content on sphericity for linseed**

The results on sphericity of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.

Table 4.10 Effect of varieties and moisture content on surface area for linseed

| Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 0.45 | 0.48 | 0.45 | 0.46 |
| M2(10.00) | 0.45 | 0.48 | 0.45 | 0.46 |
| M3(12.00) | 0.45 | 0.48 | 0.44 | 0.46 |
| M4 (14.00) | 0.46 | 0.48 | 0.44 | 0.46 |
| Mean | 0.45 | 0.48** | 0.45 | |

Table 4.11 ANOVA Table for sphericity

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.00 | 0.00 | | |
| Main plot (V) | 2 | 0.01 | 0.00 | 183.57 | 19.33 |
| Error (v) | 6 | 0.00 | 0.00 | | |
| Sub plot (MC) | 3 | 0.00 | 0.00 | 1.52 | 8.64 |
| VxMC | 6 | 0.00 | 0.00 | 18.00 | 3.84 |
| Error (mc) | 27 | 0.00 | 0.00 | | |
| Total | 47 | 0.01 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.01 | CV (a) | 1.10 |
| Sub plot (moisture content) | NS | CV (b) | 0.74 |
| Sub plot at same level of main plot | 0.01 | | |
| Main plot at same or different level of sub plot | 0.01 | Mean | 0.46 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.10). The observation were analysed in ANOVA Table 4.11. It was observed that there is significant difference at 1% level in between the varieties on sphericity. It was found highest (48%) for Shekhar variety. It was also observed that there is no significant difference at 1% level in between the moisture content on surface area.

**4.2.5 Effect of varieties and moisture content on volume of linseed**

The results on volume of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.

Table 4.12 Effect of varieties and moisture content on volume of linseed

| Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 6.91 | 5.51 | 4.78 | 5.73 |
| M2(10.00) | 7.37 | 6.04 | 5.21 | 6.21 |
| M3(12.00) | 8.14 | 6.55 | 5.51 | 6.73 |
| M4 (14.00) | 8.86 | 7.31 | 5.83 | 7.34** |
| Mean | 7.82** | 6.35 | 5.33 | |

** = Significant at 1% level of significance

Table 4.13 ANOVA Table for volume

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.04 | 0.01 | | |
| Main plot (V) | 2 | 50.07 | 25.03 | 747.94 | 19.33 |
| Error (v) | 6 | 0.20 | 0.03 | | |
| Sub plot (MC) | 3 | 17.11 | 5.70 | 589.19 | 8.64 |
| VxMC | 6 | 1.23 | 0.20 | 21.10 | 3.84 |
| Error (mc) | 27 | 0.26 | 0.01 | | |
| Total | 47 | 68.90 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.24 | CV (a) | 2.81 |
| Sub plot (moisture content) | 0.11 | CV (b) | 1.51 |
| Sub plot at same level of main plot | 0.19 | | |
| Main plot at same or different level of sub plot | 0.29 | Mean | 6.50 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.12). The observation were analysed in ANOVA Table 4.13. It was observed that there is significant difference at 1% level in between the varieties on volume. It was found highest (7.82mm$^3$) for Neelam variety and lowest in case of Sheela variety. It was also observed that moisture content also plays a vital role on volume. It was observed 7.34 mm$^3$ in case of moisture content of 14% which was significantly highest ($\alpha$=0.01).

**4.2.6 Effect of varieties and moisture content on 1000 grain weight for linseed**

The results on 1000 GW of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.

Table 4.14 Effect of varieties and moisture content on 1000 grain weight for linseed

| Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 8.83 | 8.20 | 6.52 | 7.85 |
| M2(10.00) | 9.19 | 8.30 | 6.93 | 8.14 |
| M3(12.00) | 9.73 | 8.57 | 7.16 | 8.48 |
| M4 (14.00) | 10.59 | 8.71 | 7.59 | 8.96** |
| Mean | 9.58** | 8.45 | 7.05 | |

Table 4.15 ANOVA Table for 1000 GW

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.09 | 0.03 | | |
| Main plot (V) | 2 | 51.52 | 25.76 | 693.83 | 19.33 |
| Error (v) | 6 | 0.22 | 0.04 | | |
| Sub plot (MC) | 3 | 8.24 | 2.75 | 71.47 | 8.64 |
| VxMC | 6 | 1.82 | 0.30 | 7.89 | 3.84 |
| Error (mc) | 27 | 1.04 | 0.04 | | |
| Total | 47 | 62.93 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.25 | CV (a) | 2.31 |
| Sub plot(moisture content) | 0.22 | CV (b) | 2.35 |
| Sub plot at same level of main plot | 0.38 | | |
| Main plot at same or different level of sub plot | 0.41 | Mean | 8.36 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.14). The observation were analysed in ANOVA Table 4.15. It was observed that there is significant difference at 1% level in between the varieties on thousand grain weight. It was found highest (9.58g) for Neelam variety and lowest in case of Sheela variety. It was also observed that moisture content also plays a vital role on weight of 1000 grains. It was observed 8.96g in case of moisture content of 14% which was significantly highest ($\alpha$=0.01). The observation of an increased in 1000 grain weight of linseed with regards to increase in moisture content agree with the findings reported by Coskuner and Karbaba (2007), Bhishe *et al.* 2013and Wang *et al*. 2007.

**4.2.7 Effect of varieties and moisture content on bulk density for linseed**

The results on bulk density of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.

Table 4.16 Effect of varieties and moisture content on bulk density for linseed

| Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 691.14 | 700.35 | 744.68 | 712.06** |
| M2(10.00) | 688.90 | 694.17 | 732.17 | 705.08 |
| M3(12.00) | 676.53 | 686.72 | 721.19 | 694.81 |
| M4 (14.00) | 664.03 | 675.29 | 690.67 | 676.66 |
| Mean | 680.15 | 689.13 | 722.18** | |

** = Significant at 1% level of significance

Table 4.17 ANOVA Table for bulk density

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 136.01 | 45.34 | | |
| Main plot (V) | 2 | 15674.50 | 7837.25 | 3073.71 | 19.25 |
| Error (v) | 6 | 15.30 | 2.55 | | |
| Sub plot (MC) | 3 | 8525.87 | 2841.96 | 1017.61 | 19.41 |
| VxMC | 6 | 1152.38 | 192.06 | 68.77 | 5.91 |
| Error (mc) | 27 | 75.40 | 2.79 | | |
| Total | 47 | 25579.46 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 1.57 | CV (a) | 0.23 |
| Sub plot(moisture content) | 1.49 | CV (b) | 0.24 |
| Sub plot at same level of main plot | 2.57 | | |
| Main plot at same or different level of sub plot | 2.71 | Mean | 697.15 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.16). The observation were analysed in ANOVA Table 4.17. It was observed that there is significant difference at 1% level in between the varieties on bulk density. It was found highest (722.18.kg/m$^3$) for Sheela variety and lowest in case of Neelam variety. It was also observed that moisture content also plays a vital role on bulk density. It was observed 716.06 kg/m$^3$ in case of moisture content of 8 % which was significantly highest ($\alpha$=0.01). Bulk density decreased with increasing moisture content. The observation of an increased in bulk density of linseed with regards to increase in moisture content agree with the findings reported by Coskuner and Karbaba (2007) and Selvi *et al.* (2006).

**4.2.8 Effect of varieties and moisture content on true density for linseed**

The results on true density of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.The interaction between the variety and moisture content was analysed by SPD (Table 4.18). The observation were analysed in ANOVA Table 4.19. It was observed that there is significant difference at 1% level in between the varieties on true density. It was found highest (1115.34 kg/m³) for Neelam variety and lowest in case of Sheela variety. It was also observed that moisture content also plays a vital role on true density. It was observed 1119.85 kg/ m³ in case of moisture content of 14% which was significantly highest ($\alpha$=0.01). The increased value of true density with increase in moisture content were in agreement with the findings of Coskuner and Karbaba (2007), Selvi *et al.* (2006).

Table 4.18 Effect of varieties and moisture content true density for linseed

| Moisture Content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 1097.57 | 1080.07 | 1079.92 | 1085.85 |
| M2(10.00) | 1114.08 | 1090.16 | 1090.72 | 1098.32 |
| M3(12.00) | 1121.15 | 1113.78 | 1098.24 | 1111.06 |
| M4 (14.00) | 1128.56 | 1126.65 | 1104.34 | 1119.85** |
| Mean | 1115.34** | 1102.66 | 1093.31 | |

** = Significant at 1% level of significance

Table 4.19 ANOVA Table for true density

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 25.48 | 8.49 | | |
| Main plot (V) | 2 | 3913.02 | 1956.51 | 221.00 | 19.25 |
| Error (v) | 6 | 53.12 | 8.85 | | |
| Sub plot (MC) | 3 | 7949.67 | 2649.89 | 727.80 | 19.41 |
| VxMC | 6 | 945.86 | 157.64 | 43.30 | 5.91 |
| Error (mc) | 27 | 98.31 | 3.64 | | |
| Total | 47 | 12985.46 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 2.92 | CV (a) | 0.27 |
| Sub plot(moisture content) | 1.70 | CV (b) | 0.17 |
| Sub plot at same level of main plot | 2.94 | | |
| Main plot at same or different level of sub plot | 3.85 | Mean | 1103.77 |

**4.2.9 Effect of varieties and moisture content on porosity for linseed**

The results on porosity of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%. The interaction between the variety and moisture content was analysed by SPD (Table 4.20). The observation were analysed in ANOVA Table 4.21

Table 4.20 Effect of varieties and moisture content porosity for linseed

| Moisture Content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 37.03 | 35.16 | 31.04 | 34.41 |
| M2(10.00) | 38.16 | 36.34 | 32.87 | 35.79 |
| M3(12.00) | 39.66 | 38.34 | 34.33 | 37.44 |
| M4 (14.00) | 41.16 | 40.06 | 37.46 | 39.56** |
| Mean | 39.00** | 37.47 | 33.93 | |

** = Significant at 1% level of significance

Table 4.21 ANOVA Table for porosity

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.59 | 0.20 | | |
| Main plot (V) | 2 | 216.99 | 108.49 | 1991.46 | 19.33 |
| Error (v) | 6 | 0.33 | 0.05 | | |
| Sub plot (MC) | 3 | 177.19 | 59.06 | 1577.38 | 8.64 |
| VxMC | 6 | 6.28 | 1.05 | 27.94 | 3.84 |
| Error (mc) | 27 | 1.01 | 0.04 | | |
| Total | 47 | 402.39 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot( variety) | 0.31 | CV (a) | 0.63 |
| Sub plot(moisture content) | 0.22 | CV (b) | 0.53 |
| Sub plot at same level of main plot | 0.38 | | |
| Main plot at same or different level of sub plot | 0.44 | Mean | 36.8 |

It was observed that there is significant difference at 1% level in between the varieties on porosity. It was found highest (39.00) for Neelam variety and lowest in case of Sheela variety. It was also observed that moisture content also plays a vital role on true density. It was observed 39.56 in case of moisture content of 14% which was significantly highest ($\alpha$=0.01). The observation of an increased in porosity of linseed with regards to increase in moisture content agree with the findings reported by Coskuner and Karbaba (2007), Selvi *et al.* (2006) Bhishe *et al.* 2013and Wang *et al*. 2007.

## 4.3 Mechanical Properties of Linseed

The result on design related mechanical properties of linseed such as Angle of repose, Coefficient of friction, Terminal velocity, Rupture force, were presented on this section.

### 4.3.1 Effect of varieties and moisture content on Angle of repose for linseed

The results on angle of repose of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.The interaction between the variety and moisture content was analysed by SPD (Table 4.22). The observation were analysed in ANOVA Table 4.23.

Table 4.22 Effect of varieties and moisture content on angle of repose for linseed

| Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 20.52 | 20.27 | 20.92 | 20.57 |
| M2(10.00) | 21.31 | 20.73 | 21.72 | 21.25 |
| M3(12.00) | 22.16 | 21.33 | 22.45 | 21.98 |
| M4 (14.00) | 23.19 | 21.81 | 23.11 | 22.70** |
| Mean | 21.80 | 21.04 | 22.05** | |

** = Significant at 1% level of significance

Table 4.23 ANOVA table for angle of repose

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.09 | 0.03 | | |
| Main plot (V) | 2 | 8.90 | 4.45 | 23.25 | 19.25 |
| Error (v) | 6 | 1.15 | 0.19 | | |
| Sub plot (MC) | 3 | 30.41 | 10.14 | 986.59 | 19.41 |
| VxMC | 6 | 1.45 | 0.24 | 23.53 | 5.91 |
| Error (mc) | 27 | 0.28 | 0.01 | | |
| Total | 47 | 42.28 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.43 | CV (a) | 2.02 |
| Sub plot(moisture content) | 0.09 | CV (b) | 0.47 |
| Sub plot at same level of main plot | 0.16 | | |
| Main plot at same or different level of sub plot | 0.45 | Mean | 21.63 |

It was observed that there is significant difference at 1% level in between the varieties on angle of repose. It was found highest (22.05°) for Sheela variety and lowest in case of Shekhar variety. It was also observed that moisture content also plays a vital role on angle of repose. It was observed 22.70° in case of moisture content of 14% which was significantly highest ($\alpha$=0.01)The observation of an increased in bulk density of linseed with regards to increase in moisture content agree with the findings reported by Selvi *et al.* (2006) Bhishe *et al.* 2013.

### 4.3.2 Effect of varieties and moisture content on coefficient of friction for linseed

The results on coefficient of friction of three varieties of linseed seed *i.e*. Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%. The coefficient of friction was measured on three surfaces namely GI sheet, MS sheet and plywood.

Table 4.24 Effect of varieties and moisture content on coefficient of friction for linseed

| | Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|---|
| | | Neelam | Shekhar | Sheela | |
| Coefficient of friction – GI sheet | M1(8.00) | 0.34 | 0.35 | 0.35 | 0.35 |
| | M2(10.00) | 0.36 | 0.37 | 0.39 | 0.37 |
| | M3(12.00) | 0.38 | 0.40 | 0.43 | 0.40 |
| | M4 (14.00) | 0.41 | 0.42 | 0.48 | 0.43** |
| | Mean | 0.37 | 0.38 | 0.41** | |
| Coefficient of friction – MS sheet | M1(8.00) | 0.39 | 0.39 | 0.42 | 0.40 |
| | M2(10.00) | 0.42 | 0.42 | 0.46 | 0.43 |
| | M3(12.00) | 0.45 | 0.45 | 0.50 | 0.47 |
| | M4 (14.00) | 0.47 | 0.48 | 0.53 | 0.49** |
| | Mean | 0.43 | 0.43 | 0.48** | |
| Coefficient of friction – Plywood | M1(8.00) | 0.44 | 0.39 | 0.47 | 0.43 |
| | M2(10.00) | 0.47 | 0.42 | 0.50 | 0.47 |
| | M3(12.00) | 0.50 | 0.46 | 0.54 | 0.50 |
| | M4 (14.00) | 0.53 | 0.50 | 0.56 | 0.53** |
| | Mean | 0.49 | 0.44 | 0.52** | |

** = Significant at 1% level of significance

Table 4.25ANOVA Table for static coefficient of friction-GI sheet

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.00 | 0.00 | | |
| Main plot (V) | 2 | 0.01 | 0.01 | 172.18 | 19.33 |
| Error (v) | 6 | 0.00 | 0.00 | | |
| Sub plot (MC) | 3 | 0.05 | 0.02 | 774.53 | 8.64 |
| VxMC | 6 | 0.00 | 0.00 | 34.21 | 3.84 |
| Error (mc) | 27 | 0.00 | 0.00 | | |
| Total | 47 | 0.07 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.01 | CV (a) | 1.64 |
| Sub plot(moisture content) | 0.01 | CV (b) | 1.22 |
| Sub plot at same level of main plot | 0.01 | | |
| Main plot at same or different level of sub plot | 0.01 | Mean | 0.39 |

Table 4.26 ANOVA Table for static coefficient of friction-MS sheet

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.00 | 0.00 | | |
| Main plot (V) | 2 | 0.07 | 0.03 | 655.08 | 19.33 |
| Error (v) | 6 | 0.00 | 0.00 | | |
| Sub plot (MC) | 3 | 0.06 | 0.02 | 625.04 | 8.64 |
| VxMC | 6 | 0.00 | 0.00 | 10.05 | 3.84 |
| Error (mc) | 27 | 0.00 | 0.00 | | |
| Total | 47 | 0.13 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot (variety) | 0.01 | CV (a) | 1.56 |
| Sub plot (moisture content) | 0.01 | CV (b) | 1.19 |
| Sub plot at same level of main plot | 0.01 | | |
| Main plot at same or different level of sub plot | 0.01 | Mean | 0.46 |

Table 4.27ANOVA Table for static coefficient of friction- plywood

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.00 | 0.00 | | |
| Main plot (V) | 2 | 0.05 | 0.02 | 972.34 | 19.33 |
| Error (v) | 6 | 0.00 | 0.00 | | |
| Sub plot (MC) | 3 | 0.06 | 0.02 | 700.32 | 8.64 |
| VxMC | 6 | 0.00 | 0.00 | 5.58 | 3.84 |
| Error (mc) | 27 | 0.00 | 0.00 | | |
| Total | 47 | 0.11 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.01 | CV (a) | 1.02 |
| Sub plot(moisture content) | 0.01 | CV (b) | 1.14 |
| Sub plot at same level of main plot | 0.01 | | |
| Main plot at same or different level of sub plot | 0.01 | Mean | 0.48 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.24). The observation were analysed in ANOVA (Table 4.25, Table 4.26 and Table 4.27.) It was observed that there is significant difference at 1% level in between the varieties on coefficient of friction (GI-sheet, MS-sheet and plywood). It was found highest coefficient of friction 0.41, 0.48, 0.52for Sheela variety and lowest in case of Neelam variety in GI sheet, MS sheet and plywood surface respectively. The coefficient of friction for plywood surface was highest as compare to other surfaces. These observation are in agreement with other researchers Singh *et al.* 2013, Bhise *et al.* (2013) and Selvi *et al.* (2006). It was also observed that moisture content also plays a vital role on coefficient of friction. It was observed 0.43, 0.49 and 0.53 in GI sheet, MS sheet and plywood surface respectively in case of moisture content of 14% which were significantly highest ($\alpha$=0.01).

### 4.3.3 Effect of varieties and moisture content on terminal velocity for linseed

The results on bulk density of three varieties of linseed seed *i.e.* Neelam, Shekhar and Sheela were found out within the moisture range of 8% to 14%.

Table 4.28 Effect of varieties and moisture content on terminal velocity for linseed

| Moisture content (%) | Varieties | | | Mean |
|---|---|---|---|---|
| | Neelam | Shekhar | Sheela | |
| M1(8.00) | 2.44 | 2.43 | 2.24 | 2.37 |
| M2(10.00) | 2.60 | 2.50 | 2.38 | 2.49 |
| M3(12.00) | 2.91 | 2.61 | 2.57 | 2.70 |
| M4 (14.00) | 3.14 | 3.01 | 2.78 | 2.98** |
| Mean | 2.77** | 2.64 | 2.49 | |

** = Significant at 1% level of significance

Table 4.29 ANOVA Table for terminal velocity

| S.V | d.f. | SS | MSS | Computed F value | Tabular F value at 1% |
|---|---|---|---|---|---|
| Replication | 3 | 0.00 | 0.00 | | |
| Main plot (V) | 2 | 0.64 | 0.32 | 156.66 | 19.33 |
| Error (v) | 6 | 0.01 | 0.00 | | |
| Sub plot (MC) | 3 | 2.52 | 0.84 | 712.57 | 8.64 |
| VxMC | 6 | 0.12 | 0.02 | 16.89 | 3.84 |
| Error (mc) | 27 | 0.03 | 0.00 | | |
| Total | 47 | 3.33 | | | |

| CD | | CV,% | |
|---|---|---|---|
| Main plot(variety) | 0.06 | CV (a) | 1.71 |
| Sub plot(moisture content) | 0.04 | CV (b) | 1.30 |
| Sub plot at same level of main plot | 0.07 | | |
| Main plot at same or different level of sub plot | 0.08 | Mean | 2.63 |

The interaction between the variety and moisture content was analysed by SPD (Table 4.28). The observation were analysed in ANOVA Table 4.29. It was observed that there is significant difference at 1% level in between the varieties on terminal velocity. It was found highest (2.77 m/s) for Neelam variety and lowest in case of Sheela variety. It was also observed that moisture content also plays a vital role on terminal velocity. It was observed 2.98 m/s in case of moisture content of

14% which was significantly highest (α=0.01). Similar result were found by many researchers Coskuner and Karbaba (2007) Arafa *et al*. (2009) Prasad and Sharma (2013).

