STUDIES ON DESIGN AND PERFORMANCE OF MAIZE DEHUSKER-CUM-SHELLER

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DOCTOR OF PHILOSOPHY

By

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OCTOBER, 2007

Dedicated

To

Basundhara (Wife)

Siddartha (son)

Amit (son)

CERTIFICATE

This is to certify that the thesis entitled **"Studies on Design and Performance of Maize Dehusker-cum-Sheller"** submitted by **Aum Sarma** to the **Indian Institute of Technology, Kharagpur** for the award of the Degree of **Doctor of Philosophy** in Engineering is a record of bonafide research work carried out by him under my supervision and guidance. Shri. Sarma has worked on this problem for a period of more than three years. The thesis is, in my opinion, worthy of consideration for the award of the degree of **Doctor of Philosophy** in accordance with the regulations of the Institute. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any Degree or Diploma.

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ABSTRACT

During the last 5 years there has been a growing effort by the government to increase the area under maize cultivation, because this crop has the ability to thrive under minimal water requirement of 400-600 mm. However, the desired success has not been achieved due to its lower productivity level owing to poor level of mechanization. There has been a long felt need for a high capacity maize dehusker-cum-sheller in maize growing areas of the country which can remove the husk and shell the maize cobs in a single operation. The present study was undertaken with a view to develop such a machine and suggest the farmers to adopt suitable values of crop and machine operational parameters for the optimum threshing.

The studies were carried out in three different phases. In the first phase, physical properties of maize kernel and maize cob that have bearing on dehusking and shelling performance of maize thresher were determined. These include length, breadth, thickness, bulk density, sphericity and terminal velocity for maize kernel; and cob size and grain-to-non grain ratio for maize cob. In addition, an effort was also made to determine the force required to detach husk and a single kernel from maize cobs using a pendulum device which was specially developed for this purpose. Results indicated that the size of the maize kernel ranged from 6.91 - 7.93 mm and grain-to-non grain ratio from 2.64 - 4.34. The force required to detach husk and a single kernel from maize cob ranged from 5.83 - 23.26 N and 3.89 - 17.33 N respectively.

In the second phase, a systematic design approach was established to design the different components of a maize dehusker-cum-sheller to be powered by a 25-35 hp tractor. The machine was designed for a theoretical flow rate of 4000 kg/h and cylinder peripheral speed of 13.32 m/s. The machine was fabricated using the design specifications of different components. The developed unit derives power from tractor PTO. The maize cobs fed to the hopper move axially along the length of the cylinder where dehusking and shelling of cobs is performed due to impact forces as well as shearing action between cylinder and concave assembly. A thrower-cum-blower used at the other end of the cylinder throws the husk pieces at the thrower outlet. The threshed grain and small chaff particles passing through the concave finally get cleaned and separated by a centrifugal main blower and a set of oscillating sieves. The clean sound grains are collected at the main outlet.

In the third phase, the developed machine was used to study the effect of crop moisture content, cylinder peripheral speed and concave clearance on its dehusking and shelling performance. The crop variety used was Kargil 9000. The moisture content was varied from 15.4 – 25.6 per cent (wb), peripheral speed from 10.41 – 12.91 m/s and concave clearance from 40 – 48 mm. The data obtained were used to develop empirical equations to predict dehusking, shelling and cleaning efficiencies as well as various grain losses. A Matlab program was developed to determine the suitable values of various independent parameters for optimum performance. The machine was found to give dehusking, shelling and cleaning efficiencies in the range of 98.5 – 100 per cent, 96.7 – 99.9 per cent and 99.3 – 99.5 per cent respectively. The total grain losses were found to be ranging from 3.25 - 6 per cent which included grain damage to the extent of 1-3.4 per cent. It was finally concluded that the machine may be operated at crop moisture content within 15-20 per cent while setting the peripheral speed between 10.4 – 11.4 m/s and concave clearance at 40mm.

Such a machine is expected to increase the profit margin of farmers in maize growing regions to a large extent and also will help them to partially replace their major wheat or rice crop with maize crop in the water deficient areas. The design information presented in the thesis may be useful to the scientists for developing suitable dehusking and shelling machines for maize crop.

Key words : Maize, dehusker-cum-sheller, tractor power, physical property, mechanical property, cylinder speed, concave clearance, moisture content, dehusking efficiency, shelling efficiency, cleaning efficiency, thrower loss, blower loss, grain damage, multiple regression analysis, optimization.

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LIST OF NOTATIONS

AC	alternate current
AICRP	All India Coordinated Research Project
ANGRAU	Acharya N. G. Ranga Agricultural University
ANSI	American National Standard Institute
AP	Andhra Pradesh
ASAE	American Society of Agricultural Engineers
BD	bulk Density
BD_{cob}	bulk density of cob
BD_{core}	bulk density of core
BIS	Bureau of Indian Standard
CAE	College of Agricultural Engineering
CGL	Collectable Grain Loss
CIAE	Central Institute of Agricultural Engineering
cm	centimeter
CV	co-efficient of Variance
db	dry basis
DC	direct current
Dia/dia	diameter
eqn.	equation
Fig.	figure
Figs.	figures
FIM	Farm Implement and Machinery
FMP	Farm Machinery and Power
FS	factor of safety
g	gram
g/cm^3	gram per cubic centimeter
GDP	gross domestic product
h	hour
h/t	hour per tonne
ha	hectare
hp	horse power
ICAR	Indian Council of Agricultural Research
IS	Indian Standard
kg	kilogram

kg/cm^3	kilogram per cubic centimeter
kg/m^3	kilogram per cubic meter
kg kernel/h	kilogram kernel per hour
kg/ kWh	kilogram per kilowatt hour
kg/ha	kilogram per hectare
kg/kW/h	kilogram per kilowatt per hour
kg/h	kilogram per hour
kg/min	kilo gram per minute
kg/s	kilogram per second
kPa	kilo Pascal
kW	kilowatt
kW/h	kilowatt per hour
kW/ha	kilowatt per hectare
kW/t	kilowatt per tonne
kW-h/t	kilowatt-hour per tonne
m	meter
mg	milligram
mm	millimeter
m/min	meter per minute
m/s	meter per second
man-h/ha	man-hour per hectare
MOG	material other than grain
MP	Madhya Pradesh
MPUAT	Maharana Pratap University of Agriculture &Technology
MS	mild steel
N	newton
N/mm^2	newton per square millimeter
NCGL	non-collectable grain loss
Nm/N.m	newton meter
$N\text{-}sec^2/m^2$	newton second square per meter square
N/m^2	newton per square meter
PAU	Punjab Agricultural University
PTO	power take off
q/h	quintal per hour
r/min	revolution per minute
s	second
1/s	per second