### 4.3.4 Rupture force

A time-domain image obtained by the semi-automatic texture analyzer and its supporting software. The impact force of the experimental linseed seed, linseed capsule and linseed pedicle for a single impact can be calculated indirectly. It can be seen from the figure that the linseed seed absorbs the most energy.

Table 4.30 Rupture force of linseed seed, linseed capsule and linseed pedicle at 16% moisture content.

| Sample | Linseed seed | Linseed capsule | Linseed stalk tip |
|---|---|---|---|
| | Force (g) | Force (g) | Force(g) |
| 1 | 5448.44 | 454.19 | 744.71 |
| 2 | 4674.05 | 829.43 | 756.71 |
| 3 | 4237.08 | 554.88 | 686.57 |
| 4 | 4613.68 | 578.54 | 1029.11 |
| 5 | 4153.57 | 582.21 | 823.56 |
| Mean $\bar{x}$ | 4625.37 | 599.85 | 808.13 |
| S.D. | 513.15 | 138.48 | 132.77 |
| C.V. | 0.11 | 0.23 | 0.16 |

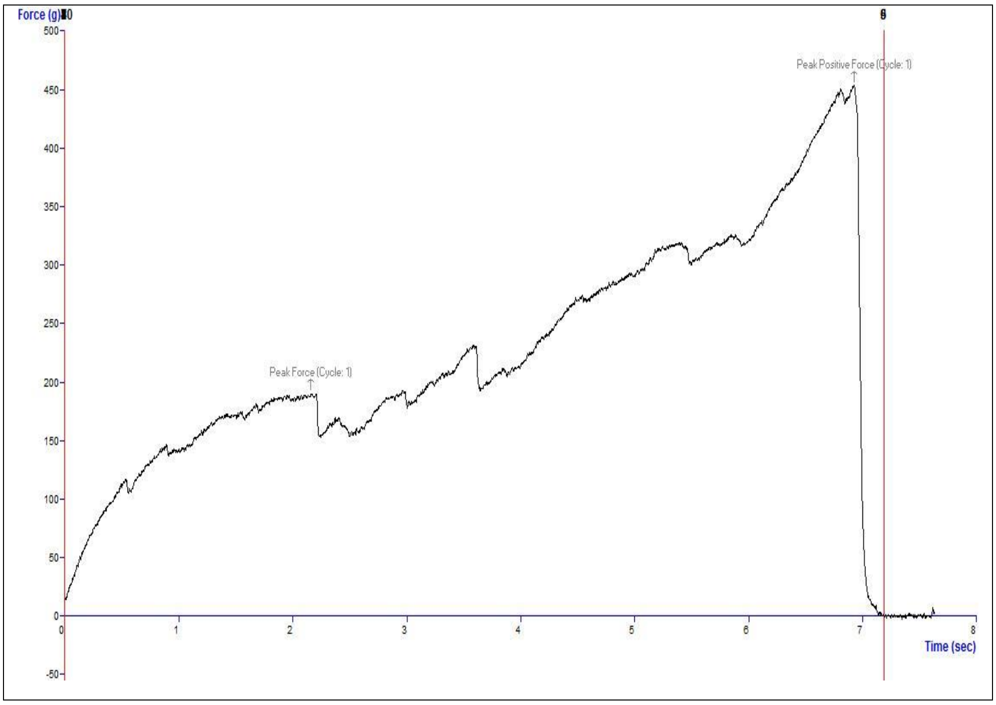



Fig. 4.1 Force vs time graph of linseed capsule

The equivalent stress-strain curves of such materials under impact loading is shown in Fig 4.1. The mean maximum force required to deform the seed, capsule and linseed pedicle were 4625g (46N), 599.85g and 808.13g respectively at moisture content of 16 % (d.b.). So that we required force for threshing linseed more than 599.85 g and less than 4625 g. similar type of observation reported by Singh *et al.* 2012, Bhatt and Prasad 2018.

## 4.4 Development of Linseed Thresher

A SOLIDWORKS drawing was prepared after the design as described in Chapter III. The development of the machine was carried out in the workshop of Farm Machinery and Power Engineering, SVCAET and RS, IGKV Raipur.

### 4.4.1 Fabrication of linseed thresher

A hold on type power operated linseed thresher was developed at Farm Machinery and Power Engineering workshop of SVCAET and RS, FAE, IGKV Raipur, consisting of a hopper, threshing cylinder, concave, oscillating sieve assembly, frame, and aspirator. The different parts of the machine were fabricated as per the theoretical design and functional requirements discussed in chapter III. For fabrication of different components of linseed thresher, the BIS test code IS 11691:1986 was followed for selecting materials as given below in Table 4.31.

Table 4.31 Selection of material for development of the linseed thresher

| Component | Particular | Material and applicable Standard |
|---|---|---|
| Frame | It is made of mild steel angle iron (35× 35 × 3) | Mild steel IS:226-1969 |
| Shaft | Diameter of shaft is 25.4mm and length 1150mm | Mild steel IS:226-1969 |
| Concave | 1.6mm thick MS sheet was turned into semi-circular shape | Mild steel sheet IS:226-1969 |
| Concave bars | 6mm square rod of 400mm length are used for making perforated concave | Mild steel |
| Threshing cylinder cover | 1.6mm thick MS sheet was turned into semi-circular shape to cover the threshing cylinder, louvers of 25×3 MS flat were provided under threshing drum cover to guide the crop | Mild steel sheet |

| | | |
|---|---|---|
| Threshing cylinder | Length700 mm<br>Diameter 390 mm | Mild steel<br>IS:1970-1961 |
| Spike | cylindrical spike of 84 mm length was used | Mild steel |
| Blower | 4 blade, Aspirator type | Mild steel<br>IS:1970-1961 |
| Sieve | 2 perforated sieve were used, size of hole of upper sieve- 4 mm, bottom sieve-1mm, sieve was Oscillated by eccentric shaft | Mild steel sheet IS:1970-1961 |
| Pulley | 4 pulley of different diameter were used | Cast iron<br>IS:210-1978 |
| Belt | V belt of size 65A, 64A and 50A was selected | Leather |
| Feeding unit | Hold on type feeding hopper was selected | Mild steel<br>IS:1970-1961 |
| Bearings | 2 ball bearing (P205) bore dia -25mm for main shaft<br>2 ball bearings for shaker shaft and 2 ball bearing for blower shaft. | Mild steel<br>IS:1970-1961 |
| Nut bolt | TVS nut bolts were selected according to use | Mild steel |

### 4.4.2 Hopper

The hopper was provided at left hand side of machine for feeding the crop material into the threshing cylinder. Hold on type feeding method is applied in which bunch of linseed crop were fed into the threshing drum with lower part of the straw being manually held. The hopper is made of mild steel sheet material having 1.6 mm thickness. Height and shape of hopper was designed on the basis of ergonomic consideration. Fabrication process of hopper was shown in Fig 4.2.

The top cover was made up of 16 gauge MS sheet material with louvers on top cover shown in Fig 4.3 and Fig 4.4

### 4.4.3 Threshing unit

Threshing unit consists of rotating threshing cylinder, top cover and perforated stationary concave

Fig.4.2: Fabrication of hopper

Fig.4.3 Fabrication of top cover

Fig 4.4 Louvers on top cover

#### 4.4.3.1 Threshing cylinder

Threshing cylinder or threshing drum of 390mm diameter and 700 mm length was made of two different parts. The first part was wire loop type threshing cylinder and the second part was combination of canvas strip and spike tooth fitted alternatively on the periphery of the threshing cylinder was used.4 equally spaced MS flat of 32 mm width and 5 mm thick 700 mm length were bolted to two end rings and one ring was placed in such a way that length of wire loop side and spike side were 300mm and 400mm respectively and form cylinder. Fig 4.5 and Fig 4.6 depicted the fabrication of cross bar over threshing cylinder to fix the wire loop system. The rings of diameter 200 mm were fabricated with MS flat of 32×5 size. Two MS flat piece of size 25×3 were welded diagonally across to the ring in order to fix the shaft at centre. An MS bush of 40mm outer diameter was fixed to both end rings. The shaft was passed through buses and fixed to the cylinder by tightening the bolts provided.

In the first part *i.e.* Wire loop type design having four MS flat were placed on the cylinder alternatively and equally distanced; the striping loop were made of GI wires of 3mm diameter. The wires were curved into loop shape and fixed to the MS flat in such a way that distance between two adjacent loop and height of loop were 15mm and 35 mm respectively. Wire loop design was selected for the striping of linseed capsule from stalk. The second part of the threshing cylinder was combination of canvas belt and spike tooth. The canvas belt of 100 mm width was fitted with the help of two MS Angle of size 25×25×3 mm, (Fig 4.7) and 5 cylindrical spike of height 84 mm were bolted on each row of MS bar in such a way that distance between two spike was 50 mm. provision were made to adjust the concave clearance either by nut bolt system or by changing the cylinder shaft on the frame. The photograph of whole threshing cylinder is given in Fig 4.5(b) The threshing cylinder was supported by the shaft fixed to the main frame with help of two ball bearings at both ends. One end of the shaft is fitted with V- pulley to take power from the electric motor with the help of V- belt


Fig. 4.5: Fabrication of threashing cylinder

Fig.4.6: Drilling of MS plate for fabrication of crossbar

Fig.4.7: Cutting of MS angle

**4.4.3.2 Concave**

The concave of length 700mm was fitted below the threshing cylinder. The semi-circular perforated concave was made of MS sheet of thickness 1.6 mm and 6mm square rods (Fig 4.8). The square rods were welded in two semi-circular MS flat together in such manner that the gap between two adjacent rods was 3.5 mm (Fig 4.9 and Fig 4.10).

Fig 4.8 Fabrication of concave

Fig 4.9 Cutting of MS rod

Fig 4.10 Fabricated concave

### 4.4.4 Frame

Frame was made by using 35×35×3 MS Angle iron having overall dimension (L×W×H) of 950×580×760 mm. All parts of thresher were supported by frame. Frame was designed according to the support requirement of threshing component. MS angle were welded together and formed rectangular shape, and bottom part of frame was made according to space requirement for sieve and electric motor. Concave, cylinder, blower, top cover and sieve assembly were attached by nuts and bolts on the frame. (Fig 4.11 and Fig 4.12).



Fig 4.11 Fabricated bottom frame

Fig 4.12 Fabrication of frame(a and b)

### 4.4.5 Aspirator

An aspirator consists of four blades mounted on the shaft was used for separating the husk from the linseed with the help of blown air. The design of the aspirator was done according to the terminal velocity of husk and linseed seeds. ( Fig 4.13)

Fig. 4.13 Fabrication of blower

### 4.4.6 Power unit

The linseed thresher was designed to be operated by 0.5hp electric motor. Electric motor (Model no.- GF6778)was used for driving the threshing unit and aspirator with the help of V- belts and pulley.


Fig.4.14 :Electric motor

### 4.4.7 Sieve

The thresher was provided with two reciprocating sieve which were fabricated with the help of 1.6 mm thick MS sheet. The upper sieve was kept horizontal and 4 mm hole diameter sieve was used in its construction. The lower sieve was kept40x700 mm in size with 1x1 mm wire mesh type. The aim of lower sieve was to remove dust and small weed seeds through clean grain and also to delivered grain to the outlet. The sieve assembly was kept as more at 310 rpm of cylinder speed through eccentric (Fig 4.16). The sides of sieve were covered with 1 mm M.S. sheet to avoided spilling of grain material. The whole assembly was hanged on four arms for its moments with four bar linkage mechanism for proper cleaning of grain and chaff. The minor adjustments in the slope of complete assembly were possible with the help of tightening or loosening of the nuts of the hangars.

Fig.4.15: Cutting of MS sheet

Fig.4.16: Eccentric assembly for sieve

Fig.4.17: Fabricated sieve

### 4.4.8 Assembly of linseed thresher

Assembled solid work drawing is shown in Fig 4.18 and assembled view of whole developed linseed thresher is given in Fig 4.19. the detailed specification of developed linseed threaher is given in Table 4.32.

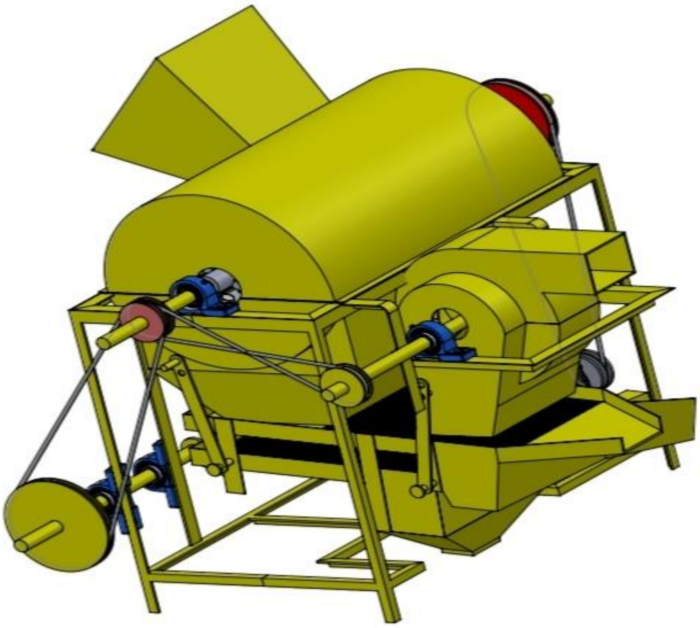


Fig 4.18 Isometric view of developed linseed thresher in Solidworks

Fig 4.19 Devloped linseed thresher

Table: 4.32 Specifications of the developed linseed thresher

| Particulars | Detail specifications |
|---|---|
| Type: | Hold on type |
| Power unit | 0.5 hp single phase electric motor |
| Rated rpm | 1425 |
| Rated voltage | 220/230 V |
| Ampere | 4.5 A |
| Type of drive | v-belt and pulley |
| Main crop | linseed |
| Overall dimensions | |
| Length(mm) | 1000 |
| Width(mm) | 1200 |
| Height(mm) | 1220 |
| weight(kg) | 130 |
| Main components | |
| 1. Main frame | |
| Length (mm) | 950 |
| Width(mm) | 580 |
| Height(mm) | 760 |
| Material | MS Angle (35× 35× 3) |
| 2. Feeding hopper | |
| Height and location of feeding system | 950 mm from ground level and Placed at LHS of thresher |
| Length(mm) | 320 |
| Width(mm) | 300 |
| depth(mm) | 310 |
| Material | 16 gauge MS sheet |
| 3. Main shaft | |
| Diameter(mm) | 25 |
| Length(mm) | 1150 |

| Particulars | Detail specifications |
|---|---|
| Material | MS |
| 4. Main drive | V-belt and pulley |
| Size of pulley: | Drive 4”diameter and driven 8” |
| Size of belt: | V belt 64A |
| Threshing cylinder | |
| Constructional feature | 3 no ring of dia. 200 mm MS flat |
| Total length of threshing cylinder(mm) | 700 |
| Ring diameter(mm) | 200 |
| Spike to spike distance(mm) | 390 |
| Spike length(mm) | 84 |
| Length over spike is provided(mm) | 400 |
| Loop to loop distance(mm) | 290 |
| Loop height(mm) | 40 |
| Length over loop is provided (mm) | 300 |
| Materials | Ring and bars (32×5 MS Flat),wire loop (spoke), spike (MS), canvas belt |
| 6. Concave | |
| Concave type | Semi-circular type |
| Concave peripheral width (mm) | 660 |
| Length(mm) | 760 |
| Concave sieve | 6 mm square rod, gape 3.5 mm, length of rod 400 mm, no of rod 68 |
| Concave clearance(mm) | 10 |
| Material | 16-gauge MS sheet |
| 7. Threshing cylinder cover | |
| Material | 1.6 mm thick MS sheet |
| Length(mm) | 760 |
| Peripheral width(mm) | 510 |

| Particulars | Detail specifications |
|---|---|
| lovers | 7 no, forward spring type, material 25×3 MS Flat |
| 8. Oscillating sieve | |
| Shaker type: | Eccentric shaft |
| Diameter(mm) | 19 |
| Length(mm) | 350 |
| Bearings(no. and type) | 2 no, ball bearing |
| Drive | v-belt and pulley |
| Pulley diameter(mm) | 230 |
| Size of v-belt | 65A |
| Upper sieve | |
| Length(mm) | 915 |
| Width(mm) | 360 |
| Material | Punctured MS Sheet |
| Size of hole (mm) | 4 |
| Lower sieve | |
| Length(mm) | 705 |
| Width(mm) | 360 |
| Material | Punctured MS Sheet |
| Size of hole (mm) | 1 |
| Main seed outlet | |
| Location | LHS of sieve |
| Height from ground level(mm) | 170 |
| 9. Aspirator blower | One, centrifugal- aspirator type |
| Blower diameter (mm) | 274 |
| No. of blade | 4 |
| Size of blade(mm) | 140×105 , 2 mm thick MS plate |
| Outlet opening size (mm) | 134×104 |

## 4.5 Performance Evaluation of Linseed Thresher

The performance of developed linseed thresher was tested at selected testing parameters and BIS test code and data were analyzed statistically as mentioned in chapter III.

### 4.5.1 Vibration and sound level testing of linseed thresher

Vibration and sound level of the developed thresher was tested at no load condition with the help of vibration meter and sound meter mobile app for 1 minute. Vibration and sound level was tested at 3 measuring point and mean value was recorded. The mean value of vibration was 4.9 which shows the comment-strong: heavy furniture moved, and mean value of sound was found 74.9 dB which shows the comment – busy traffic. The observed results were shown in Fig 4.20 and Fig 4.21 respectively.

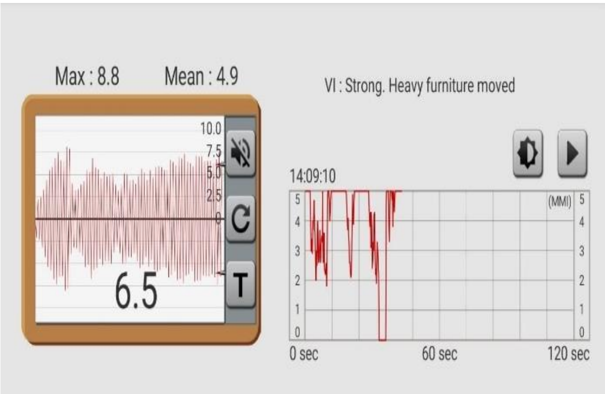



Fig 4.20 Vibration test of thresher at no load condition by mobile app (vibration meter)


Fig 4.21 Sound testing of thresher at no load condition by mobile app (sound meter)

### 4.5.2 Effect of no of pegs on threshing efficiency

The effect of no. of pegs on threshing efficiency was tested for 4 and 6 no. of pegs, the result was depicted in Table 4.33.

The maximum threshing efficiency 99.078 % was found at 6 no of pegs that was significantly highest ($\alpha = 0.05$) but in case of 4 no of pegs threshing efficiency was low. It may be due to impact force developed by 4 no of pegs were not sufficient for threshing linseed.

Table 4.33 Effect of no of pegs on threshing efficiency

| No of pegs, no | Threshing efficiency | |
|---|---|---|
| | Mean | S.E. |
| 4 | 95.656 | 0.165 |
| 6 | 99.078 | 0.077 |
| C.D. | 0.426 | |
| SE(m) | 0.129 | |
| SE(d) | 0.182 | |
| C.V. | 0.296 | |

### 4.5.3 Effect of no. of pegs on seed damage

The effect of no. of pegs on seed damage was tested for 4 and 6 no. of pegs, the result was depicted in Table 4.34.The maximum seed damage 1.95% was observed at 6 no of pegs that was significantly highest ($\alpha = 0.05$) but in acceptable range.

Table 4.34 Effect of no of peg on threshing efficiency

| No of pegs, no | Seed damage | |
|---|---|---|
| | Mean | S.E. |
| 4 | 1.51 | 0.06 |
| 6 | 1.95 | 0.05 |
| C.D. | 0.19 | |
| SE(m) | 0.06 | |
| SE(d) | 0.08 | |
| C.V. | 7.43 | |

### 4.5.4 Effect of no of loop on stripping efficiency

The effect of no. of loops on stripping efficiency was tested for 4 and 8 no. of loops, the result was depicted in Table 4.35. The maximum stripping efficiency 99.004 % was found at 8 no of loops that was significantly highest ($\alpha = 0.05$) but in case of 4 no of loops stripping efficiency was low. It may be due to 4 no of loops were not sufficient for stripping linseed capsule from plant.