SD	standard deviation
Stroke/min	stroke per minute
t/h	tonne per hour
TGL	total grain loss
TNAU	Tamil Nadu Agricultural University
UA	Uttaranchal
UP	Uttar Pradesh
V/V	volume by volume
wb	wet basis
µm	micro meter
W	watt

LIST OF SYMBOLS

τ_p	allowable shear stress
γ_a	bulk density of air
η_c	conversion efficiency
η	cleaning efficiency
τ	maximum shear stress of the shaft material
σ_{Ut}	ultimate stress
σ_y	yield stress
α	frequency of sieve oscillation
θ	side inclination angle of the trapezoidal portion with vertical plane
ρ_b	bulk density of maize cobs with husk
ρ_c	bulk density of core pieces
ρ_g	density of grain
A	proportionality coefficient for friction in bearings
A_a	surface area of thrower-cum-blower blade
A_b	surface area of main blower blade
A_c	area of concave surface
a_p	distance between adjacent paths of cylinder pegs
B	proportionality coefficient for windage of threshing drum
C_m	combined shock factor
C_t	combined fatigue factor
d	diameter of main shaft
d_b	diameter of main blower shaft
D	diameter of sieve hole
D_c	threshing cylinder diameter
dc	diameter of smallest circumscribed circle
D_b	diameter of pulley on main blower shaft
di	diameter of largest inscribed circle
D_p	diameter of pulley on main shaft
E_c	cleaning efficiency
E_d	dehusking efficiency
E_s	shelling efficiency

f	wear coefficient
F_t	tangential load working on the main shaft pulley
F_{tb}	tangential load working on the main blower shaft pulley
h_1	height of trapezoidal portion of feeding hopper
h_2	height of rectangular portion of feeding hopper
h_p	height of grain pile on a circular plate
h_t	total height of feeding hopper
K_m	combined shock and impact factors for bending moment
K_t	combined shock and impact factors for twisting moment
L_b	blower loss
l_b	bottom section dimension of feeding hopper trapezoidal portion
l_c	working length of the cylinder
L_{gd}	loss due to visible grain damage
l_p	peg length
l_s	stroke length of sieve
L_t	thrower loss
l_t	top section dimension of feeding hopper trapezoidal portion
l_{tb}	length of thrower-cum-blower
M_{bb}	bending moment experienced by main blower shaft
M_{bm}	bending moment experienced by main shaft
M_c	moisture content
M_p	bending moment experienced by the peg
m_p	number of pitch of the helix over which teeth are located
N_1	power required to thresh by impact and elongation of the plant mass
N_2	power required overcoming the bearing friction and windage
N_a	speed of thrower-cum-blower
N_b	speed of main blower
N_c	speed of threshing cylinder
N_e	speed of sieving unit
n_p	number of adjacent planes in which the teeth move
n_s	number of strokes per min for sieve shaker
N_t	total power required to run the thresher drum
P	total tangential force
P_1	impact force
P_2	extensive force
P_a	power available to operate thrower-cum-blower

P_b	power available to operate main blower
q	feed rate of the plant mass
Q_b	volume flow rate of air from main blower
q_c	quantity of core pieces coming to sieves
q_g	quantity of grain coming to sieves
q_0	permissible feed per tooth
Q_s	volume flow rate of the material coming to sieves
Q_t	volume flow rate of air from thrower-cum-blower
q_v	volume flow rate of maize cobs
R_{be}	effective radius of the main blower
R_{bi}	inner radius of the main blower
R_{bo}	outer radius of the main blower
r_{bp}	radius of circular plate
R_i	inner radius of the thrower-cum-blower
R_o	outer radius of the thrower-cum-blower
R_{te}	effective radius of the thrower-cum-blower
T	torque to be transmitted to main shaft
T_b	torque to be transmitted to the main blower shaft
T_e	equivalent twisting moment experienced by the main shaft
T_{eb}	equivalent twisting moment experienced by the blower shaft
T_p	twisting moment experienced by the peg
t_s	seed bed thickness on sieves
u	cylinder peripheral speed
u_1	speed of the plant mass before impact
u_2	speed of the plant mass after impact
u_a	peripheral velocity of thrower-cum-blower
u_b	peripheral velocity of the main blower
v_a	air velocity from thrower-cum-blower
v_b	air velocity from main blower
V_{cob}	volume of wet cob sample
V_{core}	volume of wet core sample
V_f	volume of feed in the hopper
V_R	volume of the feeding hopper rectangular portion
V_S	volume of sample
v_s	velocity of seed flow along the sieve length
Vt	threshing cylinder speed
V_T	volume of the feeding hopper trapezoidal portion

W_c	weight of whole grain per unit time obtained from main grain outlet
W_{cf}	total weight of cobs fed into the hopper per unit time
W_{cob}	weight of cob sample
W_{core}	weight of core sample
W_d	weight of dried sample
W_{dg}	quantity of damaged grain collected at all outlet per unit time
W_{gb}	quantity of detached grain collected at blower outlet per unit time
W_{gt}	quantity of detached grain obtained at thrower outlet per unit time
W_{hc}	weight of husked cobs obtained per unit time at thrower outlet
W_i	weight of total grain input per unit time
W_m	quantity of whole material per unit time at main grain outlet
W_s	weight of sample
w_s	sieve width
w_t	blade width of thrower-cum-blower
W_t	weight of threshed grain obtained per unit time from all outlets
W_u	weight of unthreshed grain per unit time obtained from all outlets
z	number of pegs on threshing cylinder
Δq	quantity of plant mass which suffers the impact
Δt	duration of impact
ϕ	angle of repose

CHAPTER I

INTRODUCTION

Rice and wheat are the two most important cereal crops in India and other South Asian Nations. The total production of cereals in India during 2006-07 has been estimated at 197.67 million tonnes and the total production of food grains at 211.78 million tonnes. Rice occupies 46 per cent of the total cereal followed by wheat at 37 per cent and maize at 9.3 per cent. Rice cultivation is highly dependent upon assured availability of water. There has been substantial lowering of ground water table due to over pumping. Wheat cultivation is also dependent upon irrigation to a certain extent. Higher yields are achieved with 2-3 irrigations at the flowering and milk formation stages. In such a scenario, increasing the area under maize would not only meet the ever-growing need of cereals but also reduce the water requirement to a larger extent. Unlike other cereals, maize has the ability to thrive under minimal water requirement of 400-600 mm (Singh, 2001). It could form a suitable replacement of wheat or rice and reduce the rapid depletion of ground water.