Table 4.35 Effect of no of loops on stripping efficiency

| No of loop, no | Stripping efficiency | |
|---|---|---|
| | Mean | S.E. |
| 4 | 95.804 | 0.283 |
| 8 | 99.004 | 0.055 |
| C.D. | 0.676 | |
| SE(m) | 0.204 | |
| SE(d) | 0.288 | |
| C.V. | 0.468 | |

According to result obtained from Table 4.33, 4.34 and 4.35 the best results were finalised *i.e*. 6 no of pegs and 8 no of loops, for linseed thresher. The effect of other independent parameter on dependent parameters were studied at finalized no of pegs and n of loops.

### 4.5.5 Threshing efficiency

The effect of moisture content, concave clearance and cylinder speed were carried out as explained in Chapter-III. The results obtained were measured and depicted in the Table 4.36, Table 4.37, Table 4.38 and Table 4.39.

The interaction effect of moisture content and concave clearance at different cylinder speed, on threshing efficiency was given in Table 4.36. It was observed that there is significant effect of all three on threshing efficiency ($\alpha$=0.05). It was also observed that threshing efficiency was obtained as significantly highest (99.31%) at 8% moisture content, 10 mm concave clearance and 14.5m/s cylinder speed.Table 4.37 depicts the effect of moisture content and concave clearance on threshing efficiency. It was found that there is no significant effect of both these parameters on threshing efficiency. It may be due to small size of the seed and it have no effects on the threshing efficiency. Threshing efficiency was significantly affected by moisture content and speed (Table 4.38). It was observed highest at 8% moisture content and at a speed of 14.5m/s. It may be due to lower moisture content make the capsule ductile and easily rupture from it. Similar types of results were also obtained by many researchers in threshing of different crop including linseed. (Badawy 2002, Afify *et al.* 2007 and Salari *et al.* 2013).

Table 4.36 Effect of moisture content and concave clearance at different cylinder speed, on threshing efficiency

| | Threshing efficiency , % | | | | | |
|---|---|---|---|---|---|---|
| Moisture content (%) | MC (8%) | | MC (12%) | | MC (16%) | |
| Concave clearance, mm | C(8mm) | C(10mm) | C(8mm) | C(10mm) | C(8mm) | C(10mm) |
| Cylinder speed, m/s | | | | | | |
| S(13.27) | 98.15 | 98.27 | 97.95 | 98.02 | 97.73 | 97.81 |
| S(14.50) | 99.21 | 99.31 | 99.08 | 99.18 | 98.89 | 98.94 |
| S(15.71) | 98.35 | 98.44 | 98.03 | 98.17 | 97.83 | 97.85 |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Concave Clearance X Speed | 0.052 | 0.026 | 0.018 |

Where, MC = Moisture content, C = Concave clearance, S= Cylinder peripheral speed

Table 4.37 Effect of moisture content & concave clearance on threshing efficiency

| | Threshing efficiency , % | | |
|---|---|---|---|
| Concave clearance, mm | C(8mm) | C(10mm) | Mean MC |
| Moisture content (%) | | | |
| MC (8%) | 98.569 | 98.674 | 98.621 |
| MC (12%) | 98.353 | 98.458 | 98.406 |
| MC (16%) | 98.148 | 98.199 | 98.173 |
| Mean C | 98.357 | 98.444 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Concave Clearance | NS | 0.015 | 0.011 |

Table 4.38 Effect of moisture content and different cylinder speed, on threshing efficiency

| | Threshing efficiency , % | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean MC |
| Moisture Content, % | | | | |
| MC (8%) | 98.21 | 99.26* | 98.40 | 98.62 |
| MC (12%) | 97.98 | 99.13 | 98.10 | 98.41 |
| MC (16%) | 97.77 | 98.91 | 97.84 | 98.17 |
| Mean S | 97.99 | 99.10 | 98.11 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Speed | 0.037 | 0.018 | 0.013 |

Table 4.39 depicts the effect of cylinder speed and concave clearance on threshing efficiency. It was found that there is no significant effect of both these parameters on threshing efficiency. It may be due to small size of the seed and it have no effects on the threshing efficiency. Similar types of results were also obtained by many researchers (El- Fawal *et al.*2012

Table 4.39 Effect concave clearance at different cylinder speed, on threshing efficiency

| | Threshing efficiency , % | | | |
|---|---|---|---|---|
| Speed m/s | S(13.27) | S(14.50) | S(15.71) | Mean C |
| Concave clearance, mm | | | | |
| C(8 mm) | 97.941 | 99.06 | 98.07 | 98.357 |
| C(10mm) | 98.035 | 99.141 | 98.155 | 98.444 |
| Mean S | 97.988 | 99.1 | 98.112 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Concave clearance X Speed | NS | 0.015 | 0.011 |

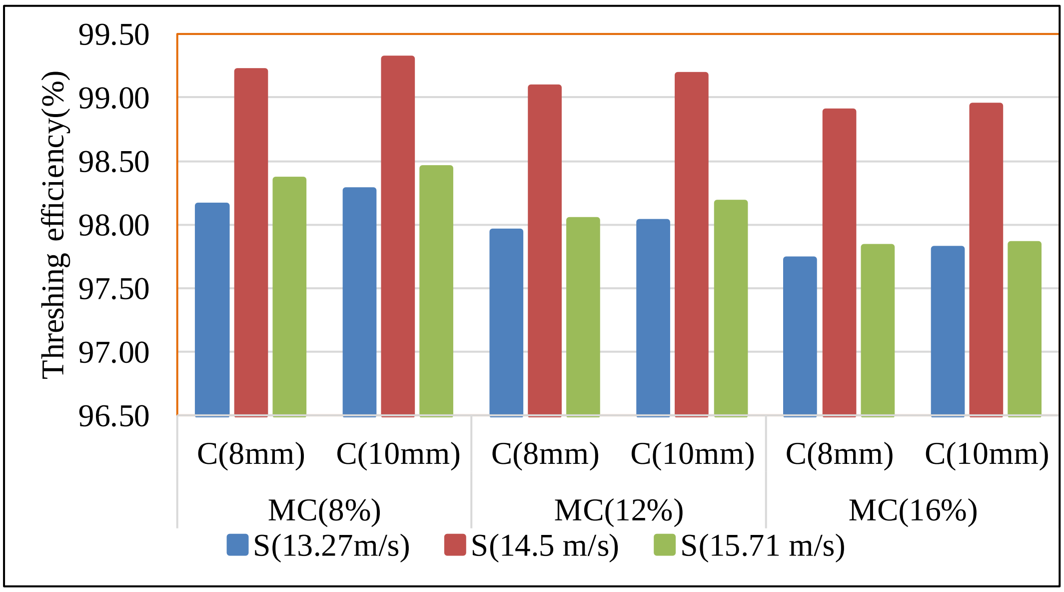



Fig. 4.22 Effect of moisture content and concave clearance at different speed on threshing efficiency

### 4.5.6 Effect of feed rate and speed on threshing efficiency

Table 4.40 depicts the effect of feed rate and speed at fixed moisture content (8%) and concave clearance (10mm) on threshing efficiency. It was found that there is no significant effect of both these parameters on threshing efficiency.

Table 4.40 Effect of feed rate and speed on stripping efficiency

| Threshing efficiency , % | | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean F |
| Feed rate, kg/h | | | | |
| F(200) | 96.49 | 98.28 | 95.71 | 96.83 |
| F(250) | 97.40 | 99.26 | 96.50 | 97.72 |
| F(300) | 95.03 | 97.09 | 94.17 | 95.43 |
| Mean S | 96.31 | 98.21 | 95.46 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Feed rate X Speed | NS | 0.18 | 0.127 |

Where, S= Cylinder peripheral speed, F= Feed rate

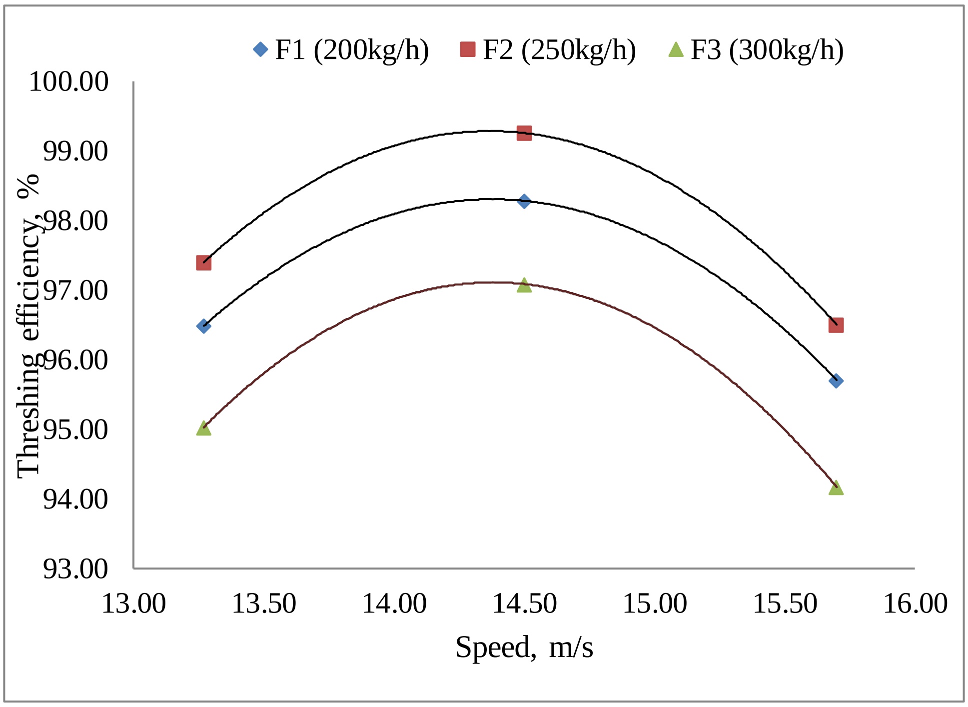



Fig.4.23 Effect of feed rate and speed on threshing efficiency

Similar types of results were also obtained by many researchers for different crop (Abougela *et al.* 2007, Afify *et al.* 2007, Nave *et al.* (1980) Hadad 2000, Vejasit and Salokhe 2004).

### 4.5.7 Stripping efficiency

The effect of moisture content, concave clearance and cylinder speed were carried out as explained in Chapter-III. The results obtained were measured and depicted in the Table 4.41Table 4.42, Table4.43 and Table 4.44.

The interaction effect of moisture content and concave clearance at different cylinder speed, on stripping efficiency was given in Table 4.41. It was observed that there is significant effect of all three on stripping efficiency ($\alpha$=0.05). It was also observed that stripping efficiency was obtained as significantly highest (99.29%) at 8% moisture content, 10 mm concave clearance and 14.5m/s cylinder speed.

Table 4.41 Effect of moisture content and concave clearance at different cylinder speed, on stripping efficiency

| Stripping efficiency , % | | | | | | |
|---|---|---|---|---|---|---|
| Moisture content (%) | MC (8%) | | MC (12%) | | MC (16%) | |
| Concave clearance , mm | C(8mm) | C(10mm) | C(8mm) | C(10mm) | C(8mm) | C(10mm) |
| Cylinder speed, m/s | | | | | | |
| S(13.27) | 97.24 | 97.43 | 96.78 | 97.11 | 94.99 | 95.92 |
| S(14.50) | 99.11 | 99.29 | 98.23 | 98.35 | 97.88 | 97.78 |
| S(15.71) | 98.08 | 98.14 | 97.43 | 97.66 | 96.02 | 96.50 |
| Factors | | | | C.D. | SE(d) | SE(m)± |
| Moisture Content X Concave Clearance X Speed | | | | 0.264 | 0.13 | 0.092 |

Where, MC = Moisture content, C = Concave clearance, S= Cylinder peripheral speed.

Table 4.42 depicts the effect of moisture content and concave clearance on stripping efficiency. It was found that there is no significant effect of both these parameters on stripping efficiency. Stripping efficiency was significantly affected by moisture content and speed (Table 4.43). It was observed highest 99.2% at 8%

moisture content and at a speed of 14.5m/s. It may be due to lower moisture content make the capsule easily detachable from linseed plant. Similar type of results were found by many researchers (Afify *et al.* 2007 for black seed, El-Ashary *et al*. (2003). Table 4.44 depicts the effect of concave clearance and speed on stripping efficiency. It was found that there is no significant effect of both these parameters on stripping efficiency

Table 4.42 Effect of moisture content and concave clearance on stripping efficiency

| Stripping efficiency , % | | | |
|---|---|---|---|
| Concave clearance, mm | C(8mm) | C(10mm) | Mean MC |
| Moisture content (%) | | | |
| MC (8%) | 98.141 | 98.287 | 98.214 |
| MC (12%) | 97.48 | 97.706 | 97.593 |
| MC (16%) | 96.299 | 96.736 | 96.518 |
| Mean C | 97.306 | 97.576 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Interaction Moisture Content X Concave Clearance | NS | 0.075 | 0.053 |

Table 4.43 Effect of moisture content and different cylinder speed, on stripping efficiency

| Stripping efficiency , % | | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean MC |
| Moisture Content, % | | | | |
| MC (8%) | 97.333 | 99.2 | 98.108 | 98.214 |
| MC (12%) | 96.943 | 98.293 | 97.543 | 97.593 |
| MC (16%) | 95.458 | 97.833 | 96.261 | 96.518 |
| Mean S | 96.578 | 98.442 | 97.304 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content (A) X Speed (C) | 0.186 | 0.092 | 0.065 |

.

Table 4.44 Effect concave clearance at different cylinder speed, on stripping efficiency

| | Stripping efficiency , % | | | |
|---|---|---|---|---|
| Speed m/s | S(13.27) | S(14.50) | S(15.71) | Mean C |
| Concave clearance, mm | | | | |
| C(8mm) | 96.339 | 98.407 | 97.174 | 97.306 |
| C(10mm) | 96.818 | 98.478 | 97.434 | 97.576 |
| Mean S | 96.578 | 98.442 | 97.304 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Concave clearance X Speed | NS | 0.075 | 0.053 |

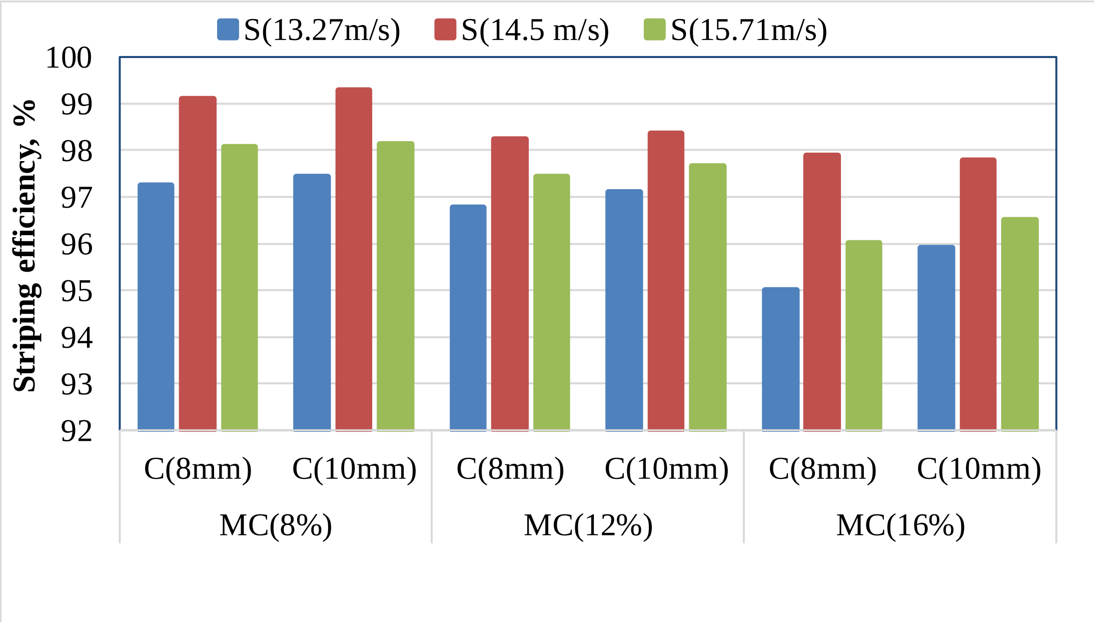



Fig. 4.24 Effect of moisture content and concave clearance at different speed on stripping efficiency

### 4.5.8 Effect of feed rate and speed on stripping efficiency

Table 4.45 depicts the effect of feed rate and speed at fixed moisture content (8%) and concave clearance (10mm) on stripping efficiency. It was found that there is significant effect of both these parameters on stripping efficiency. Highest stripping efficiency (98.41%) was found at 14.5 m/s speed and 250 kg/h feed rate. Similar types of results were also obtained by many researchers Similar types of results were also obtained by many researchers for different crop including linseed (Abougela *et al.* 2007, Afify *et al.* 2007).

Table 4.45 Effect of feed rate and speed on stripping efficiency

| | Stripping efficiency , % | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean F |
| Feed rate, kg/h | | | | |
| F(200) | 96.71 | 98.04 | 95.92 | 96.89 |
| F(250) | 97.17 | 98.41 | 96.82 | 97.47 |
| F(300) | 95.96 | 97.48 | 95.32 | 96.25 |
| Mean S | 96.61 | 97.98 | 96.02 | |
| Factors | | C.D. | SE(d) | SE(m)± |
| Feed rate X Speed | | 0.282 | 0.133 | 0.094 |

Where, S= Cylinder peripheral speed, F= Feed rate.

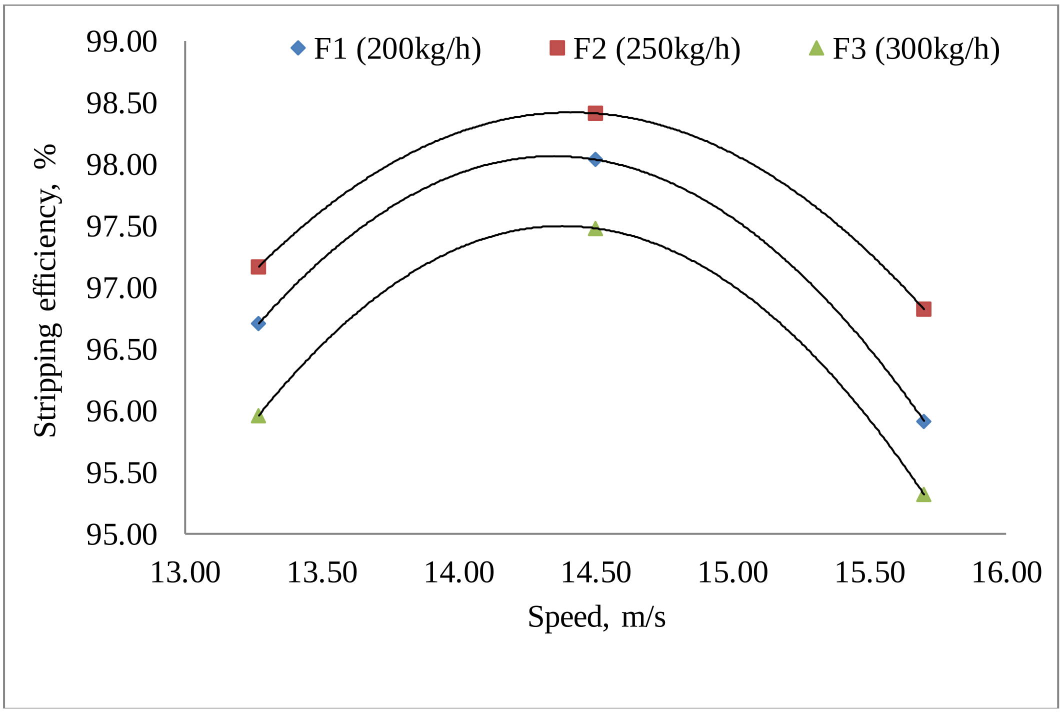



Fig. 4.25 Effect of feed rate and speed on stripping efficiency

### 4.5.9 Threshing capacity

The effect of moisture content, concave clearance and cylinder speed were carried out as explained in Chapter-III. The results obtained were measured and depicted in the Table 4.46Table 4.47, Table4.48 and Table 4.49.

The interaction effect of moisture content and concave clearance at different cylinder speed, on threshing capacity was given in Table 4.46. It was observed that there is no significant effect of all three on threshing capacity ($\alpha$=0.05). It was also observed that threshing capacity was obtained as highest (178.62 kg/h) at 8% moisture content, 10 mm concave clearance and 14.5m/s cylinder speed.

Table 4.48 depicts the effect of moisture content and concave clearance on threshing capacity. It was found that there is no significant effect of both these parameters on threshing capacity.

Table 4.46 Effect of moisture content and concave clearance at different cylinder speed, on threshing capacity

| Threshing capacity , kg/h | | | | | | |
|---|---|---|---|---|---|---|
| Moisture content (%) | MC (8%) | | MC (12%) | | MC (16%) | |
| Concave clearance | C(8mm) | C(10mm) | C(8mm) | C(10mm) | C(8mm) | C(10mm) |
| Cylinder speed, m/s | | | | | | |
| S(13.27) | 175.20 | 175.66 | 174.25 | 174.89 | 172.53 | 173.21 |
| S(14.50) | 177.23 | 178.62 | 176.15 | 177.19 | 175.66 | 176.74 |
| S(15.71) | 176.46 | 177.03 | 175.37 | 175.85 | 174.63 | 174.63 |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Concave Clearance X Speed | NS | 0.271 | 0.191 |

Where, MC = Moisture content, C = Concave clearance, S= Cylinder peripheral speed.

Table 4.47 Effect of moisture content and concave clearance on threshing capacity

| Threshing capacity , kg/h | | | |
|---|---|---|---|
| Concave clearance, mm | C(8mm) | C(10mm) | Mean MC |
| Moisture content (%) | | | |
| MC (8%) | 176.30 | 177.10 | 176.70 |
| MC (12%) | 175.25 | 175.98 | 175.62 |
| MC (16%) | 174.27 | 174.86 | 174.57 |
| Mean C | 175.27 | 175.98 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Interaction Moisture Content X Concave Clearance | NS | 0.156 | 0.111 |

Threshing capacity was significantly affected by moisture content and speed (Table 4.48). It was observed highest 177.92 kg/h at 8% moisture content and at a speed of 14.5m/s. It may be due to lower moisture content make the capsule easily detachable from linseed plant. Similar type of results were found by many researchers for different crop including linseed (El-Ashary *et al*. 2003, Afify *et al*. 2007).

Table 4.48 Effect of moisture content and different cylinder speed, on threshing capacity

| | Threshing capacity , kg/h | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean MC |
| Moisture Content, % | | | | |
| MC (8%) | 175.428 | 177.924 | 176.749 | 176.7 |
| MC (12%) | 174.569 | 176.667 | 175.61 | 175.615 |
| MC (16%) | 172.866 | 176.2 | 174.633 | 174.566 |
| Mean C | 174.288 | 176.93 | 175.664 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Interaction Moisture Content X Speed | 0.388 | 0.191 | 0.135 |

Threshing capacity was significantly affected by concave clearance and speed (Table 4.49). It was observed highest 177.51 kg/h at 10 mm concave clearance and at a speed of 14.5m/s.

Table 4.49 Effect concave clearance at different cylinder speed, on threshing capacity

| | Threshing capacity , kg/h | | | |
|---|---|---|---|---|
| Speed m/s | S(13.27) | S(14.5) | S(15.71) | Mean C |
| Concave clearance, mm | | | | |
| C(8mm) | 173.99 | 176.35 | 175.49 | 175.27 |
| C(10mm) | 174.59 | 177.51 | 175.84 | 175.98 |
| Mean S | 174.29 | 176.93 | 175.66 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Concave clearance X Speed | 0.317 | 0.156 | 0.111 |

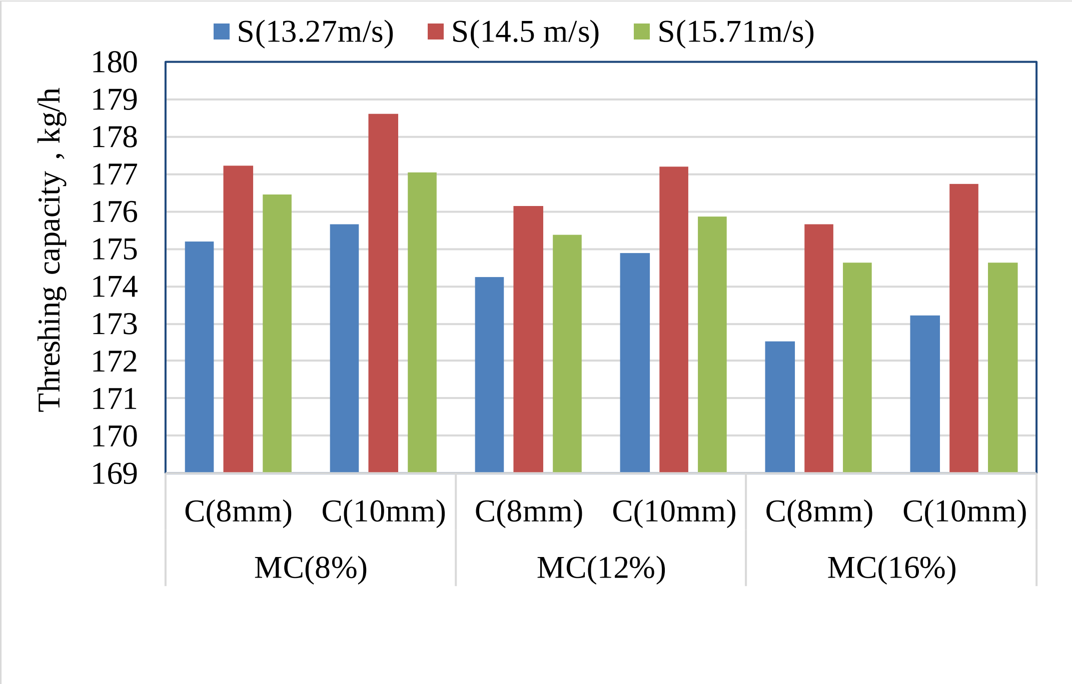



Fig. 4.26 Effect of moisture content and concave clearance at different speed on threshing capacity

### 4.5.10 Effect of feed rate and speed on threshing capacity

Table 4.50 depicts the effect of feed rate and speed at fixed moisture content (8%) and concave clearance (10mm) on threshing capacity. It was found that there is no significant effect of both these parameters on threshing capacity.

Table 4.50 Effect of feed rate and speed on threshing capacity

| | Threshing capacity , kg/h | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.5) | S(15.71) | Mean F |
| Feed rate, kg/h | | | | |
| F(200) | 141.65 | 144.40 | 142.61 | 142.89 |
| F(250) | 175.36 | 178.62 | 177.09 | 177.02 |
| F(300) | 209.22 | 212.67 | 210.47 | 210.78 |
| Mean S | 175.41 | 178.56 | 176.72 | |
| Factors | | C.D. | SE(d) | SE(m)± |
| Feed rate X Speed | | NS | 0.292 | 0.206 |

Where, S= Cylinder peripheral speed, F= Feed rate

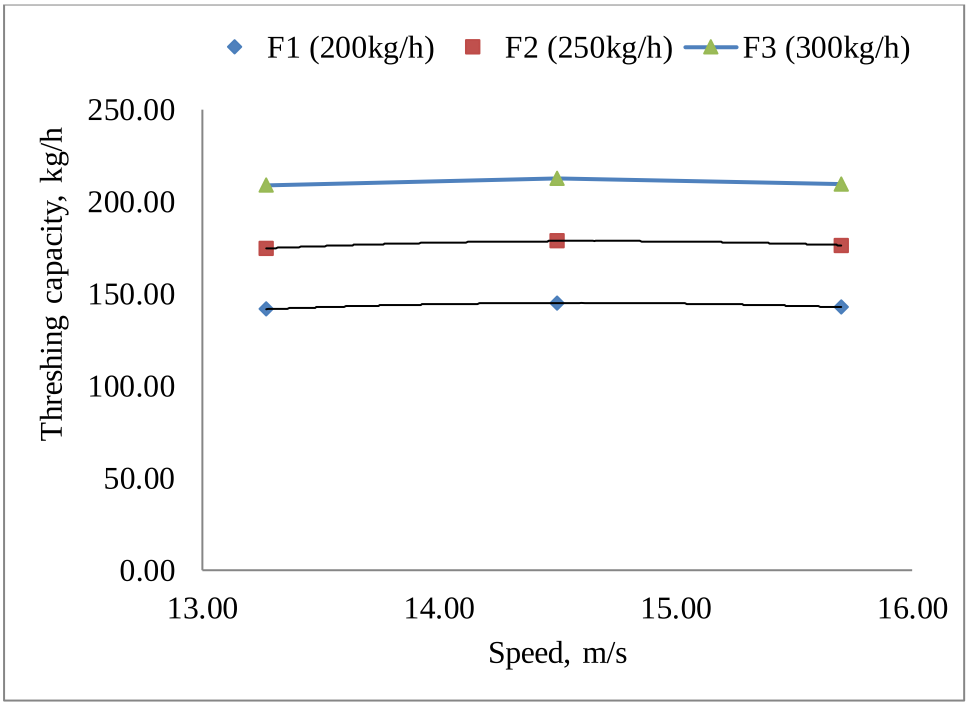



Fig 4.27 Effect of feed rate and speed on threshing capacity

### 4.5.11 Cleaning efficiency

The effect of moisture content, concave clearance and cylinder speed were carried out as explained in Chapter-III. The results obtained were measured and depicted in the Table 4.51 Table 4.52, Table 4.53 and Table 4.54.

Table 4.51 Effect of moisture content and concave clearance at different cylinder speed, on cleaning efficiency

| Cleaning efficiency , % | | | | | | |
|---|---|---|---|---|---|---|
| Moisture content (%) | MC (8%) | | MC (12%) | | MC (16%) | |
| Concave clearance ,mm | C(8mm) | C(10mm) | C(8mm) | C(10mm) | C(8mm) | C(10mm) |
| Cylinder speed, m/s | | | | | | |
| S(13.27) | 86.26 | 87.36 | 84.33 | 84.47 | 83.65 | 83.76 |
| S(14.50) | 90.10 | 90.50 | 88.74 | 89.12 | 87.62 | 87.80 |
| S(15.71) | 84.81 | 85.32 | 83.82 | 84.08 | 82.93 | 83.24 |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Concave Clearance X Speed | 0.38 | 0.187 | 0.132 |

Where, MC = Moisture content, C = Concave clearance, S= Cylinder peripheral speed.

The interaction effect of moisture content and concave clearance at different cylinder speed, on cleaning efficiency was given in Table 4.51. It was observed that there is significant effect of all three on cleaning efficiency ($\alpha$=0.05). It was also observed that cleaning efficiency was obtained as significantly highest (90.50%) at 8% moisture content, 10 mm concave clearance and 14.5m/s cylinder speed. Cleaning efficiency was significantly affected by moisture content and concave clearance (Table4.52). It was observed highest 87.73% at 8% moisture content and at a 10 mm concave clearance. It may be due to lower moisture content lower the weight of chaff that can be easily suck by aspirator blower so that higher cleaning efficiency  Similar types of results were also obtained by many researchers (Ghaly, 1985).

Table 4.52 Effect of moisture content and concave clearance on cleaning efficiency

| Cleaning efficiency , % | | | |
|---|---|---|---|
| Concave clearance, mm | C(8mm) | C(10mm) | Mean MC |
| Moisture content (%) | | | |
| MC (8%) | 87.06 | 87.73 | 87.39 |
| MC (12%) | 85.63 | 85.89 | 85.76 |
| MC (16%) | 84.73 | 84.93 | 84.83 |
| Mean C | 85.81 | 86.18 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Concave Clearance | 0.219 | 0.108 | 0.076 |

Table 4.53 Effect of moisture content and speed on cleaning efficiency

| Cleaning efficiency , % | | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean MC |
| Moisture Content, % | | | | |
| MC (8%) | 86.81 | 90.30 | 85.06 | 87.39 |
| MC (12%) | 84.40 | 88.93 | 83.95 | 85.76 |
| MC (16%) | 83.70 | 87.71 | 83.09 | 84.83 |
| Mean S | 84.97 | 88.98 | 84.03 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Speed | 0.268 | 0.132 | 0.094 |

Cleaning efficiency was significantly affected by moisture content and speed (Table 4.53). It was observed highest 90.3% at 8% moisture content and at a speed of 14.5 m/s. It may be due to lower moisture content lower the weight of chaff that can be easily suck by aspirator blower so that higher cleaning efficiency Similar types of results were also obtained by many researchers for different crop including linseed (Afify *et al.* 2007, Ghaly, 1985, Gbabo *et al.* 2013).

Table 4.54 Effect of concave clearance and speed on cleaning efficiency

| | Cleaning efficiency , % | | | |
|---|---|---|---|---|
| Speed m/s | S(13.27) | S(14.50) | S(15.71) | Mean C |
| Concave clearance, mm | | | | |
| C(8mm) | 84.75 | 88.82 | 83.85 | 85.81 |
| C(10mm) | 85.20 | 89.14 | 84.21 | 86.18 |
| Mean S | 84.97 | 88.98 | 84.03 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Concave clearance X Speed | NS | 0.108 | 0.076 |

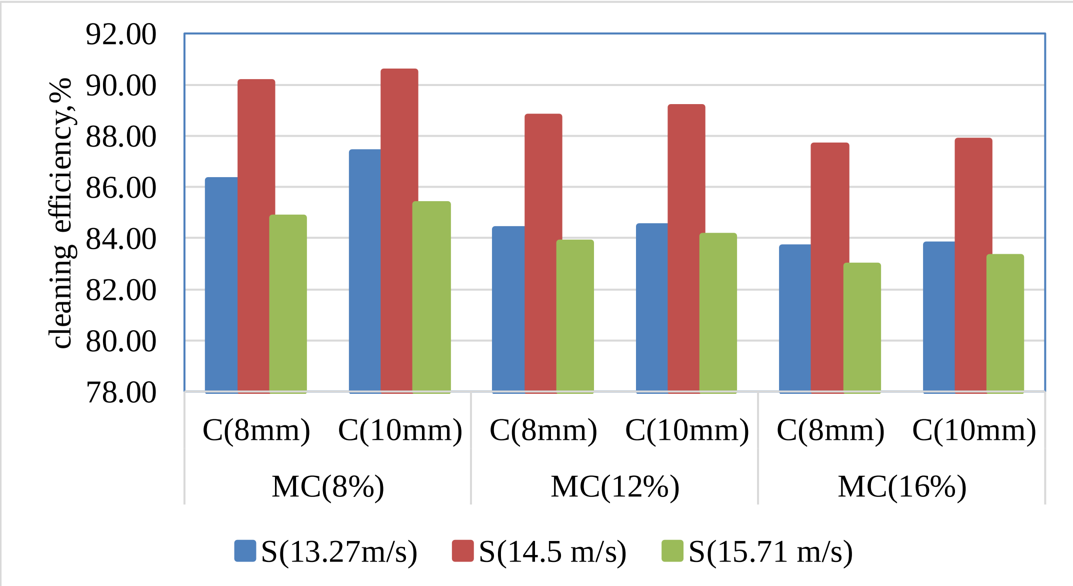



Fig.4.28 Effect of moisture content and concave clearance at different cylinder speed, on cleaning efficiency

Table 4.54 depicts the effect of concave clearance and speed on cleaning efficiency. It was found that there is no significant effect of both these parameters on cleaning efficiency.Similar types of results were also obtained by many researchers (El- Fawal *et al.*2012 Ghaly, 1985, Gbabo *et al.* 2013).

### 4.5.12 Effect of feed rate and speed on cleaning efficiency

Table 4.55 depicts the effect of feed rate and speed at fixed moisture content (8%) and concave clearance (10mm) on cleaning efficiency. Cleaning efficiency was significantly affected by feed rate and speed. It was observed highest 90.43% at 250kg/h feed rate and at a speed of 14.5 m/s. Similar types of results were also obtained by many researchers for different crops (Simonyan 2009, Sale *et al.* 2017).

Table 4.55 Effect of feed rate and speed on cleaning efficiency

| | Cleaning efficiency , % | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean F |
| Feed rate, kg/h | | | | |
| F(200) | 88.08 | 89.25 | 87.35 | 88.23 |
| F(250) | 88.32 | 90.43 | 87.82 | 88.86 |
| F(300) | 85.41 | 87.75 | 84.39 | 85.85 |
| Mean S | 87.27 | 89.14 | 86.52 | |
| Factors | C.D. | SE(d) | SE(m)± | |
| Feed rate X Speed | 0.537 | 0.254 | 0.179 | |

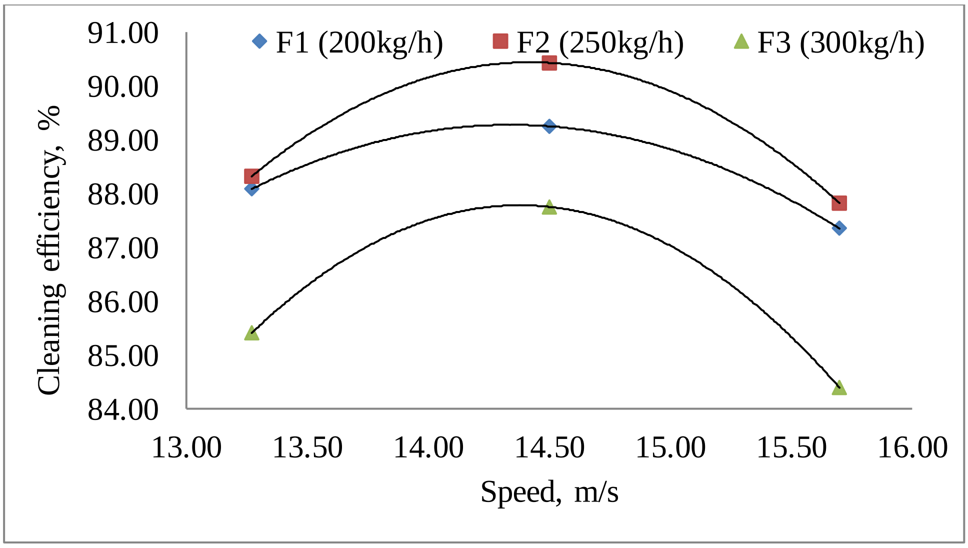



Fig. 4.29 Effect of feed rate and speed on cleaning efficiency

### 4.5.13 Visible seed damage

The effect of moisture content, concave clearance and cylinder speed were carried out as explained in Chapter-III. The results obtained were measured and depicted in the Table 4.56, Table 4.57 Table 4.58 and Table 4.59.

Table 4.56 Effect of moisture content and concave clearance at different cylinder speed, on visible seed damage.

| Visible seed damage, % | | | | | | |
|---|---|---|---|---|---|---|
| Moisture content (%) | MC (8%) | | MC (12%) | | MC (16%) | |
| Concave clearance, mm | C(8mm) | C(10mm) | C(8mm) | C(10mm) | C(8mm) | C(10mm) |
| Cylinder speed, m/s | | | | | | |
| S(13.27) | 1.683 | 1.762 | 1.466 | 1.333 | 1.242 | 1.063 |
| S(14.50) | 1.938 | 1.844 | 1.538 | 1.423 | 1.318 | 1.123 |
| S(15.71) | 2.046 | 1.925 | 1.68 | 1.541 | 1.441 | 1.217 |
| | | | | C.D. | SE(d) | SE(m)± |
| Moisture Content X Concave Clearance X Speed | | | | 0.018 | 0.009 | 0.006 |

Where, MC = Moisture content, C = Concave clearance, S= Cylinder peripheral speed.

Table4.57 Effect of moisture content and concave clearance on visible seed damage

| Visible seed damage, % | | | |
|---|---|---|---|
| Concave clearance, mm | C(8mm) | C(10mm) | Mean MC |
| Moisture content (%) | | | |
| MC (8%) | 1.89 | 1.84 | 1.87 |
| MC (12%) | 1.56 | 1.43 | 1.50 |
| MC (16%) | 1.33 | 1.13 | 1.23 |
| Mean C | 1.59 | 1.47 | |
| Factors | C.D. | SE(d) | SE(m)± |
| Moisture Content X Concave Clearance | 0.011 | 0.005 | 0.004 |

The interaction effect of moisture content and concave clearance at different cylinder speed, on cleaning efficiency was given in Table 4.56. It was observed that there is significant effect of all three on visible seed damage ($\alpha$=0.05). It was also observed that visible seed damage was obtained as significantly lowest (2.046%) at 8% moisture content, 8 mm concave clearance and 15.71m/s cylinder speed. Similar types of results were also obtained by many researchers for different crops (Salari *et al* 2013, Ghaly, 1985).Visible seed damage was significantly affected by moisture content and concave clearance (Table4.56). It was observed lowest 1.13% at16 % moisture content and at a concave clearance of 10 mm. similar types of results were also obtained by many researchers (Ghaly, 1985).