1.1 Agricultural Mechanization Scenario in India

Agriculture is both a way of life and principal means of livelihood for nearly sixty five per cent population of about 105 crore Indians. Presently, Indian agriculture is in crises. Growth in agriculture sector, on which half the rural population is dependent, is barely 1.84 per cent per annum since mid-90's. On the other hand Indian economy has witnessed an annual growth rate of well over 8 per cent in the GDP, thereby pushing India among the front-rank of fast-growing developing countries. It is a cause of worry to one and all that average farm size is becoming smaller and smaller by each passing year and the cost-risk-return structure of farming is getting acutely distorted.

The greatest challenge for India during the 20th century was to enhance agricultural production and productivity to ensure food security for a fast-growing population to avert large-scale starvation of her people. This challenge was duly met by ushering in the Green Revolution beginning mid-60's. This was achieved through adoption of biological, chemical and mechanical innovations coupled with right government policies by providing the required infrastructures, inputs and incentives such as Minimum Support Price to the farmers. Consequently, the country could increase the food production from a mere 51 million tonnes in 1950-51 to 211 million tonnes by 2000-01 and since then it has been maintaining a uniform level. Today, India is the second largest producer of rice, wheat, groundnut, fruits and vegetables as well as fish; fourth largest producer of coarse grains, rape seed and cotton (lint). To sustain the growing population of the country by 2025, agricultural production will have to be increased by 85 per cent and the productivity by 100 per cent from the present level. These targets are to be achieved against many odds and constraints for sustainable agricultural development. Intensive, input-based hi-tech agriculture during the last four decades has stressed the natural resources of soil, water, vegetation and climate to the maximum. Degradation of natural resources is threatening the agricultural produce. Hence, during the 21st century balancing food, nutritional and environmental security is going to be the toughest challenge for India.

Agricultural mechanization ensures timeliness and precision in the application and utilization of various inputs, curtails the losses at different stages, reduces the cost of production, removes the drudgery of men and animals, upgrades the quality of farm operations and produce, creates additional employment opportunities and above all enhances the cropping intensity, agricultural productivity and production. Hence, it is sine-qua-non for ensuring food, nutritional and environmental security for our country.

The country evolved a Selective Mechanization model using a power-mix based on animate and inanimate power sources. The animate power sources include the human beings and animals and the inanimate power sources include electro-mechanical power sources such as diesel engines, tractors, power tillers and electric motors. One of the globally used indices of agricultural mechanization is power availability per unit area. The power availability is computed by taking both animate and inanimate power sources. Nearly 80 per cent of the farm power in India at present is contributed by inanimate power sources. The present level of power availability in the country is 1.15 kW/ha and the productivity of cereal crops is 2642 kg/ha. The level of farm mechanization for different farming operations is given in Table 1.1 (Singh, 2002). These data indicate that the mechanization level has to be increased substantially for various operations to boost the agricultural productivity.

1.2 Mechanization in Maize Cultivation

Maize (*Zea mays L.*) is a coarse cereal and is the staple food in many developed countries. It is also an important input for many industrial products. Its uses range from the production of malt, alcohol and starch sweetener to scores of animal feed. The area under maize in India is 7.42 million hectares with productivity of 1983 kg/ha. While maize has a much higher genetic yield potential, it is yet to be realized in the Indian context. A proper mix of production and processing technologies can easily achieve 10-15 per cent increase in the productivity of maize. The technology mission adopted by the Government of India on maize is expected to give rise to a surplus of 3-3.5 million tonnes, which could be exported. Shelling of the grain immediately after its maturity is necessary for the best utilization of the grain by industrial and domestic consumers. Harvest of the crop and subsequent post-harvest of the grain at the appropriate time and moisture content is a pre-requisite for the success of the mission.

Rice – Rice and Rice – Wheat are the two major crop rotations followed in many parts of the country. Declining ground water table and excessive use of natural sources has become a problem of the present times and poses a great danger to sustainable agriculture. To replace rice with other crops like cotton, maize and pulses is a possible solution to save the most precious natural resource i.e. water. Maize is a potential crop that can replace partly rice throughout the country. Tillage machinery viz rotavators, harrows and cultivators and different designs of maize shellers for shelling of cobs are available for various farm operations which are being partially adopted in the country by the maize growers. But the level of maize mechanization is 47.8 per cent only (Table 1.1). Maize headers for combines, high capacity maize threshers and maize dehusker-cum-shellers are today the most needed equipment for maize mechanization in India keeping in view the size of land holdings. The recent trends in agro-processing technologies demand mechanization for value added products.

Table 1.1 Level of Agricultural Mechanization in India

Operation	Level, %
Tillage	40.2
a) Tractor	15.6
b) Animal	24.7
Sowing with drills and planters	28.9
a) Tractor	8.3
b) Animal	20.6
Irrigation	37
Threshing	
a) Thresher for wheat, maize	47.8
b) Paddy and others	4.4
Harvesting:	
a) Reapers	0.56
b) Combines	0.37
Plant protection	34.2

1.3 Techniques of Maize Threshing and their Limitations

Threshing of maize is one of the critical operations. Maize is shelled from the cobs by manual methods and also by a variety of shelling machines. Manual harvesting of maize is highly labour intensive, accounting for 250-400 man-h/ha (Gupta *et al.,* 1985). Combine harvesting of maize results in grain damage and other losses if it is carried out at high moisture content (Anadozo *et al.*, 1981). Losses are reported to occur chiefly in gathering, threshing, separating and cleaning devices of the machine. Many designs of power threshers driven by Tractor PTO or electric motors/engines are available to thresh different crops. About 90 per cent threshers in use are primarily for wheat and paddy. The power threshers used for maize crop have a rotating cylinder with pegs, spiral flutes or paddles around the periphery. The axial flow design of these threshers is getting popularized due to its better handling capacity and less grain damage (Pandey *et al.*, 1997). Ordinarily popular maize shellers are not capable of handling the cobs with husk. The cobs must first be dehusked for which a number of machines and methods have been developed. Rasp bar type cylinders are capable of dehusking and shelling the cobs, but these machines are not common due to their high cost, excessive grain damage and inability to thresh multi crops.

Adoption of maize cultivation on a large scale has led to the development of several designs of multi-crop threshers by many research and development organizations. These threshers require prior dehusking of the cob, which in itself is a distinct unit operation. Such threshers are therefore, not popular owing to their high overall cost of threshing. Attempts have been made to develop machines for carrying out dehusking and threshing in a single operation to reduce processing time and cost of operation. However, such machines require relook into their design with a view to improve their threshing performance and make them more cost effective.

1.4 Justification and Scope of Work

The present trend in diversification of agriculture from paddy to other cereal crops such as maize indicates that there is a need in mechanization of threshing operation demanding high capacity machines to be used for contract services. The machine should be capable of removing husk and grain in a single operation. Safety and comfort in design and development of threshing machinery require special attention. A thresher should perform with maximum threshing efficiency and with minimum breakage, grain losses and input power. Different components of the thresher should match with the power and capacity for which the thresher is designed.

Past studies indicate that very little efforts have been made to generate empirical data necessary for the design of maize dehusker-cum-shellers particularly in the Indian context. As a result, the development of a suitable thresher for maize has not met with the desired level of acceptability. An effective design of thresher requires the input data related to physical and engineering properties of maize, as well as various forces encountered by different components during threshing. It is also essential to study the effect of major design parameters such as peripheral speed, concave clearance and grain moisture with a view to achieve high efficiency and low grain damage. Keeping these requirements in mind, the present study was undertaken with the following objectives:

1. To study the properties of maize kernel and maize cobs, which have bearing on mechanical dehusking and shelling.
2. To design and fabricate a prototype maize dehusker-cum-sheller based on functional and strength requirements.
3. To study the effect of some of the operational parameters such as crop moisture content, cylinder peripheral speed and concave clearance on dehusking and shelling of maize cobs.
4. To develop empirical models for evaluating the performance of the maize dehusker-cum-sheller.
5. To determine the suitable values of the operational parameters of the developed machine for optimum dehusking and shelling performance.

To achieve the above mentioned objectives, initially the physical properties of a few common varieties of maize were studied. A special device for the determination of the force required to detach the kernel from the cob by impact action was designed and fabricated. It was subjected to extensive studies to determine the forces required to detach the husk and maize kernel for threshing operation. Some of these data were used to design and fabricate a prototype maize dehusker-cum-sheller satisfying the functional and strength requirements. The studies were further conducted to optimize the operational parameters such as crop moisture content, cylinder peripheral speed and concave clearance for maximum shelling efficiency and minimum overall loss. Finally the experimental data were used to develop various empirical equations for predicting the performance of the developed maize dehusker-cum-sheller and optimize its operational parameters.

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the review of literature on topics related to various studies conducted on maize dehusker-cum-sheller. The chapter has been presented under the following sub-heads.

- Physical and Mechanical Properties of Maize
- Methods of Maize Threshing
- Effect of Various Parameters on Performance of Maize Thresher
- Performance of Maize Threshers
- Mathematical Modeling

2.1 Physical and Mechanical Properties of Maize

It is well known that physical and mechanical properties of grains are essential for the design of machines used for various operations such as seeding, planting, harvesting, threshing, processing and storage. Many researchers have studied the physical and mechanical properties of food grains, pulses, oilseeds and other crops and determined the interaction between various parameters. Standard methods and procedures have been adopted for this purpose.

Zoerb and Hall (1960) studied the physical and rheological properties of grain in order to predict the reaction of seed to actual handling circumstances. They reported that moisture content had greatest influence on the mechanical properties of grain. All strength properties decreased in magnitude as moisture increased. At high moisture content more energy was required to rupture grain kernels by impact-shear than static-shear. Elastic properties were present at low and plastic properties at high moisture contents.

Waziri and Mittal (1983) studied the physical properties of agricultural materials and pointed out their practical utility in machine and structural design and in process and control engineering. They established methods for determining physical properties such as shape, size, weight, density, porosity, surface area, angle of repose and angle of internal friction for tropical agricultural products.

Gorial and O'Callaghan (1990) studied aerodynamic and physical properties of grains. Based on his study the properties of maize grain are given in Table 2.1.

Table 2.1 Aerodynamic and Physical Properties of Maize Grain

Mass, mg	321.20
Terminal velocity, m/s	11.60
Geom. Dia. mm	7.50
Equivalent dia. mm	7.62
Drag coefficient	0.81
Sphericity	0.70
Shape factor	0.29

Kachru *et al.* (1994) studied the various physical properties such as moisture content, length, width, thickness, size, sphericity, terminal velocity, bulk density, specific gravity, and angle of repose, coefficient of static friction, hardness and thermal conductivity for small, medium and large size seeds of food crops. They have reported the range of the various physical properties related to different varieties of maize as given in Table 2.2.

Varshney *et al.* (2004) has reported the material factors relating to shape and size of maize kernel to be considered for the design of air screen grain cleaners. These are length 9.52 mm, width 8.44 mm, thickness 4.35 mm, equivalent diameter 7.04 mm and sphericity 0.74.

In the present study, the data related to some of these properties were used for designing of feeding hopper, sieves and concave systems.