Table4.58 Effect of moisture content and speed on visible seed damage

| | Visible seed damage, % | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean MC |
| Moisture Content, % | | | | |
| MC (8%) | 1.72 | 1.89 | 1.99 | 1.87 |
| MC (12%) | 1.40 | 1.48 | 1.61 | 1.50 |
| MC (16%) | 1.15 | 1.22 | 1.33 | 1.23 |
| Mean S | 1.43 | 1.53 | 1.64 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Speed | 0.013 | 0.006 | 0.005 |

Visible seed damage was significantly affected by moisture content and speed (Table 4.58). It was observed lowest 1.15% at16 % moisture content and at a speed of 13.27m/s. Similar types of results were also obtained by many researchers (Dauda 2001, Ghaly, 1985).

Table 4.59 Effect of concave clearance and speed on visible seed damage

| | Visible seed damage , % | | | |
|---|---|---|---|---|
| Speed m/s | S(13.27) | S(4.50) | S(15.71) | Mean C |
| Concave clearance, mm | | | | |
| C(8mm) | 1.46 | 1.60 | 1.72 | 1.60 |
| C(10mm) | 1.39 | 1.46 | 1.56 | 1.47 |
| Mean S | 1.43 | 1.53 | 1.64 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Concave clearance X Speed | 0.011 | 0.005 | 0.004 |

Visible seed damage was significantly affected by speed and concave clearance (Table 4.59). It was observed lowest 1.39% at 13.27 m/s and at a concave clearance of 10 mm. Similar types of results were also obtained by many researchers (El- Fawal *et al.* 2012, Ghaly, 1985, Bansal and Lohan 2009).

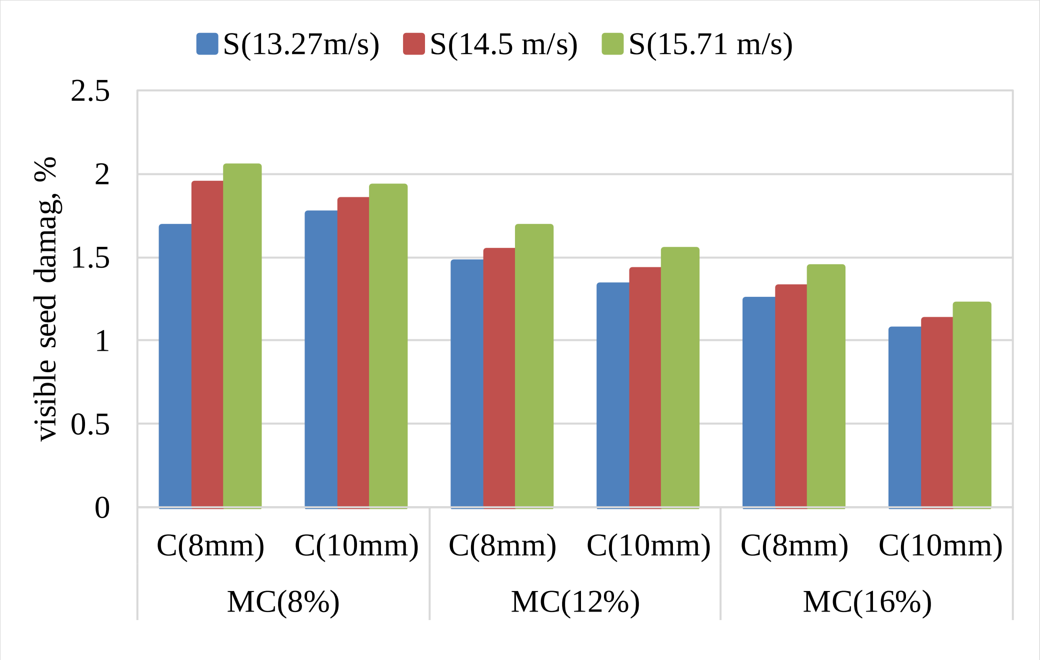



Fig. 4.29 Effect of moisture content and concave clearance at different cylinder speed, on cleaning efficiency

### 4.5.14 Effect feed rate and speed on visible seed damage

Table 4.60 depicts the effect of feed rate and speed at fixed moisture content (8%) and concave clearance (10mm) on visible seed damage. Visible seed damage was significantly affected by feed rate and speed (Table 4.45). It was observed highest 2.60at 300 kg/h feed rate and at a speed of 15.71 m/s. Similar types of results were also obtained by many researchers (Ghaly, 1985, Vejasit and Salokhe 2004).

Table 4.60 Effect feed rate and speed on visible seed damage

| Visible seed damage, % | | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(4.50) | S(15.71) | Mean F |
| Feed rate, kg/h | | | | |
| F(200) | 1.29 | 1.32 | 1.47 | 1.36 |
| F(250) | 1.60 | 1.72 | 1.93 | 1.75 |
| F(300) | 1.81 | 1.84 | 2.60 | 2.08 |
| Mean S | 1.57 | 1.63 | 2.00 | |
| Factors | | C.D. | SE(d) | SE(m)± |
| Feed rate X Speed | | 0.144 | 0.068 | 0.048 |

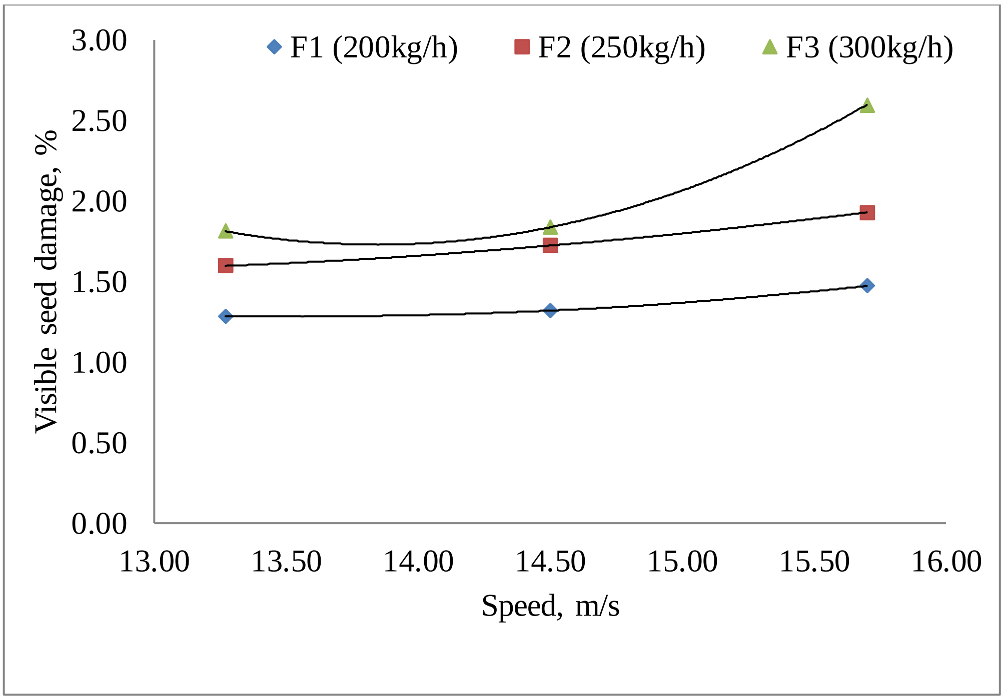



Fig.4.30 Effect of feed rate and speed on visible seed damage

### 4.5.15 Invisible seed damage

The effect of moisture content, concave clearance and cylinder speed were carried out as explained in Chapter-III. The results obtained were measured and depicted in the Table 4.61, Table 4.62, Table 4.63 and Table 4.64.

The interaction effect of moisture content and concave clearance at different cylinder speed, on cleaning efficiency was given in Table 4.61. It was observed that there is significant effect of all three on visible seed damage ($\alpha$=0.05). It was also observed that visible seed damage was obtained as significantly lowest (2.046%) at 8% moisture content, 8 mm concave clearance and 15.71m/s cylinder speed. Similar types of results were also obtained by many researchers for different crops (Salari *et al*.2013, Sinha and Pandita, 2002, Sinha *et al*. 2009). Invisible seed damage was significantly affected by moisture content and concave clearance (Table4.62). It was observed lowest 1.028% at16 % moisture content and at a concave clearance of 10 mm. similar types of results were also obtained by many researchers (Sinha and Pandita, 2002, Bansal and Lohan 2009). Invisible seed damage was significantly affected by moisture content and speed (Table 4.63).

Table 4.61 Effect of moisture content and concave clearance at different cylinder speed, on invisible seed damage

| Invisible seed damage, % | | | | | | |
|---|---|---|---|---|---|---|
| Moisture content (%) | MC (8%) | | MC (12%) | | MC (16%) | |
| Concave clearance, | C(8mm) | C(10mm) | C(8mm) | C(10mm) | C(8mm) | C(10mm) |
| Cylinder speed, m/s | | | | | | |
| S(13.27) | 1.56 | 1.47 | 1.24 | 1.16 | 1.12 | 0.93 |
| S(14.50) | 1.73 | 1.68 | 1.35 | 1.28 | 1.21 | 1.03 |
| S(15.71) | 1.91 | 1.78 | 1.56 | 1.37 | 1.29 | 1.12 |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Concave Clearance X Speed | 0.03 | 0.015 | 0.01 |

Where, MC = Moisture content, C = Concave clearance, S= Cylinder peripheral speed.

It was observed lowest 1.02% at16 % moisture content and at a speed of 13.27m/s. Similar types of results were also obtained by many researchers (Dauda 2001, Bansal and Lohan 2009). Invisible seed damage was significantly affected by speed and concave clearance (Table 4.63). It was observed lowest 1.18% at 13.27 m/s and at a concave clearance of 10 mm. Similar types of results were also obtained by many researchers (El- Fawal et al.2012, Bansal and Lohan 2009).

Table 4.62 Effect of moisture content and concave clearance on invisible seed damage

| Invisible seed damage, % | | | |
|---|---|---|---|
| Concave clearance, mm | C(8mm) | C(10mm) | Mean MC |
| Moisture content (%) | | | |
| MC (8%) | 1.733 | 1.645 | 1.689 |
| MC (12%) | 1.383 | 1.271 | 1.327 |
| MC (16%) | 1.207 | 1.028 | 1.117 |
| Mean C | 1.441 | 1.314 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Moisture Content X Concave Clearance | 0.017 | 0.008 | 0.006 |

Table 4.63 Effect of moisture content and speed on invisible seed damage

| | Invisible seed damage, % | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean MC |
| Moisture Content, % | | | | |
| MC (8%) | 1.512 | 1.707 | 1.847 | 1.689 |
| MC (12%) | 1.2 | 1.316 | 1.465 | 1.327 |
| MC (16%) | 1.022 | 1.12 | 1.21 | 1.117 |
| Mean S | 1.245 | 1.381 | 1.507 | |
| Factors | | C.D. | SE(d) | SE(m)± |
| Moisture Content X Speed | | 0.021 | 0.01 | 0.007 |

Table 4.64 Effect of speed and concave clearance on invisible seed damage

| | Invisible seed damage, % | | | |
|---|---|---|---|---|
| Speed m/s | S(13.27) | S(14.50) | S(15.71) | Mean C |
| Concave clearance, mm | | | | |
| C(8mm) | 1.304 | 1.43 | 1.588 | 1.441 |
| C(10mm) | 1.185 | 1.332 | 1.427 | 1.314 |
| Mean S | 1.245 | 1.381 | 1.507 | |
| Factors | | C.D. | SE(d) | SE(m)± |
| Concave clearance X Speed | | 0.017 | 0.008 | 0.006 |

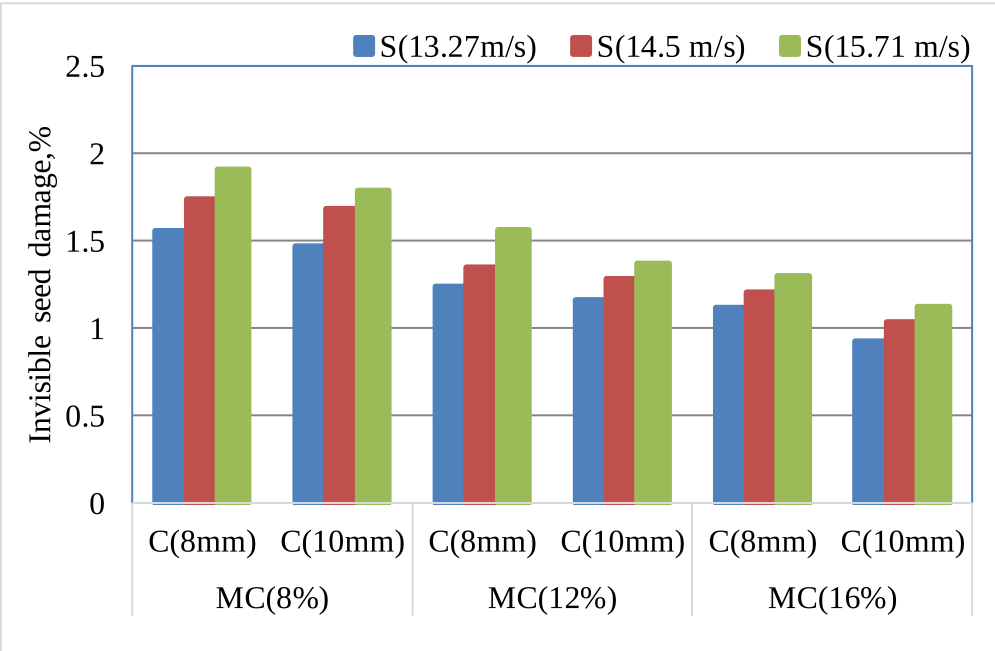



Fig.4.31 Effect of moisture content and concave clearance at different cylinder speed, on invisible seed damage

### 4.5.16 Effect of feed rate and speed on invisible seed damage

Table 4.65 depicts the effect of feed rate and speed at fixed moisture content (8%) and concave clearance (10mm) on invisible seed damage. Invisible seed damage was significantly affected by feed rate and speed. It was observed highest 2.06 at 300 kg/h feed rate and at a speed of 15.71 m/s. Similar types of results were also obtained by many researchers (Sinha *et al*. 2009).

Table 4.65 Effect of feed rate and speed on invisible seed damage

| | Invisible seed damage, % | | | |
|---|---|---|---|---|
| Speed, m/s | S(13.27) | S(14.50) | S(15.71) | Mean F |
| Feed rate, kg/h | | | | |
| F(200) | 0.92 | 1.14 | 1.22 | 1.09 |
| F(250) | 1.40 | 1.58 | 1.66 | 1.55 |
| F(300) | 1.73 | 1.83 | 2.06 | 1.87 |
| Mean S | 1.35 | 1.52 | 1.65 | |

| Factors | C.D. | SE(d) | SE(m)± |
|---|---|---|---|
| Feed rate X Speed | 0.057 | 0.026 | 0.019 |

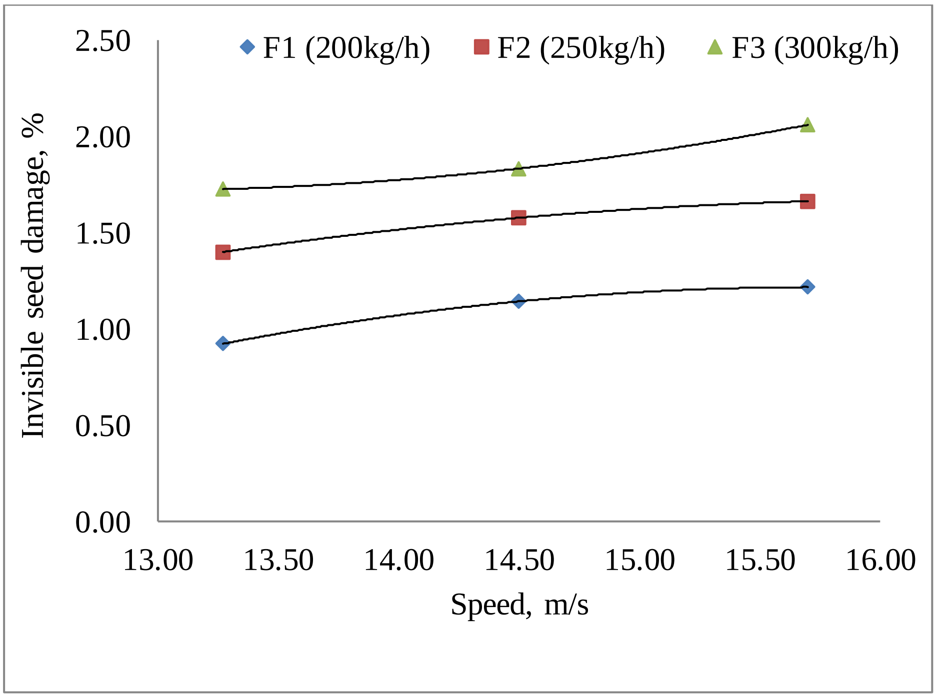



Fig.4.33 Effect of feed rate and speed on invisible seed damage

## 4.6 Cost Estimation

The cost of linseed thresher was calculated based on material required for fabrication considering material cost in the local market. The cost of the machine was calculated as Rs. 50000 as given in Table 4.66.

Table 4.66 Material billing of the developed linseed thresher

| S.N. | Material description | Quantity | Rate (Rs) | Cost (Rs) |
|---|---|---|---|---|
| 1 | Mild steal sheet 1.6mm thick, kg | 12 | 60 | 720.00 |
| 2 | 35× 35 × 3 Angle iron, kg | 19.6 | 60 | 1176.00 |
| 3 | 25×25×3 Angle iron | 3.5 | 55 | 192.50 |
| 4 | 25mm diameter shaft(1150 mm), 3m | 1 | 750 | 750.00 |
| 5 | 19mm diameter shaft(40mm), 1 m | 1 | 750 | 750.00 |
| 6 | 6×6 square rod , kg | 7.84 | 45 | 352.80 |
| 7 | Welding rod, packet | 2 | 300 | 600.00 |
| 8 | Driven, pulley, 8 inch | 1 | 480 | 480.00 |
| 9 | Driver pulley, 4 inch | 1 | 240 | 240.00 |
| 10 | Shaker shaft offset pulley, 230 mm | 1 | 500 | 500.00 |
| 11 | 32×5 flat bar, kg | 10 | 45 | 450.00 |
| 12 | Electric motor(0.5hp) | 1 | 7800 | 7800.00 |
| 13 | TVS bolt and nut for spike , 100x mm, 12 mm | 24 | 100 | 2400.00 |
| 14 | Canvas strip, 100 mm x 10 mm | 4 | 350 | 1400.00 |
| 15 | V- belt , 3 piece | 3 | 350 | 1050.00 |
| 16 | Aspiratory blower fittings and accessories | 1 | 4500 | 4500.00 |
| 17 | Nut bolt and accessories LS | 1 | 2500 | 2500.00 |
| 18 | Colour for Spray paint | 8 | 450 | 3600.00 |
| 19 | Bearings | 6 | 600 | 3600.00 |
| 20 | Sieve, different size | 3 | 1400 | 4200.00 |
| 21 | Electric wire and fittings | 1 | 1500 | 1500.00 |
| 22 | Fabrication cost (25% of cost of above material) | 25% | 37261.3 | 9315.33 |
| | Total | | | 48076.63 = 50000/- |

### 4.6.1 Total cost of operation

The total cost of linseed thresher operation was determined based on fixed and variable cost as described in chapter III. The following variables were considered in calculating the cost operation.

### 4.6.1.1 Fixed cost

**a. Depreciation:**

This cost reflects the reduction in value of a machine with use (wear) and time (obsolescence). It is the loss of value of a machine with the passing of time and calculated by the formula (IS 9164: 1979)

$$D = \frac{C - S}{L \times H} = \frac{50000 - 50000x0.10}{6 \times 240} = \text{Rs.}\,31.25$$

Where,

D = Depreciation per hour;

C = Initial cost of implement, Rs 50000.00

S = Salvage value @ 10 % of C, Rs. =5000

L = Working life of machine in years=6 year

H = Number of working hours per year=240 hours

**b. Interest:**

Interest was calculated on the average investment of the machine, taking into consideration the value of the machine in first and last year (IS 9164: 1979)

$$I = \frac{(C + S)}{2} \times \frac{i}{H} = \frac{(50000 + 5000)}{2} \times \frac{0.1}{240} = \text{Rs.}\,11.45$$

Where,

i = Interest rate = 10% per annum of initial cost

**c. Housing cost**

Housing cost was calculated on the basis of the prevailing rate of the locality and generally taken as 1% of the initial cost of the machine per year. (IS 9164: 1979)

$$HC = \frac{C}{H} \times \frac{1}{100} = \frac{50000}{240} \times \frac{1}{100} = \text{Rs.}\,2.08$$

Therefore,

Total fixed cost = Depreciation + Interest + Housing

= Rs. (31.25+11.45+2.08)

=Rs. 44.78

Table 4.67. Fixed cost of machine

| S. No. | Particulars | Amount(Rs) |
|---|---|---|
| 1 | Cost of machine, Rs. | 50000.00 |
| 2 | Life of the machine (year) | 6.00 |
| 3 | Annual use (Working hour per year) | 240.00 |
| 4 | Salvage value, @10% | 5000.00 |
| 5 | Depreciation, Rs./ h | 31.25 |
| 6 | Interest investment @10% per annum | 11.45 |
| 7 | Housing cost @1% of cost of machine | 2.08 |
| Σ(5+6+7) | Fixed cost Rs./h | 44.78 |

#### 4.6.1.2 Variable cost

The variable costs are those cost which incurred due to operation of the machine

a. **Electricity charges**

Electricity cost = electricity consumed (kWh/h) × electricity charges (Rs/kWh)

= 0.372× 4. 5 = Rs 1.67

b. **Repair maintenance cost**

Cost of repairs and maintenance varies between 5 to 10% of the initial cost of the machine per year. (IS 9164: 1979)

i.e. assumed to be 10% per annum of initial cost

$$\text{R\&}M\ cost \quad = \frac{\text{C}}{\text{H}} \times \frac{\text{R\&}M\ rate}{100} = \frac{50000}{240} \times \frac{6}{100} = \text{Rs } 12.5$$

c. **Labour wages**

Wages of labour was calculated on the basis of actual wages of the worker in present time. (IS 9164: 1979)

Lc = Number of worker × Wage per hour (Rs 300/day of 8 hours)

= 2 x300/8 =Rs 75.00

d. **Total variable cost**

Total variable cost is calculated by adding all variable cost occurred by above and it is calculated as follows and presented in Table 4.49.

TVC = Repair and maintenance cost + Labour wages =1.67 + 12.5 +75.00 = Rs 89.17

Table 4.68. Operating cost of the machine

| S. No. | Particulars | Amount (Rs) |
|---|---|---|
| 1 | Electricity charges @ Rs 4.5 for 0.372 kW | 1.67 |
| 2 | Repair and maintenance cost @ 10% of initial cost, Rs./h | 12.5 |
| 3 | Wage of 2 operator (300 Rs./ 8 h) | 75.00 |
| Total | Operational cost, Rs./h | 89.17 |

**4.6.1.3 Total cost of operation**

The total cost of operation was calculated by adding both fixed cost as well as variable cost per hour.

**Total cost (TC)** = Total Fixed Cost (TFC) + Total Variable Cost (TVC)

=Rs. (44.78+89.17) = Rs 133.95 / hour

Cost of operation per kg of output @ 178kg /h = Rs 133.95/178 = Rs 0.75/kg

**4.6.1.4 Cost of operation by traditional method**

Cost of operation by using manual hand beating method of linseed threshing =

$$= \frac{\text{Wage}}{\text{Total maize shelled per hour}} = \frac{\text{Rs 37.5 per hour for two labour}}{5\,\frac{\text{kg}}{\text{head}}\,\text{x2 worker}}$$

$$= \frac{75}{10} = \text{Rs. } 7.50 \text{ kg}$$

Hence, profit over manual hand beating by developed linseed thresher = 5.63 times.

The developed machine have output of 17.8 times more than the traditional method with profit of more than 5.63 times.

**4.6.2 Breakeven point**

Assuming 20% profit on adding 20% overhead charges in the variable cost of operation the custom hiring charges for the machine will be calculated as follows

FC (Fixed cost /Annum) =Rs. 44.78

| | | |
|---|---|---|
| VC | =Rs. | 89.17 |
| VC+20%OH | =Rs. | 107.004 |
| 25% profit | =Rs. | 33.5 |
| CH | =Rs. | 140.5 |

$$\text{BEP} = \frac{\text{FC x AU}}{\text{CH} - \text{VC}} = \frac{44.78 \text{ x}240}{140.5 - 89.17} = 209 \text{ hour per annum}$$

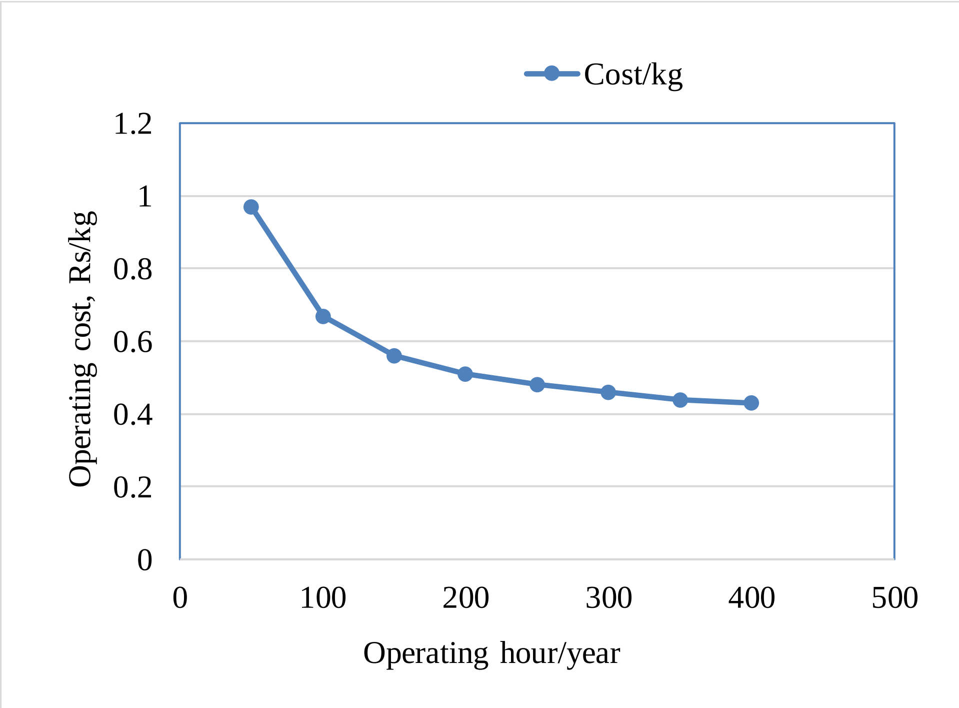



Fig. 4. 34 Effect of operating hour per year on operating cost

### 4.6.3 Payback period

The payback period for the developed linseed thresher was calculated to know the time required to get back the investment. The payback period was estimated by using the following formula (Reddy *et al.*, 2003).

$$\text{PBP} = \frac{\text{IC}}{\text{ANP}}$$

Where,

PBP = Payback period, Years;

I = Investment i.e. initial cost of the machine, rupees= Rs 50000

ANP = Annual net profit, rupees= (CH –TC) x Annual Use

= (140.5-89.17) x240 = Rs 12319.20/year

$$\text{Hence Pay Back Period (PBP)} = \frac{\text{IC}}{\text{ANP}}$$

$$= \frac{50000}{12319.20} = 4.05 \text{ years or } 972 \text{ hours of work}$$

## 4.7 Advantage of the Developed Linseed Thresher

1. There is no stalk damage during threshing, s that stalk can be efficiently utilized as fiber.
2. It saved the use of physical labor so reduce that dependency on labor.
3. It facilitated faster work and increased efficiency.
4. The developed thresher is portable easily transportable.
5. The developed thresher required only 0.5 hp motor so it is affordable for small farmers of the state.

## 4.8 Disadvantage of the Developed Machine

1. Electricity is required for operating this machine
2. Cleaning efficiency is low.
3. Vibration and noise level of machine while operating condition is high.

# CHAPTER-V
# SUMMARY AND CONCLUSIONS

Linseed (*Linum usitatissimum* L) has many health benefits, every part of linseed were utilized. The traditional method is a very labour intensive and time consuming process. In traditional method of threshing high seed and grain damage occur. This reducing the quality and quantity of linseed seed and it's by product utilization as fibre. Some multi crop thresher are currently available that are suitable for linseed but it is not specific to this crop. The fibre is also a useful part of the plant and it could be harvested if stem will be in full length. The present threshers will not prove to earn more income through the extraction of fibre. Hence, there is need of a thresher which will provide both threshing operation as well as stem separation simultaneously. Mechanized threshing of linseed may reduce the dependency on high labour requirement and time of operation and also saves the energy requirement, and cost of operation to increase the net benefits to the farmers of state. Keeping above mentioned fact in mind, a research on design and development of a mechanical linseed thresher has been planned with following objectives:

1. To study the physical and engineering properties of linseed.
2. To design and develop linseed thresher.
3. To test and evaluate the performance of developed linseed thresher.

The engineering properties of linseed were studied with three different varieties *i.e*. Neelam, Shekhar and Sheela at different level of moisture content. The properties like length width, thickness, GMD, , bulk density, TGW, true density, porosity, angle of repose, terminal velocity, coefficient of friction and rupture force were studied for designing different component of thresher.

Based on the studied engineering properties, the major components of linseed thresher should be design such as power requirement, feed rate, threshing cylinder diameter and length, no of pegs, size of concave, size pulley and belt length used for power transmission, diameter of cylinder shaft, aspirator blower, frame, sieve etc. were determined.

According the design of components, the conceptual design and drawing was built with the help of solid-works software. After the 3D model building materials for developing different components were selected. According to conceptual drawing the fabrication of linseed thresher was done at SVCAET and RS FMPE workshop. In light of the issues that occurred during the operation of the prototype, various modifications were implemented to address the problems. Finally, after three to four phases of modification, the linseed thresher was developed, which produced effective results.

The performance of the machine was tested for the effect of six independent parameters like 2 level of no of pegs, 2 level of no of loops, 3 level of moisture content, 3 level of feed rate, 3 level cylinder peripheral speed and 2 level of concave clearance on 5 dependent parameters like threshing capacity, stripping efficiency, threshing efficiency, cleaning efficiency and seed damage. The newly developed linseed thresher has been evaluated economically, and the cost of operation has been compared to the traditional threshing method.

**Summary of Research Work:**

1. The mean value of physical property of linseed capsule, no. of capsule per plant, no of seed per capsule , length , width and thickness of capsule and geometric mean diameter(GMD) were 37.50, 9.59,7.79mm, 6.57mm, 6.49 mm and 6.91mm respectively.
2. It was concluded that the mean value of linear dimensions i.e. length, width, thickness and geometric mean diameter (GMD) of linseed seed increased with increase in moisture content for all three varieties. However, the highest length, width and thickness was observed for the Neelam Variety of linseed as 5.53mm, 2.92mm 0.90 mm and 2.56 mm respectively at moisture content of 14 %.
3. The mean value of surface area, volume, 1000 grain weight of linseed increased with increase in moisture content for all three varieties. However, the highest surface area, sphericity, volume and 1000 grain weight were observed for the Neelam Variety of linseed as 21.51mm$^2$, 8.86mm$^3$10.59 g respectively at moisture content of 14 %.

4. The mean value of true density, porosity of linseed increased with increase in moisture content for all three varieties. Whereas bulk density of linseed decrease with increase in moisture content However, the highest true density , porosity and lowest value of bulk density were observed for the Neelam Variety of linseed as 1128.56 $kg/m^3$, 41.16 and 664.03 $kg/m^3$respectively at moisture content of 14 %.
5. The mean value of angle of repose, coefficient of friction at GI sheet, MS sheet and plywood surface, terminal velocity of linseed increased with increase in moisture content for all three varieties. However, the highest angle of repose, coefficient of friction at GI sheet, MS sheet and plywood surface, terminal velocity were observed23.19˚, 0.41, 0.47, 0.53, and 3.14 at 14% moisture content.
6. The mean value of rupture force for linseed seed, linseed capsule, linseed stalk tip were observed 46.25 N, 5.99 N and 8.08 N respectively.
7. The threshing efficiency, and stripping efficiency was found highest 99.07% and 99.004 % at 6 no of pegs and 8 no of loops respectively.
8. It was observed that the threshing capacity was having significant effect by speed, moisture content and concave clearance. The highest value of threshing capacity was observed as 178.62 kg/h.
9. It was observed that the stripping efficiency was having significant effect by speed, moisture content and concave clearance. The highest value of stripping efficiency was observed as 99.29 per cent.
10. It was observed that the threshing efficiency was having significant effect by speed, moisture content and concave clearance. The highest value of threshing efficiency was observed as 99.31 per cent. Increase in feed rate after 250 kg/h decreases the threshing efficiency.
11. It was observed that the cleaning efficiency was having significant effect by speed, moisture content and concave clearance. The highest value of cleaning efficiency was observed as 90.5per cent. Increase in feed rate after 250 kg/h decreases the cleaning efficiency as 84.39 per cent.
12. It was observed that the visible and invisible seed damage both was having significant effect by speed, moisture content and concave clearance. The

highest value of seed damage was observed at higher speed, low moisture content and lower concave clearance. It was observed minimum as 1.06 % and 0.93% respectively and highest as 2.46 and 1.91 per cent respectively. Increase in feed rate increases the damage percentage.

13. Total operational cost of operating linseed thresher was found Rs 89.17 /h. and total cost of threshing one kilogram linseed was observed as Rs 0.75 /kg. Which is much cheaper than traditional method of threshing linseed as Rs 7.5 /kg.

**Conclusions:**

1. The physical parameters were changed as per the varieties as well as by moisture content. The physical properties play an important role in the design of the linseed thresher.
2. A linseed thresher was designed and developed successfully in the Department of Farm Machinery and Power Engineering. The stripping efficiency, threshing capacity, threshing efficiency, cleaning efficiency, visible and invisible seed damage of developed machine was found to be 99.29%, 178.62 kg/h, 99.31% and 90.5%, 1.844% and1.68% respectively at 250 kg/h feed rate, 14.4 m/s cylinder speed, 10 mm concave clearance and 8% moisture content.
3. The cost of machine was found to be Rs.50000. The cost of operation of the machine is Rs 89.17 /h and Rs 0.75/ kg.

## Suggestions for Future Work

1. The linseed thresher should be tested for other small seed crops.
2. Modification should be done on improvement of cleaning efficiency.
3. Attempts should be made to operate this thresher by solar power as an alternate source of power.

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## APPENDIX-A

APPENDIX A1: Length (mm) of linseed

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 5.23 | 5.32 | 5.2 | 5.31 | 5.267 |
| | M2(10.00) | 5.31 | 5.39 | 5.42 | 5.39 | 5.378 |
| | M3(12.00) | 5.48 | 5.45 | 5.49 | 5.48 | 5.488 |
| | M4 (14.00) | 5.51 | 5.50 | 5.61 | 5.5 | 5.528 |
| Shekhar | M1(8.00) | 4.62 | 4.53 | 4.51 | 4.46 | 4.527 |
| | M2(10.00) | 4.71 | 4.64 | 4.69 | 4.60 | 4.660 |
| | M3(12.00) | 4.91 | 4.80 | 4.83 | 4.81 | 4.837 |
| | M4 (14.00) | 5.08 | 4.95 | 5.04 | 4.96 | 5.008 |
| Sheela | M1(8.00) | 4.57 | 4.54 | 4.63 | 4.58 | 4.580 |
| | M2(10.00) | 4.78 | 4.73 | 4.70 | 4.69 | 4.726 |
| | M3(12.00) | 4.89 | 4.87 | 4.90 | 4.92 | 4.895 |
| | M4 (14.00) | 5.02 | 5.07 | 4.98 | 5.06 | 5.033 |

APPENDIX A2: Breadth (mm) of linseed

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 2.73 | 2.768 | 2.8 | 2.79 | 2.772 |
| | M2(10.00) | 2.86 | 2.84 | 2.89 | 2.84 | 2.8575 |
| | M3(12.00) | 2.89 | 2.88 | 2.9 | 2.894 | 2.891 |
| | M4 (14.00) | 2.93 | 2.91 | 2.924 | 2.931 | 2.923 |
| Shekhar | M1(8.00) | 2.51 | 2.48 | 2.5 | 2.494 | 2.496 |
| | M2(10.00) | 2.57 | 2.593 | 2.601 | 2.597 | 2.590 |
| | M3(12.00) | 2.621 | 2.643 | 2.67 | 2.66 | 2.648 |
| | M4 (14.00) | 2.69 | 2.7 | 2.73 | 2.689 | 2.705 |
| Sheela | M1(8.00) | 2.37 | 2.368 | 2.379 | 2.365 | 2.370 |
| | M2(10.00) | 2.39 | 2.397 | 2.399 | 2.38 | 2.391 |
| | M3(12.00) | 2.4 | 2.408 | 2.41 | 2.399 | 2.405 |
| | M4 (14.00) | 2.431 | 2.417 | 2.43 | 2.42 | 2.424 |

APPENDIX A3: Thickness (mm) of linseed

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 0.898 | 0.902 | 0.921 | 0.895 | 0.904 |
| | M2(10.00) | 0.91 | 0.916 | 0.923 | 0.921 | 0.9175 |
| | M3(12.00) | 0.97 | 0.979 | 0.99 | 0.986 | 0.98125 |
| | M4 (14.00) | 1.03 | 1.05 | 1.08 | 1.09 | 1.0625 |
| Shekhar | M1(8.00) | 0.923 | 0.931 | 0.94 | 0.931 | 0.93125 |
| | M2(10.00) | 0.973 | 0.956 | 0.943 | 0.949 | 0.95525 |
| | M3(12.00) | 0.995 | 0.987 | 0.95 | 0.968 | 0.975 |
| | M4 (14.00) | 1.01 | 1.032 | 1.05 | 1.031 | 1.03075 |
| Sheela | M1(8.00) | 0.845 | 0.834 | 0.839 | 0.842 | 0.84 |
| | M2(10.00) | 0.873 | 0.886 | 0.885 | 0.87456 | 0.87964 |
| | M3(12.00) | 0.898 | 0.899 | 0.893 | 0.8867 | 0.894175 |
| | M4 (14.00) | 0.913 | 0.904 | 0.921 | 0.912 | 0.9125 |

APPENDIX A4 : GMD (mm) of linseed

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 2.32 | 2.347 | 2.355 | 2.346 | 2.342 |
| | M2(10.00) | 2.378 | 2.39 | 2.414 | 2.394 | 2.397 |
| | M3(12.00) | 2.463 | 2.47 | 2.484 | 2.47 | 2.474 |
| | M4 (14.00) | 2.537 | 2.53 | 2.582 | 2.575 | 2.553 |
| Shekhar | M1(8.00) | 2.186 | 2.169 | 2.179 | 2.16 | 2.174 |
| | M2(10.00) | 2.256 | 2.239 | 2.239 | 2.228 | 2.240 |
| | M3(12.00) | 2.319 | 2.302 | 2.286 | 2.294 | 2.303 |
| | M4 (14.00) | 2.377 | 2.377 | 2.413 | 2.374 | 2.388 |
| Sheela | M1(8.00) | 2.076 | 2.062 | 2.083 | 2.073 | 2.073 |
| | M2(10.00) | 2.136 | 2.141 | 2.137 | 2.121 | 2.133 |
| | M3(12.00) | 2.175 | 2.175 | 2.175 | 2.17 | 2.174279 |
| | M4 (14.00) | 2.215 | 2.211 | 2.215 | 2.217 | 2.215052 |

APPENDIX A5: 1000 GW (g) of linseed

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 8.876 | 8.592 | 8.913 | 8.936 | 8.829 |
| | M2(10.00) | 9.265 | 9.319 | 8.967 | 9.189 | 9.185 |
| | M3(12.00) | 9.682 | 9.381 | 9.952 | 9.891 | 9.727 |
| | M4 (14.00) | 10.791 | 10.502 | 10.635 | 10.418 | 10.587 |
| Shekhar | M1(8.00) | 7.946 | 8.291 | 8.192 | 8.363 | 8.198 |
| | M2(10.00) | 8.414 | 8.263 | 8.032 | 8.502 | 8.303 |
| | M3(12.00) | 8.661 | 8.442 | 8.463 | 8.723 | 8.572 |
| | M4 (14.00) | 8.906 | 8.735 | 8.710 | 8.494 | 8.711 |
| Sheela | M1(8.00) | 6.521 | 6.436 | 6.648 | 6.489 | 6.524 |
| | M2(10.00) | 7.034 | 6.731 | 7.114 | 6.831 | 6.928 |
| | M3(12.00) | 7.401 | 7.449 | 6.821 | 6.952 | 7.156 |
| | M4 (14.00) | 7.715 | 7.823 | 7.432 | 7.382 | 7.588 |

APPENDIX A6: Bulk density ($kg/m^3$)