Table 2.2 Physical Properties of common Varieties of Maize Grown in India

S. No.	Properties	Values
1.	Length, mm	8.67 - 12.33
2.	Width, mm	7.07 – 12.33
3.	Thickness, mm	5.45 – 6.55
4.	Size, mm	6.94 – 8.12
5.	Sphericity	0.66 – 0.80
6.	Bulk density, g/cm^3	0.740 – 0.836
7.	Specific gravity	1.30 – 1.41
8.	Volume of single grain , mm^3	252.3 – 286.0
9.	Angle of repose, degree	26.2 – 38.0
10.	Terminal velocity, m/s	11.21 – 14.15

2.2 Methods of Maize Threshing

Shelling / threshing is removal of maize grain from the cob followed by winnowing / cleaning which involves separating the broken bits of cob from the grain. Maize shelling is difficult at a moisture level above 25 per cent. With this moisture content, grain stripping efficiency is very poor with high operational energy and causing mechanical damage to the kernels. A more efficient shelling is achieved when the grain has been suitably dried to less than 20 per cent moisture content.

2.2.1 Manual shelling

Traditional maize shelling is carried out as a manual operation. Maize kernels are separated from the cob by pressing on the grains with the thumbs. According to the operator's ability the work rate is about 10 kg/h. This method of shelling reduces required storage capacity, facilitates effective application of insecticide and reduces grain susceptibility to large grain borer and other pests. This method of shelling is followed by natural wind winnowing which increases purity and market value of the grain. However, this method is tedious, inefficient and causes grain losses. Some low cost equipment were developed with a view to help the small growers. These include hand-held devices, small rotary hand shellers and free standing manually operated shellers.

Hand-held shellers

With this sheller, maize cob held on hand is rotated against a stationary shelling device held on the other hand or vice versa. In the process, the teeth of the sheller entangle and remove the grain from the cob (Fig. 2.1). This type of sheller can be fabricated artesanaly and using local material. It is cheap and suitable for small scale farm. The losses and damage to the kernel is minimum and it is much more efficient compared to direct hand shelling. It does not require special skills to fabricate, but its output is low (8-15 kg/h). Small, broken or large cobs can not be easily handled. Winnowing and cleaning of the shelled grains has to be done by traditional methods.

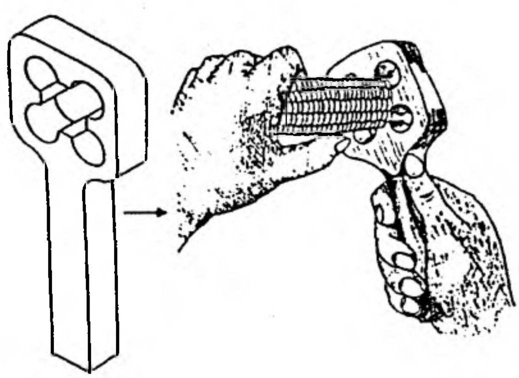


Fig. 2.1 Hand-held Sheller

Small rotary hand sheller

These are made with fixture, facilitating mounting of the equipment on a stationary stand or bench for stability. They have an opening into which single cob is fed for shelling. A hand operated lever rotates a spike disc against the maize cob. This presses the cob downward at the same time rotating against the spikes of the disc which removes the grain (Fig. 2.2). This is particularly suitable for small farmers and operation is simple. The machine is quite effective with productivity up to 100 kg/h and above depending on the design. There is significant grain damage and relatively slow shelling (only one cob at a time).

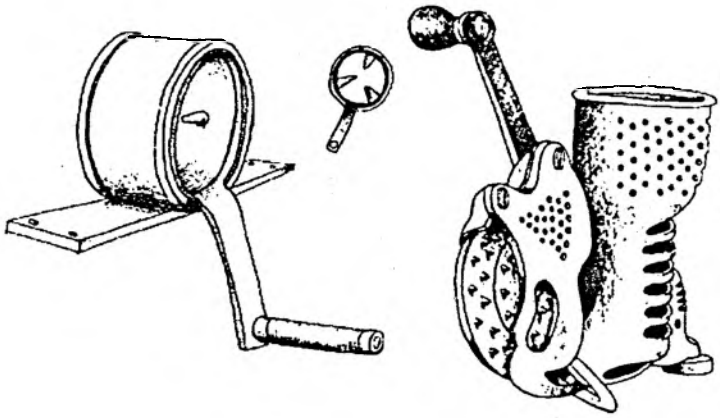


Fig. 2.2 Maize Rotary Sheller

Free-standing manually operated sheller

The mode of grain removal in free-standing manually operated maize shellers is similar to that in small rotary hand operated shellers, but includes some modifications to improve the capacity and efficiency of the machine. Such modifications include use of a flywheel to maintain momentum required for smooth operation, mechanical cob feed rolls and a simple grain cleaning screen or winnowing fan. These equipments can be operated by hand, pedal or engine powered form (Fig. 2.3). The out put of such maize shellers is 80-100 kg/h for hand operated model and 150-300 kg/h for engine operated model.

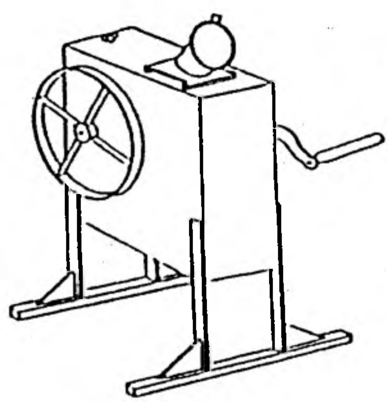


Fig. 2.3 Free-Standing Manually Operated Maize Sheller

2.2.2 Motorized threshing

Now-a-days many small size maize shellers, equipped with a rotating cylinder of peg or bar type are available in the market. Their output ranges between 500 and 2000 kg/h, and they may be driven from a tractor power take off or have their own engine; power requirements vary between 5 and 15 hp according to the equipment involved. The motorized threshers are generally designated according to the type of threshing cylinder fitted with the machine. These are spike-tooth type, axial-flow type, rasp-bar type and wire-loop type. Different types of cylinders are shown in Fig. 2.4 and their constructional details are given as follows.