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 691.234 | 690.541 | 692.012 | 690.792 | 691.14 |
| | M2(10.00) | 689.763 | 688.896 | 690.098 | 686.854 | 688.90 |
| | M3(12.00) | 680.512 | 678.459 | 677.235 | 669.897 | 676.53 |
| | M4 (14.00) | 667.265 | 663.781 | 662.892 | 662.164 | 664.03 |
| Shekhar | M1(8.00) | 701.1123 | 700.584 | 701.047 | 698.674 | 700.35 |
| | M2(10.00) | 696.107 | 694.567 | 694.345 | 692 | 694.17 |
| | M3(12.00) | 690.127 | 688.471 | 684.409 | 683.872 | 686.72 |
| | M4 (14.00) | 677.356 | 675.78 | 676.324 | 672 | 675.29 |
| Sheela | M1(8.00) | 745.789 | 744.376 | 745.108 | 743.458 | 744.68 |
| | M2(10.00) | 737.521 | 728.349 | 732.487 | 730.325 | 732.17 |
| | M3(12.00) | 724.638 | 721.19 | 719.643 | 719.294 | 721.19 |
| | M4 (14.00) | 693.509 | 690.287 | 689.765 | 689.109 | 690.67 |

**APPENDIX A7:** True Density(kg/m3)

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 1103.187 | 1094.397 | 1101.098 | 1091.592 | 1097.57 |
| | M2(10.00) | 1116.345 | 1112.208 | 1115.643 | 1112.109 | 1114.08 |
| | M3(12.00) | 1122.458 | 1120.569 | 1122.186 | 1119.389 | 1121.15 |
| | M4 (14.00) | 1128.87 | 1127.673 | 1129.327 | 1128.364 | 1128.56 |
| Shekhar | M1(8.00) | 1078.34 | 1081.27 | 1081.08 | 1079.597 | 1080.07 |
| | M2(10.00) | 1090.387 | 1089.421 | 1088.765 | 1092.051 | 1090.16 |
| | M3(12.00) | 1116.439 | 1114.824 | 1111.639 | 1112.208 | 1113.78 |
| | M4 (14.00) | 1128.145 | 1127.515 | 1125.854 | 1125.102 | 1126.65 |
| Sheela | M1(8.00) | 1078.356 | 1079.298 | 1081.235 | 1080.79 | 1079.92 |
| | M2(10.00) | 1091.378 | 1093.561 | 1089.478 | 1088.45 | 1090.72 |
| | M3(12.00) | 1096.387 | 1099.324 | 1099.081 | 1098.167 | 1098.24 |
| | M4 (14.00) | 1106.18 | 1103.642 | 1103.057 | 1104.498 | 1104.34 |

APPENDIX A8: Porosity

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 37.3421 | 36.9021 | 37.1526 | 36.717 | 37.02845 |
| | M2(10.00) | 38.2124 | 38.0605 | 38.1435 | 38.2386 | 38.16374 |
| | M3(12.00) | 39.3731 | 39.4541 | 39.6504 | 40.1551 | 39.65815 |
| | M4 (14.00) | 40.8909 | 41.1371 | 41.302 | 41.302 | 41.16162 |
| Shekhar | M1(8.00) | 34.9823 | 35.2073 | 35.1531 | 35.2838 | 35.15662 |
| | M2(10.00) | 36.2124 | 36.2444 | 36.2264 | 36.6628 | 36.32331 |
| | M3(12.00) | 38.185 | 38.244 | 38.4324 | 38.5122 | 38.3434 |
| | M4 (14.00) | 39.9584 | 40.0647 | 39.9279 | 40.2982 | 40.0623 |
| Sheela | M1(8.00) | 30.8402 | 31.0315 | 31.0873 | 31.2116 | 31.04265 |
| | M2(10.00) | 32.423 | 33.3966 | 32.7672 | 32.9023 | 32.87225 |
| | M3(12.00) | 33.9067 | 34.397 | 34.5232 | 34.5005 | 34.33185 |
| | M4 (14.00) | 37.306 | 37.4537 | 37.4679 | 37.6089 | 37.4591 |

APPENDIX A9: Angle of repose

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 20.631 | 20.31 | 20.481 | 20.663 | 20.52125 |
| | M2(10.00) | 21.345 | 20.927 | 21.401 | 21.583 | 21.314 |
| | M3(12.00) | 22.201 | 22.032 | 22.196 | 22.204 | 22.15825 |
| | M4 (14.00) | 23.531 | 22.873 | 22.998 | 23.376 | 23.1945 |
| Shekhar | M1(8.00) | 19.848 | 20.426 | 20.433 | 20.392 | 20.27475 |
| | M2(10.00) | 20.385 | 20.893 | 20.741 | 20.91 | 20.73225 |
| | M3(12.00) | 20.996 | 21.54 | 21.368 | 21.412 | 21.329 |
| | M4 (14.00) | 21.487 | 21.893 | 21.943 | 21.901 | 21.806 |
| Sheela | M1(8.00) | 21.052 | 20.915 | 20.912 | 20.794 | 20.91825 |
| | M2(10.00) | 21.802 | 21.763 | 21.71 | 21.593 | 21.717 |
| | M3(12.00) | 22.685 | 22.409 | 22.395 | 22.312 | 22.45025 |
| | M4 (14.00) | 23.194 | 23.045 | 22.987 | 23.205 | 23.10775 |

APPENDIXA10: Coefficient of friction GI sheet

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 0.334 | 0.338 | 0.341 | 0.34 | 0.33825 |
| | M2(10.00) | 0.357 | 0.362 | 0.352 | 0.363 | 0.3585 |
| | M3(12.00) | 0.378 | 0.383 | 0.373 | 0.385 | 0.37975 |
| | M4 (14.00) | 0.409 | 0.412 | 0.4 | 0.404 | 0.40625 |
| Shekhar | M1(8.00) | 0.342 | 0.348 | 0.3567 | 0.338 | 0.346175 |
| | M2(10.00) | 0.368 | 0.371 | 0.369 | 0.363 | 0.36775 |
| | M3(12.00) | 0.396 | 0.402 | 0.397 | 0.399 | 0.3985 |
| | M4 (14.00) | 0.421 | 0.42 | 0.415 | 0.41 | 0.4165 |
| Sheela | M1(8.00) | 0.345 | 0.358 | 0.354 | 0.349 | 0.3515 |
| | M2(10.00) | 0.38 | 0.39 | 0.397 | 0.386 | 0.38825 |
| | M3(12.00) | 0.434 | 0.438 | 0.425 | 0.421 | 0.4295 |
| | M4 (14.00) | 0.478 | 0.482 | 0.473 | 0.471 | 0.476 |

APPENDIX A11: Terminal velocity

| Main plot | Sub plot | R1 | R2 | R3 | R4 | Mean |
|---|---|---|---|---|---|---|
| Neelam | M1(8.00) | 2.446 | 2.441 | 2.433 | 2.449 | 2.44225 |
| | M2(10.00) | 2.608 | 2.596 | 2.589 | 2.609 | 2.6005 |
| | M3(12.00) | 2.898 | 2.867 | 2.923 | 2.967 | 2.91375 |
| | M4 (14.00) | 3.189 | 3.098 | 3.14 | 3.134 | 3.14025 |
| Shekhar | M1(8.00) | 2.432 | 2.421 | 2.433 | 2.432 | 2.4295 |
| | M2(10.00) | 2.503 | 2.49 | 2.51 | 2.502 | 2.50125 |
| | M3(12.00) | 2.587 | 2.608 | 2.612 | 2.62 | 2.60675 |
| | M4 (14.00) | 2.898 | 3.035 | 3.14 | 2.98 | 3.01325 |
| Sheela | M1(8.00) | 2.213 | 2.256 | 2.21 | 2.281 | 2.24 |
| | M2(10.00) | 2.378 | 2.38 | 2.367 | 2.388 | 2.37825 |
| | M3(12.00) | 2.582 | 2.578 | 2.552 | 2.581 | 2.57325 |
| | M4 (14.00) | 2.76 | 2.787 | 2.789 | 2.764 | 2.775 |

**APPENDIX B**

APPENDIX B1: Table effect of feed rate and speed on threshing efficiency

| Feed rate,kg/h | Speed, m/s | Threshing efficiency,% | | | |
|---|---|---|---|---|---|
| | | R1 | R2 | R3 | Mean |
| 200 | 13.27 | 96.25 | 96.43 | 96.78 | 96.487 |
| | 14.5 | 98.08 | 98.34 | 98.43 | 98.283 |
| | 15.71 | 95.89 | 95.67 | 95.56 | 95.707 |
| 250 | 13.27 | 97.12 | 97.32 | 97.76 | 97.400 |
| | 14.5 | 99.42 | 99.23 | 99.12 | 99.257 |
| | 15.71 | 96.67 | 96.27 | 96.57 | 96.503 |
| 300 | 13.27 | 95.09 | 95.12 | 94.88 | 95.030 |
| | 14.5 | 97.12 | 96.89 | 97.25 | 97.087 |
| | 15.71 | 94.43 | 94.21 | 93.87 | 94.170 |

APPENDIX B2: ANOVA Table for feed rate (A) and cylinder speed (B) on Threshing efficiency

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculate | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 23.988 | 11.994 | 248.022 | 0 |
| Factor B | 2 | 35.682 | 17.841 | 368.934 | 0 |
| Interaction A X B | 4 | 0.114 | 0.028 | 0.588 | 0.67529 |
| Error | 18 | 0.87 | 0.048 | | |
| Total | 26 | 60.654 | | | |

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.219 | 0.104 | 0.073 |
| Factor(B) | 0.219 | 0.104 | 0.073 |
| Factor(A X B) | N/A | 0.18 | 0.127 |

APPENDIX B3**:** Effect of moisture content, concave clearance and speed on threshing efficiency

| Moisture content (%) | Concave clearance(mm) | Speed (m/s) | Threshing efficiency,% | | | |
|---|---|---|---|---|---|---|
| | | | R1 | R2 | R3 | Mean |
| 8 | 8 | 13.27 | 98.13 | 98.15 | 98.17 | 98.15 |
| | | 14.50 | 99.19 | 99.21 | 99.23 | 99.21 |
| | | 15.71 | 98.32 | 98.35 | 98.38 | 98.35 |
| | 10 | 13.27 | 98.25 | 98.23 | 98.34 | 98.27 |
| | | 14.50 | 99.28 | 99.30 | 99.34 | 99.31 |
| | | 15.71 | 98.45 | 98.43 | 98.44 | 98.44 |
| 12 | 8 | 13.27 | 97.95 | 97.93 | 97.96 | 97.95 |
| | | 14.5 | 99.08 | 99.07 | 99.09 | 99.08 |
| | | 15.71 | 97.99 | 98.05 | 98.06 | 98.03 |
| | 10 | 13.27 | 97.99 | 97.98 | 98.09 | 98.02 |
| | | 14.50 | 99.18 | 99.19 | 99.17 | 99.18 |
| | | 15.71 | 98.17 | 98.18 | 98.18 | 98.18 |
| 16 | 8 | 13.27 | 97.74 | 97.73 | 97.72 | 97.73 |
| | | 14.50 | 98.89 | 98.88 | 98.90 | 98.89 |
| | | 15.71 | 97.82 | 97.84 | 97.82 | 97.83 |
| | 10 | 13.27 | 97.79 | 97.82 | 97.82 | 97.81 |
| | | 14.5 | 98.93 | 98.93 | 98.94 | 98.94 |
| | | 15.71 | 97.84 | 97.86 | 97.85 | 97.85 |

APPENDIX B4**:** ANOVA Table for moisture content (A), concave clearance (B) at different cylinder speed (C) on Threshing efficiency

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 1.809 | 0.904 | 910.306 | 0 |
| Factor B | 1 | 0.149 | 0.149 | 150.447 | 0 |
| Int A X B | 2 | -0.039 | -0.02 | -19.832 | NS |
| Factor C | 2 | 13.366 | 6.683 | 6,727.47 | 0 |
| Int A X C | 4 | 0.088 | 0.022 | 22.106 | 0 |
| Int B X C | 2 | -0.024 | -0.012 | -11.897 | NS |
| Int A X B X C | 4 | 0.031 | 0.008 | 7.75 | 0.00013 |
| Error | 36 | 0.036 | 0.001 | | |
| Total | 53 | 15.416 | | | |

APPENDIX B5

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.021 | 0.011 | 0.007 |
| Factor(B) | 0.017 | 0.009 | 0.006 |
| Interaction A X B | N/A | 0.015 | 0.011 |
| Factor(C) | 0.021 | 0.011 | 0.007 |
| Interaction A X C | 0.037 | 0.018 | 0.013 |
| Interaction B X C | N/A | 0.015 | 0.011 |

APPENDIX B6 : Table effect of, no of pegs on threshing efficiency

| | Threshing efficiency,% | | | | | |
|---|---|---|---|---|---|---|
| No of peg, No | R1 | R2 | R3 | R4 | R5 | Mean |
| 4 | 95.34 | 95.26 | 96.14 | 95.67 | 95.87 | 95.656 |
| 6 | 99.15 | 99.21 | 98.9 | 99.25 | 98.88 | 99.078 |

**APPENDIX C**

APPENDIX C1 : Table effect of feed rate and speed on threshing efficiency

| Feed rate,kg/h | Speed, m/s | Stripping efficiency,% | | | |
|---|---|---|---|---|---|
| | | R1 | R2 | R3 | Mean |
| 200 | 13.27 | 96.76 | 96.83 | 96.53 | 96.707 |
| | 14.5 | 98.13 | 98.02 | 97.96 | 98.037 |
| | 15.71 | 95.89 | 95.74 | 96.12 | 95.917 |
| 250 | 13.27 | 97.13 | 97.03 | 97.35 | 97.170 |
| | 14.5 | 98.34 | 98.25 | 98.65 | 98.413 |
| | 15.71 | 96.9 | 96.87 | 96.7 | 96.823 |
| 300 | 13.27 | 96.12 | 95.87 | 95.9 | 95.963 |
| | 14.5 | 97.67 | 97.56 | 97.21 | 97.480 |
| | 15.71 | 95.32 | 95.43 | 95.21 | 95.320 |

APPENDIX C2 : ANOVA Table for feed rate (A) and cylinder speed (B) on stripping efficiency

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 6.641 | 3.32 | 124.715 | 0 |
| Factor B | 2 | 18.106 | 9.053 | 340.044 | 0 |
| Interaction A X B | 4 | 0.355 | 0.089 | 3.336 | 0.03281 |
| Error | 18 | 0.479 | 0.027 | | |
| Total | 26 | 25.581 | | | |

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.163 | 0.077 | 0.054 |
| Factor(B) | 0.163 | 0.077 | 0.054 |
| Factor(A X B) | 0.282 | 0.133 | 0.094 |

APPENDIX C3: Table effect of moisture content, concave clearance and speed on stripping efficiency

| Moisture content (%) | Concave clearance(mm) | Speed (m/s) | Stripping efficiency,% | | | |
|---|---|---|---|---|---|---|
| | | | R1 | R2 | R3 | Mean |
| 8 | 8 | 13.27 | 97.23 | 97.34 | 97.15 | 97.24 |
| | | 14.50 | 99.12 | 98.97 | 99.23 | 99.11 |
| | | 15.71 | 98.10 | 97.80 | 98.33 | 98.08 |
| | 10 | 13.27 | 97.30 | 97.42 | 97.56 | 97.43 |
| | | 14.50 | 99.32 | 99.42 | 99.14 | 99.29 |
| | | 15.71 | 98.12 | 98.21 | 98.09 | 98.14 |
| 12 | 8 | 13.27 | 96.66 | 96.78 | 96.90 | 96.78 |
| | | 14.5 | 98.23 | 98.25 | 98.22 | 98.23 |
| | | 15.71 | 97.44 | 97.43 | 97.41 | 97.43 |
| | 10 | 13.27 | 97.16 | 96.98 | 97.18 | 97.11 |
| | | 14.50 | 98.45 | 98.26 | 98.35 | 98.35 |
| | | 15.71 | 97.66 | 97.55 | 97.77 | 97.66 |
| 16 | 8 | 13.27 | 94.89 | 95.32 | 94.78 | 95.00 |
| | | 14.50 | 97.77 | 97.75 | 98.12 | 97.88 |
| | | 15.71 | 95.85 | 96.23 | 95.98 | 96.02 |
| | 10 | 13.27 | 96.29 | 95.67 | 95.80 | 95.92 |
| | | 14.5 | 97.79 | 97.79 | 97.78 | 97.79 |
| | | 15.71 | 96.50 | 96.50 | 96.51 | 96.50 |

APPENDIX C4: ANOVA Table for moisture content (A), concave clearance (B) at different cylinder speed (C) on stripping efficiency

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 26.73 | 13.36 | 527.72 | 0.00 |
| Factor B | 1 | 1.22 | 1.22 | 48.22 | 0.00 |
| Int A X B | 2 | -0.01 | -0.01 | -0.21 | 1.23 |
| Factor C | 2 | 31.99 | 15.99 | 631.62 | 0.00 |
| Int A X C | 4 | 1.57 | 0.39 | 15.45 | 0.00 |
| Int B X C | 2 | 0.13 | 0.06 | 2.48 | 0.10 |
| Int A X B X C | 4 | 0.67 | 0.17 | 6.64 | 0.00 |
| Error | 36 | 0.91 | 0.03 | | |
| Total | 53 | 63.20 | | | |

APPENDIX C5

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.108 | 0.053 | 0.038 |
| Factor(B) | 0.088 | 0.043 | 0.031 |
| Interaction A X B | N/A | 0.075 | 0.053 |
| Factor(C) | 0.108 | 0.053 | 0.038 |
| Interaction A X C | 0.186 | 0.092 | 0.065 |
| Interaction B X C | N/A | 0.075 | 0.053 |
| Interaction A X B X C | 0.264 | 0.13 | 0.092 |

APPENDIX C6 Table Effect of no of loops on stripping efficiency

| | Stripping efficiency, % | | | | | |
|---|---|---|---|---|---|---|
| No of loop, No | R1 | R2 | R3 | R4 | R5 | Mean |
| 4 | 96.57 | 94.86 | 95.8 | 95.67 | 96.12 | 95.804 |
| 8 | 99.13 | 98.87 | 98.92 | 99.11 | 98.99 | 99.004 |

**APPENDIX D**

APPENDIX D1: Table effect of feed rate and speed on threshing capacity

| Feed rate,kg/h | Speed, m/s | Threshing capacity, kg/h | | | |
|---|---|---|---|---|---|
| | | R1 | R2 | R3 | Mean |
| 200 | 13.27 | 141.63 | 141.8 | 141.53 | 141.653 |
| | 14.5 | 145.24 | 145.85 | 144.12 | 145.070 |
| | 15.71 | 143.15 | 142.41 | 142.78 | 142.780 |
| 250 | 13.27 | 174.33 | 174.54 | 175.21 | 174.693 |
| | 14.5 | 178.39 | 178.45 | 179.01 | 178.617 |
| | 15.71 | 176.01 | 176.87 | 176.4 | 176.427 |
| 300 | 13.27 | 208.32 | 208.97 | 209.36 | 208.883 |
| | 14.5 | 212.23 | 213.12 | 212.65 | 212.667 |
| | 15.71 | 209.41 | 209.23 | 209.76 | 209.467 |

APPENDIX D2 : ANOVA Table for feed rate (A) and cylinder speed (B) on threshing capacity

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 0.184 | | | |
| Factor B | 2 | 20,742.98 | 10,371.49 | 81,252.74 | 0 |
| Interaction A X B | 4 | 45.168 | 22.584 | 176.93 | 0 |
| Error | 18 | 0.777 | 0.194 | 1.522 | 0.24287 |
| Total | 26 | 2.042 | 0.128 | | |

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.36 | 0.168 | 0.119 |
| Factor(B) | 0.36 | 0.168 | 0.119 |
| Factor(A X B) | N/A | 0.292 | 0.206 |