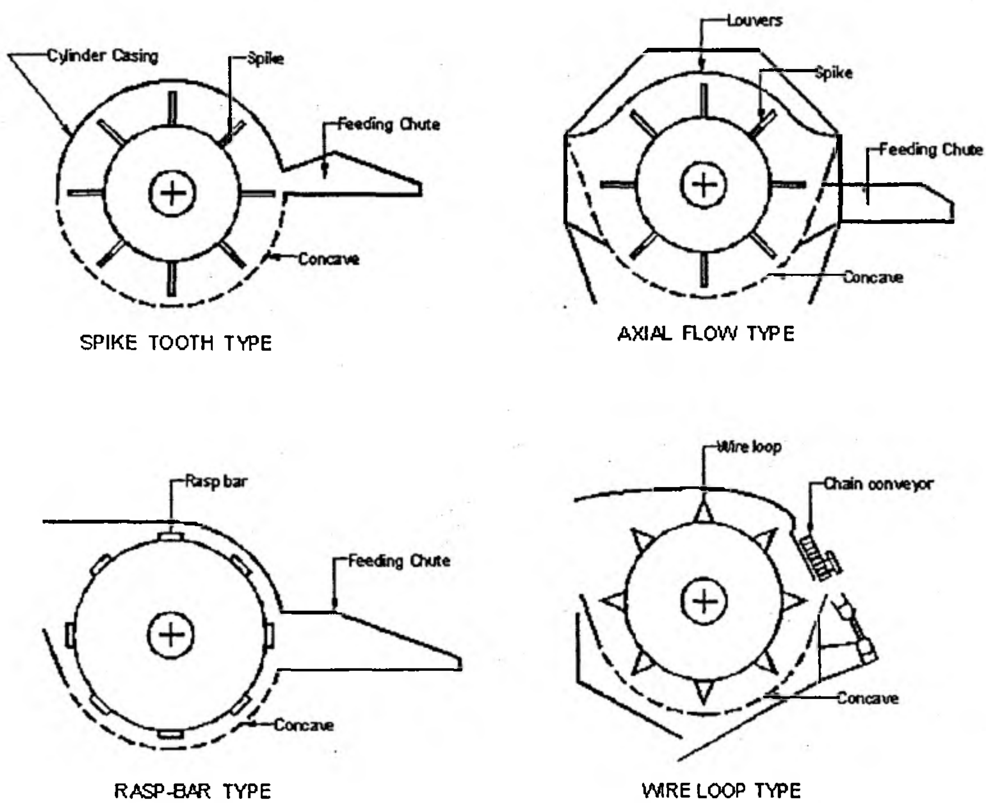


Fig. 2.4 Different Types of Cylinders

Spike-tooth type: Spikes are mounted on the periphery of a cylinder. It is provided with cleaning sieves and aspirator type blower.

Axial flow type: It consists of spike tooth cylinder, woven-wire mesh concave and upper casing provided with helical louvers.

Rasp bar type: Corrugated bars are mounted axially on the periphery of the cylinder. It is fitted with an upper casing and an open type concave at the bottom of the cylinder. The cleaning system is provided with a blower fan and a straw walker.

Wire-loop type: Wire-loops are fitted on the periphery of a closed type cylinder and woven wire mesh type concave is provided at the bottom.

Kepner *et al.* (1978) reported that a spike tooth cylinder has a more positive feeding action than a rasp-bar cylinder, does not plug as easily, and requires less power. Rasp-bar cylinders are readily adoptable to a wide variety of crop conditions, are easy to adjust and maintain and are relatively simple and durable. A rasp-bar cylinder with an open grate concave has greater seed separating capacity than a spike-tooth cylinder. Majority of the power driven threshers use spike-tooth type cylinder for threshing maize crop because of their simplicity in design and low cost.

2.3 Effect of Various Parameters on Performance of Maize Thresher

The influence of various parameters on threshing performance of maize crop is discussed below.

2.3.1 Crop type, variety and moisture content

Burrough and Herbage (1953) reported that the percentage of kernels damaged by the shelling unit was almost directly proportional to the moisture content of the kernel.

Hurlbut (1955) summarized that the threshing and separating units wasted only about 2 per cent of the total corn yield. It was also concluded that the combining of corn could be done at approximately 26 per cent of grain moisture content.

Johnson *et al.* (1969) studied the characteristics and analyzed the corn ear failure to contribute towards understanding the fundamental principles of corn shelling in order to provide a basis for more scientific design procedures for corn sheller.

They examined the effect of mode and level of impact and kernel moisture content on shelling corn ear. The modes were transversal and axial, and range of moisture contents were 25-30 per cent, 15-20 per cent and about 10 per cent. The drop heights were 450, 600, 680, 750, 830 and 900 mm; 380, 450, 530, 600, 680 and 750 mm; and 230, 300, 380, 450 and 530 mm for high, medium and low moisture contents respectively. It was reported that an increase in drop height reduced the energy requirements for shelling and there was a significant increase in energy with higher kernel moisture content. The kernel damage increased with increase in moisture content and impact levels.

Hunt (1973) concluded in his study that moisture content of the crop was probably the single most important crop factor influencing harvesting and post-harvest operations for maize. Up to 10 per cent moisture kernel loss could be suffered during shelling alone for high moisture maize picker shellers. It was pointed out that 5 per cent grain loss was approximately equivalent to a 25 per cent loss of profit (Anazodo, 1980).

Singh and Linville (1977) and Singh and Singh (1981) reported that the variety of grains had much influence on grain loss during threshing. In a survey, Arnold and Jones (1963) observed that the damage present in wheat samples was more than barley under similar machine settings.

Paulsen and Nave (1980) evaluated conventional rasp-bar cylinder combine and single and double-rotor combines for their effect on breakage, damage and germination percentage of corn. Field tests were performed at average corn moisture contents of 28.8, 20.3, and 18.6 per cent. It was concluded that the corn breakage was less than 1 per cent for all the three combines at all moisture contents and cylinder speeds. It was further concluded that the less damage was observed at 18.6 per cent moisture content and highest was at 28.8 per cent moisture content.

Singh and Singh (1981) concluded that the unthreshed grain increased with the increase in pod moisture content whereas the grain damage decreased with increase in grain moisture content.

Anand (2001) tested and evaluated the maize sheller using husked maize for its performance. The sheller was tested at a grain moisture content ranging from 7-36 per cent. It was reported that the maximum shelling efficiency of 99.36 per cent was obtained at a moisture content of 7 to 12 per cent and at a feed rate of 0.5 q/h.

Dauda and Aviara (2001) investigated the effect of different shelling methods of maize namely bare hand shelling, shelling with hand-held manually operated sheller, stick beating, pounding in mortar and tractor operated sheller on threshing output, grain damage and seedling emergence of planted maize grains of three varieties of maize (Hybrid 8341-6, TZESR-Y and TZESR-W). It was reported that the tractor operated sheller gave a maximum output of 626.67 kg/h and bare hand threshing gave the lowest grain damage (0.5 per cent for Hybrid 8341-6, 0.3 per cent for TZESR-Y and 0.2 per cent for TZESR-W), while the stick beating gave the highest percentage of kernel damage (4.0 per cent for Hybrid 8341-6, 2.0 per cent for TZESR-Y and 1.0 per cent for TZESR-W). It was concluded that the threshing method and variety of maize were found to have significant effect on output and kernel damage.

Araujo *et al.* (2002) tested the seeds of sweet-corn cultivar BR-400 (superdoce) with 17.4, 15.1, 13.4, 11.7 and 9.1 per cent moisture content manually and mechanically with a threshing cylinder speed of 250 r/min. It was concluded that seeds with moisture content of approximately 11.7 and 12 per cent were the most suitable to thresh. It was stated that mechanical threshing decreased seed germination and decreased seed vigour immediately after threshing.

According to ASAE standard (ANSI/ASAE S343.3 FEB04) the acceptable range of material other than grain-to-grain ratio for maize should be 0.4-0.8 and the range of moisture content for grain should be 10-35 per cent, the recommended processing loss is 1 per cent.

2.3.2 Types of threshing cylinder

Harrington (1970) studied the performance of a multicrop thresher. The major design objectives of the multi-crop thresher were a good functional performance in paddy, wheat and maize. The type of cylinder used was spike tooth at a fixed concave clearance of 25 mm. The best performance was observed at a cylinder speed of about 10 m/s. A grain damage of 3.5 per cent at the grain moisture content (Composite maize) of 23 per cent was reported at the cylinder peripheral speed of 10 m/s and it was reduced to 1.3 per cent at a moisture content of 13 per cent.

Majumdar (1981) conducted studies on different crops with different types of commercial threshers. The studies revealed that the spike-tooth type thresher having independent drive to cylinder and blower could thresh major crops effectively but the cylinder speed was to be adjusted according to the crop conditions.

Ali *et al.* (1986) included axial flow maize sheller in their technical and feasibility studies on dehusking and shelling systems. The dehuskers were designed and developed by Baraga and Devnani (1986). Pedal operated dehusker-sheller was recommended for medium farms. This machine had a single octagonal cylinder, one half of which was provided with rasp- bars and the other with rubber strips to act as dehusking and shelling units respectively. Maximum dehusking and shelling efficiencies were found to be 90 and 95 per cent respectively at optimum moisture contents of 17 and 19 per cent.

Kunjara *et al.* (1988) tested and evaluated two models of a locally-made maize shellers, rasp bar and peg-tooth type to determine their operational performance at 14.5 per cent moisture content (wb). Shelling capacity of rasp-bar and peg-tooth types were found as 1.4 and 8.8 t/h at a drum speed of 540 and 680 r/min respectively. It was observed that a shelling efficiency of 99 per cent and shelling loss of less than 1.5 per cent was observed for both the shellers.

Tajuddin and Karnunadhi (1997) compared the performance of different hand operated maize shellers, namely, wrench type wooden maize sheller, tubular maize sheller, rotary disc type maize sheller and bench mounted tubular maize sheller. Rotary disc type maize sheller had the maximum output and efficiency of 20.7 kg kernels/h and 86.6 per cent respectively, whereas the hand-held tubular maize sheller had the least output of 2.86 kg kernels/h and efficiency of 100 per cent. The performance index was high for rotary disc type maize sheller (243.73 kg/h-kW) and least for hand-held tubular maize sheller (38.90 kg/h-kW). It was concluded that out of all the types of hand operated maize shellers tested, rotary disc type and bench mounted tubular maize sheller were found to perform better in terms of output, performance index and operational cost.

2.3.3 Cylinder speed and concave clearance

Cylinder speed is the most important operating parameter in regard to cylinder loss and also in regard to seed damage. Increasing the speed reduces cylinder loss but may substantially increase damage. In general, seed damage increases as the seed moisture content is reduced.

Hopkins and Pickard (1953) compared two combine cylinders viz. 6-bar cylinder with filler plate and 12-bar cylinder. It was found that the optimum cylinder peripheral speed falls between 11.99 and 15.95 m/s. The best shelling was obtained at a front concave clearance between 9.52 to 12.7 mm and rear concave clearance between 12.7 to 19.05 mm. The percentage of unshelled corn with optimum adjustment was found to be dependent upon cob and kernel moisture content. The optimum moisture content was found to be below 22 per cent.

Pickard (1955) conducted experiments on different types of cylinder and concave bars at different variables like moisture content of grain of 30, 25 and 21 per cent, cylinder speed of 15.75 and 11.94 m/s, and concave clearance of 19.05 and 15.88mm. It was concluded that rasp bar cylinder appeared to be superior to angle bar cylinder in shelling efficiency and kernel damage. Concave clearance of 15.86 mm and cylinder speed of 15.75 m/s were found to be satisfactory while the critical moisture content falls between 30 per cent and 25 per cent.

Scranton (1955) worked for the development of corn combines. It was found that the angle bar cylinder at a speed of 15.96 m/s and at a concave clearance of 19.05 mm is most suitable for corn shelling, which would result in very less grain damage.

Hall and Johnson (1970) evaluated the two shelling units i.e. combine cylinder with mating closed concave and an axial-flow cage sheller. The combine cylinder was operated at 400, 500 and 600 r/min with a shelling rate of 0.26 m^3/min. The cage sheller was operated at 750 r/min and at a shelling rate of 0.13 and 0.26 m^3/min. It was revealed from the germination of the corn kernel that passed through different concave clearances that the breakage of 12 per cent was obtained at 15 mm concave clearance and at 32 per cent moisture content.

Brass and Marley (1973) compared a cylinder type sheller with a roller sheller. The shelling principle used was a combination of compression and ear rotation between a rotating roller and a fixed concave. It was concluded that induction in damage was as high as 50 per cent with the roller sheller compared to cylinder type sheller depending upon the moisture content. It was stated that the cylinder speed, concave clearance and grain moisture content were all significant variables affecting the kernel damage.