APPENDIX D3: Table effect of moisture content, concave clearance and speed on Threshing capacity

| Moisture content (%) | Concave clearance(mm) | Speed (m/s) | Threshing capacity, kg/h | | | |
|---|---|---|---|---|---|---|
| | | | R1 | R2 | R3 | Mean |
| 8 | 8 | 13.27 | 175.244 | 175.167 | 175.176 | 175.196 |
| | | 14.50 | 177.211 | 177.333 | 177.143 | 177.229 |
| | | 15.71 | 176.466 | 176.650 | 176.276 | 176.464 |
| | 10 | 13.27 | 175.311 | 175.547 | 176.122 | 175.660 |
| | | 14.50 | 178.112 | 178.499 | 179.245 | 178.619 |
| | | 15.71 | 177.011 | 176.877 | 177.212 | 177.033 |
| 12 | 8 | 13.27 | 174.324 | 173.956 | 174.457 | 174.245 |
| | | 14.5 | 176.387 | 175.878 | 176.168 | 176.145 |
| | | 15.71 | 175.198 | 175.354 | 175.545 | 175.366 |
| | 10 | 13.27 | 175.131 | 175.421 | 174.124 | 174.892 |
| | | 14.50 | 176.933 | 177.377 | 177.257 | 177.189 |
| | | 15.71 | 175.732 | 175.655 | 176.176 | 175.854 |
| 16 | 8 | 13.27 | 172.542 | 172.154 | 172.879 | 172.525 |
| | | 14.50 | 175.343 | 175.733 | 175.915 | 175.664 |
| | | 15.71 | 174.521 | 174.656 | 174.721 | 174.633 |
| | 10 | 13.27 | 173.112 | 173.367 | 173.144 | 173.208 |
| | | 14.5 | 176.567 | 176.787 | 176.855 | 176.736 |
| | | 15.71 | 174.332 | 174.245 | 175.322 | 174.633 |

APPENDIX D4 : ANOVA Table for moisture content (A), concave clearance (B) at different cylinder speed (C) on threshing capacity

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 41.238 | 20.619 | 187.555 | 0 |
| Factor B | 1 | 6.909 | 6.909 | 62.843 | 0 |
| Int A X B | 2 | -0.058 | -0.029 | -0.264 | 1.30464 |
| Factor C | 2 | 63.138 | 31.569 | 287.162 | 0 |
| Int A X C | 4 | 2.025 | 0.506 | 4.605 | 0.00417 |
| Int B X C | 2 | 1.32 | 0.66 | 6.003 | 0.00562 |
| Int A X B X C | 4 | 0.601 | 0.15 | 1.367 | 0.26466 |
| Error | 36 | 3.958 | 0.11 | | |
| Total | 53 | 119.13 | | | |

APPENDIX D3

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.224 | 0.111 | 0.078 |
| Factor(B) | 0.183 | 0.09 | 0.064 |
| Interaction A X B | N/A | 0.156 | 0.111 |
| Factor(C) | 0.224 | 0.111 | 0.078 |
| Interaction A X C | 0.388 | 0.191 | 0.135 |
| Interaction B X C | 0.317 | 0.156 | 0.111 |
| Interaction A X B X C | N/A | 0.271 | 0.191 |

APPENDIX E

APPENDIX E1 : Table effect of feed rate and speed on cleaning efficiency

| Feed rate, kg/h | Speed, m/s | Cleaning efficiency,% | | | |
|---|---|---|---|---|---|
| | | R1 | R2 | R3 | Mean |
| 200 | 13.27 | 88.12 | 87.9 | 88.23 | 88.083 |
| | 14.5 | 89.45 | 89.76 | 88.54 | 89.250 |
| | 15.71 | 87.67 | 87.24 | 87.13 | 87.347 |
| 250 | 13.27 | 88.32 | 88.43 | 88.21 | 88.320 |
| | 14.5 | 90.43 | 90.32 | 90.54 | 90.430 |
| | 15.71 | 87.7 | 87.89 | 87.88 | 87.823 |
| 300 | 13.27 | 85.67 | 85.34 | 85.21 | 85.407 |
| | 14.5 | 88.12 | 87.8 | 87.34 | 87.753 |
| | 15.71 | 84.34 | 84.23 | 84.6 | 84.390 |

APPENDIX E2 : ANOVA Table for feed rate (A) and cylinder speed (B) on stripping efficiency

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 45.259 | 22.63 | 257.964 | 0 |
| Factor B | 2 | 32.87 | 16.435 | 187.349 | 0 |
| Interaction A X B | 4 | 2.003 | 0.501 | 5.707 | 0.0038 |
| Error | 18 | 1.579 | 0.088 | | |
| Total | 26 | 81.711 | | | |
| Factors | | C.D. | | SE(d) | SE(m) |
| Factor(A) | | 0.296 | | 0.14 | 0.099 |
| Factor(B) | | 0.296 | | 0.14 | 0.099 |
| Factor(A X B) | | 0.512 | | 0.242 | 0.171 |

APPENDIX E3 : Table effect of moisture content, concave clearance and speed on cleaning efficiency

| Moisture content (%) | Concave clearance(mm) | Speed (m/s) | Cleaning efficiency,% | | | |
|---|---|---|---|---|---|---|
| | | | R1 | R2 | R3 | Mean |
| 8 | 8 | 13.27 | 86.83 | 85.73 | 86.23 | 86.26 |
| | | 14.50 | 90.08 | 90.16 | 90.056 | 90.10 |
| | | 15.71 | 84.88 | 84.76 | 84.79 | 84.81 |
| | 10 | 13.27 | 87.67 | 87.87 | 86.55 | 87.36 |
| | | 14.50 | 90.49 | 90.58 | 90.43 | 90.50 |
| | | 15.71 | 85.29 | 85.13 | 85.53 | 85.32 |
| 12 | 8 | 13.27 | 84.22 | 84.34 | 84.44 | 84.33 |
| | | 14.5 | 88.71 | 88.78 | 88.73 | 88.74 |
| | | 15.71 | 83.89 | 83.81 | 83.76 | 83.82 |
| | 10 | 13.27 | 84.45 | 84.52 | 84.43 | 84.47 |
| | | 14.50 | 89.13 | 89.11 | 89.12 | 89.12 |
| | | 15.71 | 83.98 | 84.15 | 84.1 | 84.08 |
| 16 | 8 | 13.27 | 83.65 | 83.67 | 83.62 | 83.65 |
| | | 14.50 | 87.63 | 87.62 | 87.61 | 87.62 |
| | | 15.71 | 82.9 | 83.13 | 82.75 | 82.93 |
| | 10 | 13.27 | 83.68 | 83.81 | 83.786 | 83.76 |
| | | 14.5 | 87.73 | 87.78 | 87.88 | 87.80 |
| | | 15.71 | 83.15 | 83.31 | 83.27 | 83.24 |

APPENDIX E4 : ANOVA Table for moisture content (A), concave clearance (B) at different cylinder speed (C) on cleaning efficiency

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 33.629 | 16.814 | 3,924.44 | 0 |
| Factor B | 1 | 0.664 | 0.664 | 154.906 | 0 |
| Int A X B | 2 | -0.108 | -0.054 | -12.569 | 2,328,930,044 |
| Factor C | 2 | 262.808 | 131.404 | 30,669.36 | 0 |
| Int A X C | 4 | 1.206 | 0.301 | 70.347 | 0 |
| Int B X C | 2 | -0.104 | -0.052 | -12.18 | 670,533,419.72 |
| Int A X B X C | 4 | 0.175 | 0.044 | 10.198 | 0.00001 |
| Error | 36 | 0.154 | 0.004 | | |
| Total | 53 | 298.423 | | | |

APPENDIX E5

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.044 | 0.022 | 0.015 |
| Factor(B) | 0.036 | 0.018 | 0.013 |
| Interaction A X B | N/A | 0.031 | 0.022 |
| Factor(C) | 0.044 | 0.022 | 0.015 |
| Interaction A X C | 0.077 | 0.038 | 0.027 |
| Interaction B X C | N/A | 0.031 | 0.022 |
| Interaction A X B X C | 0.108 | 0.053 | 0.038 |

**APPENDIX F**

APPENDIX F1: Table effect of feed rate and speed on visible seed damage

| Feed rate, kg/h | Speed, m/s | Visible seed damage ,% | | | |
|---|---|---|---|---|---|
| | | R1 | R2 | R3 | Mean |
| 200 | 13.27 | 1.23 | 1.35 | 1.28 | 1.287 |
| | 14.5 | 1.34 | 1.36 | 1.26 | 1.320 |
| | 15.71 | 1.55 | 1.45 | 1.42 | 1.473 |
| 250 | 13.27 | 1.65 | 1.59 | 1.55 | 1.597 |
| | 14.5 | 1.77 | 1.65 | 1.75 | 1.723 |
| | 15.71 | 1.94 | 1.86 | 1.99 | 1.930 |
| 300 | 13.27 | 1.75 | 1.83 | 1.86 | 1.813 |
| | 14.5 | 1.84 | 1.75 | 1.92 | 1.837 |
| | 15.71 | 2.63 | 2.75 | 2.41 | 2.597 |

APPENDIX F2 : ANOVA Table for feed rate (A) and cylinder speed (B) on visible seed damage

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 2.352 | 1.176 | 170.086 | 0 |
| Factor B | 2 | 0.996 | 0.498 | 71.988 | 0 |
| Interaction A X B | 4 | 0.426 | 0.106 | 15.384 | 0.00001 |
| Error | 18 | 0.124 | 0.007 | | |
| Total | 26 | 3.898 | | | |

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.083 | 0.039 | 0.028 |
| Factor(B) | 0.083 | 0.039 | 0.028 |
| Factor(A X B) | 0.144 | 0.068 | 0.048 |

APPENDIX F3 : Table effect of moisture content, concave clearance and speed on visible seed damage

| Moisture content (%) | Concave clearance(mm) | Speed (m/s) | Visible seed damage,% | | | |
|---|---|---|---|---|---|---|
| | | | R1 | R2 | R3 | Mean |
| 8 | 8 | 13.27 | 1.69 | 1.678 | 1.68 | 1.68 |
| | | 14.50 | 1.94 | 1.93 | 1.945 | 1.94 |
| | | 15.71 | 2.02 | 2.05 | 2.067 | 2.05 |
| | 10 | 13.27 | 1.75 | 1.77 | 1.765 | 1.76 |
| | | 14.50 | 1.843 | 1.84 | 1.85 | 1.84 |
| | | 15.71 | 1.921 | 1.93 | 1.923 | 1.92 |
| 12 | 8 | 13.27 | 1.467 | 1.46 | 1.47 | 1.47 |
| | | 14.5 | 1.539 | 1.534 | 1.542 | 1.54 |
| | | 15.71 | 1.67 | 1.68 | 1.69 | 1.68 |
| | 10 | 13.27 | 1.33 | 1.32 | 1.35 | 1.33 |
| | | 14.50 | 1.43 | 1.42 | 1.42 | 1.42 |
| | | 15.71 | 1.53 | 1.55 | 1.543 | 1.54 |
| 16 | 8 | 13.27 | 1.23 | 1.25 | 1.245 | 1.24 |
| | | 14.50 | 1.316 | 1.317 | 1.32 | 1.32 |
| | | 15.71 | 1.44 | 1.454 | 1.43 | 1.44 |
| | 10 | 13.27 | 1.04 | 1.07 | 1.08 | 1.06 |
| | | 14.5 | 1.11 | 1.13 | 1.13 | 1.12 |
| | | 15.71 | 1.22 | 1.21 | 1.22 | 1.22 |

APPENDIX F4: ANOVA Table for moisture content (A), concave clearance (B) at different cylinder speed (C) on visible seed damage.

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 3.631 | 1.816 | 14,887.71 | 0 |
| Factor B | 1 | 0.209 | 0.209 | 1,713.28 | 0 |
| Int A X B | 2 | 0.053 | 0.027 | 218.682 | 0 |
| Factor C | 2 | 0.423 | 0.212 | 1,735.11 | 0 |
| Int A X C | 4 | 0.021 | 0.005 | 42.987 | 0 |
| Int B X C | 2 | 0.017 | 0.008 | 68.37 | 0 |
| Int A X B X C | 4 | 0.021 | 0.005 | 42.579 | 0 |
| Error | 36 | 0.004 | 0 | | |
| Total | 53 | 4.38 | | | |

APPENDIX F5

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.007 | 0.004 | 0.003 |
| Factor(B) | 0.006 | 0.003 | 0.002 |
| Interaction A X B | 0.011 | 0.005 | 0.004 |
| Factor(C) | 0.007 | 0.004 | 0.003 |
| Interaction A X C | 0.013 | 0.006 | 0.005 |
| Interaction B X C | 0.011 | 0.005 | 0.004 |
| Interaction A X B X C | 0.018 | 0.009 | 0.006 |

APPENDIX F6: Table effect of no of pegs on visible seed damage

| | visible seed damage | | | | | |
|---|---|---|---|---|---|---|
| No of pegs, No | R1 | R2 | R3 | R4 | R5 | Mean |
| 4 | 1.58 | 1.42 | 1.67 | 1.55 | 1.32 | 1.508 |
| 6 | 1.98 | 1.88 | 2.13 | 1.93 | 1.82 | 1.948 |

**APPENDIX G**

APPENDIX G1: Table effect of feed rate and speed on invisible seed damage

| Feed rate, kg/h | Speed, m/s | Invisible seed damage ,% | | | |
|---|---|---|---|---|---|
| | | R1 | R2 | R3 | Mean |
| 200 | 13.27 | 0.93 | 0.95 | 0.89 | 0.923 |
| | 14.5 | 1.13 | 1.16 | 1.14 | 1.143 |
| | 15.71 | 1.23 | 1.21 | 1.21 | 1.217 |
| 250 | 13.27 | 1.4 | 1.42 | 1.38 | 1.400 |
| | 14.5 | 1.56 | 1.59 | 1.58 | 1.577 |
| | 15.71 | 1.68 | 1.65 | 1.66 | 1.663 |
| 300 | 13.27 | 1.73 | 1.707 | 1.74 | 1.726 |
| | 14.5 | 1.82 | 1.85 | 1.83 | 1.833 |
| | 15.71 | 2.09 | 2.13 | 1.96 | 2.060 |

APPENDIX G2 : ANOVA Table for feed rate (A) and cylinder speed (B) on invisible seed damage

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculated | Significance |
|---|---|---|---|---|---|
| Replication | 2 | 0.004 | | | |
| Factor A | 2 | 2.751 | 1.376 | 1,311.78 | 0 |
| Factor B | 2 | 0.399 | 0.2 | 190.346 | 0 |
| Interaction A X B | 4 | 0.023 | 0.006 | 5.575 | 0.00525 |
| Error | 16 | 0.017 | 0.001 | | |
| Total | 26 | 3.195 | | | |
| Factors | | | C.D. | SE(d) | SE(m) |
| Factor(A) | | | 0.033 | 0.015 | 0.011 |
| Factor(B) | | | 0.033 | 0.015 | 0.011 |
| Factor(A X B) | | | 0.057 | 0.026 | 0.019 |

APPENDIX G3: Table effect of moisture content, concave clearance and speed on invisible seed damage

| Moisture content (%) | Concave clearance(mm) | Speed (m/s) | Invisible seed damage,% | | | |
|---|---|---|---|---|---|---|
| | | | R1 | R2 | R3 | Mean |
| 8 | 8 | 13.27 | 1.557 | 1.550 | 1.560 | 1.56 |
| | | 14.50 | 1.740 | 1.730 | 1.734 | 1.73 |
| | | 15.71 | 1.900 | 1.910 | 1.913 | 1.91 |
| | 10 | 13.27 | 1.476 | 1.470 | 1.460 | 1.47 |
| | | 14.50 | 1.670 | 1.680 | 1.690 | 1.68 |
| | | 15.71 | 1.800 | 1.790 | 1.770 | 1.79 |
| 12 | 8 | 13.27 | 1.240 | 1.230 | 1.250 | 1.24 |
| | | 14.5 | 1.350 | 1.340 | 1.360 | 1.35 |
| | | 15.71 | 1.570 | 1.560 | 1.550 | 1.56 |
| | 10 | 13.27 | 1.160 | 1.150 | 1.170 | 1.16 |
| | | 14.50 | 1.280 | 1.295 | 1.270 | 1.28 |
| | | 15.71 | 1.370 | 1.360 | 1.380 | 1.37 |
| 16 | 8 | 13.27 | 1.120 | 1.120 | 1.110 | 1.12 |
| | | 14.50 | 1.200 | 1.220 | 1.200 | 1.21 |
| | | 15.71 | 1.300 | 1.290 | 1.300 | 1.30 |
| | 10 | 13.27 | 0.900 | 0.890 | 0.990 | 0.93 |
| | | 14.5 | 1.000 | 1.040 | 1.060 | 1.03 |
| | | 15.71 | 1.100 | 1.130 | 1.140 | 1.12 |

APPENDIX G4 : ANOVA Table for moisture content (A), concave clearance (B) at different cylinder speed (C) on invisible seed damage

| Source of Variation | DF | Sum of Squares | Mean Squares | F-Calculate | Significance |
|---|---|---|---|---|---|
| Factor A | 2 | 3.011 | 1.505 | 4,708.71 | 0 |
| Factor B | 1 | 0.216 | 0.216 | 674.74 | 0 |
| Int A X B | 2 | 0.02 | 0.01 | 31.315 | 0 |
| Factor C | 2 | 0.622 | 0.311 | 972.461 | 0 |
| Int A X C | 4 | 0.036 | 0.009 | 28.315 | 0 |
| Int B X C | 2 | 0.009 | 0.005 | 14.38 | 0.00003 |
| Int A X B X C | 4 | 0.008 | 0.002 | 6.179 | 0.00068 |
| Error | 36 | 0.012 | 0 | | |
| Total | 53 | 3.933 | | | |

APPENDIX G5

| Factors | C.D. | SE(d) | SE(m) |
|---|---|---|---|
| Factor(A) | 0.012 | 0.006 | 0.004 |
| Factor(B) | 0.01 | 0.005 | 0.003 |
| Interaction A X B | 0.017 | 0.008 | 0.006 |
| Factor(C) | 0.012 | 0.006 | 0.004 |
| Interaction A X C | 0.021 | 0.01 | 0.007 |
| Interaction B X C | 0.017 | 0.008 | 0.006 |
| Interaction A X B X C | 0.03 | 0.015 | 0.01 |

**APPENDIX H**

**INSTRUMENT USED**

Vernier Calliper

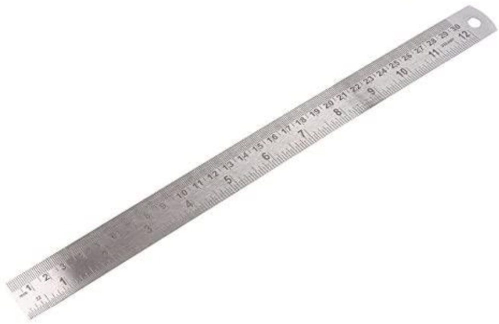
- Digital type
- least count reading 0.01 mm
- Used to measure internal and external distance accuratly


Measuring tape

- 3m steel tape for measuring crop and machine parameters

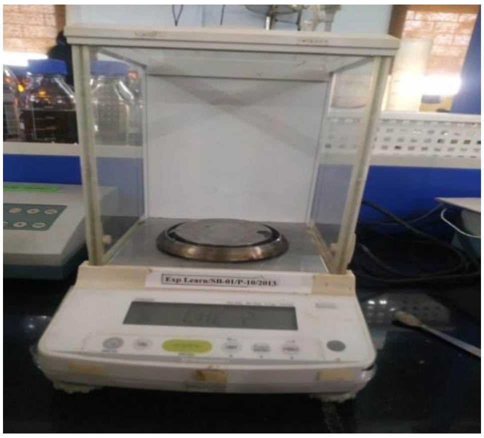

Measuring scale

- 30cm steal scale is used to measuring crop and machine parameters



Weighing machine

- Electronic analytical type
- It can measure 0.1 mg accurately.



Hot air oven

- Used to determine moisture content
- The temperature range covered by oven is between 50-250℃

Coefficient of friction measuring instrument

- horizontal plane and bottomless open container and the container was tied with a cord passing over a frictionless pulley
- Sets of weight having 100g, 50g, 20g, 10g, 5g, and 2g.

Angle of repose

- box measuring 950mm×100mm×150mm,
- having a open ended cylinder of 70mm diameter
- and  height of cone 45mm

Stop watch

- 0-15 min
- Least count- 0.1 sec

Tachometer

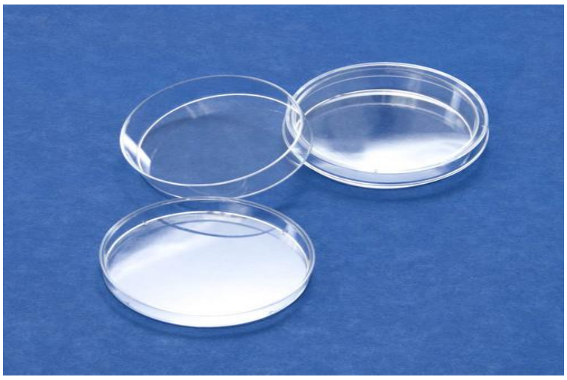
- 0-2000 rpm
- For measurement of speed of rotating parts


Abney level

- 0-90°
- Least count- 0.1
- For measuring sieve slope

Petri dishes

- For determination of germination rate and moisture content



# RESUME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**Signature**