Pickett (1973) indicated that threshing loss was dependent on pod moisture level and that this loss could be reduced by increasing the cylinder speed or decreasing the concave clearance.

Sandhar and Panwar (1974) studied the effect of machine crop variables viz cylinder speed (4.1 to 13.2 m/s), concave clearance (22 to 34mm), shape of the shelling member (rasp bar, square bar and round bar) and the grain moisture content (12.5 to 24.5 per cent) on the performance of a prototype maize sheller. The different combinations of variables such as moisture contents of the grain, concave clearance and cylinder peripheral speed were studied with square bar, round bar and rasp bar shelling elements. It was concluded that higher the cylinder speed, lower the concave clearance, lower the moisture content and for the square bar of shelling member greater was the shelling efficiency.

Mahmoud and Buchele (1975) studied the effect of corn ear orientation on mechanical damage and forces on concave. Different orientations of the kernels were tip-in, random and roll-in and moisture content levels were 18, 20, 22, 24, 26, 28 and 30 per cent. The cylinder was run at a constant speed of 500 r/min and at a front concave clearance of 25.4 mm and rear clearance of 19 mm. It was concluded that the roll-in feeding orientation produced the least damage for all moisture contents and tip- in orientation suffered the most damage.

Chowdhary and Buchele (1976) developed a numerical damage index for critical evaluation of mechanical damage of corn, using a rubber roller corn sheller. The sheller was operated at four levels of cylinder speed (175, 250, 350 and 450 r/min) and at 4 levels of roller inflation pressure (41.37, 68.95, 96.95 and 124.11 kPa). The grain moisture content was varied from 18 to 29 per cent (wb). It was concluded that the kernel moisture content, cylinder inflation pressure and cylinder speed were highly significant on the damage index.

Chowdhary and Buchele (1978) conducted experiments to investigate the type of damage in shelling by grain combine by collecting the shelled out grains from the concave at different zones. Performance of the shelling crescent of combines was evaluated at grain moisture contents of 27, 22, 19 and 16 per cent (wb) and at cylinder speeds of 12.87, 15.8 and 18.73 m/s keeping the concave clearance of 25.4 mm in the front and 15.9 mm in the rear. It was concluded that the damage increased with increase in speed in all the cases. It was also found that the per cent damage was more as the grains moved along the length.

Kepner *et al.* (1978) suggested a typical range of cylinder peripheral speed and clearance for various crops as shown in Table 2.3. These are based upon research results and a summary of recommendations found in operator's manuals published by the various manufacturers.

Hamid *et al.* (1980) developed a low-damage corn-shelling machine based on the principle of axial flow to reduce the shelling force and increase the shelling efficiency. The machine consists of three differential rollers inclined at an angle of 20^{O} with vertical. The corn passes through the gap (33 mm) provided between the rollers due to the rubbing action of the differential rollers. The tests were carried out at the moisture contents of 24, 22, 20, 18 and 16 per cent and at speeds of 900, 1000, 1100, and 1200 r/min. The shelling capacity and shelling efficiency were found to be 330 kg/h and 97.4 per cent respectively at cylinder speed of 1200 r/min and moisture content of below 20 per cent.

Table 2.3 Recommended Cylinder Peripheral Speeds and Concave Clearances for various Crops

Crop	Peripheral speed Rasp- bar or spike tooth, (m/s)	Mean clearance for Rasp bar, (mm)
Barely	23-28	6-13
Corn, field	13-20	22-29
Grain sorghum	20-25	6-13
Peas	10-15	8-19
Rice	23-28	5-10
Soybeans	15-20	10-19
Wheat	25-30	5-13

Gupta *et al.* (1985) conducted studies on the performance of tractor-operated combine for maize shelling. The machine was tested on maize with and without husk. The performance of the machine was evaluated in terms of capacity, cylinder loss and grain crackage. It was concluded that the combine gave satisfactory results for husked maize at a cylinder speed of 500 r/min, concave clearance of 25 mm and feed rate of 30 q/h. However, for the un-husked maize crop the satisfactory results were obtained at a cylinder speed of 575 r/min and cylinder concave clearance of 25 mm and the capacity of the machine was found to be 20-25 q/h. The damage in case of husked and un-husked maize was found to be below 3 per cent.

Majumdar (1985) studied the power requirements of different moving components in a spike tooth thresher and results are summarized in Table 2.4.

Norris and Wall (1986) conducted experiments for the different concave designs. The number of bars, concave rod spacing and concave bar heights were 10, 6, 8, 12 and 9; 33, 30, 25, 24, and 21 mm; and 7, 13, 12, 8 and 10 mm respectively. All the five concaves were kept at a fixed concave clearance of 25 mm at front and 16 mm at the rear. The cylinder peripheral speed and the kernel moisture content were 14.7 m/s and 23.3 per cent (wb) respectively. It was concluded that the kernel damage was least for 6 bar concave compared to 12 bars concave.

Table 2.4 Power Requirement for different Moving Components of Spike-Tooth Thresher

Components	Power requirement, per cent	
	3.7-7.5 kW threshers	11-15 kW threshers
Cylinder	57-64	50-60
Aspirator blower	34-40	30-35
Shaker	2.0-5.0	3.0-5.0
Feed roller	-	8.0-12.0
Grain lifter	-	2.0-3.0

Oni and Ali (1986) investigated the factors influencing the threshability of maize in a maize sheller. Effect of cylinder speed (500 to 1000 r/min), feed rate (10 and 20 kg/min), ear size ($\leq$44 and $\geq$ 44 mm) and variety of maize were studied on the performance of maize sheller in terms of shelling efficiency. The best shelling efficiency of more than 90 per cent was obtained at a cylinder speed of 500 r/min, cob size >44 mm and feed rate of 20 kg/min for variety TZB.

Saxena and Ojha (1988) reported that percentage of unthreshed grain of soybean decreased with an increase in cylinder speed and decrease in pod moisture content. It was, however, noticed that cylinder speed had more pronounced effect on unthreshed and damaged grain than moisture content of pod or grain. They also reported that the energy requirement increased with increase in pod moisture content as well as cylinder speed.

Majumdar (1993) has also recommended that the permissible limits for different performance parameters must be met for a thresher as given below.

Capacity, kg (grain)/kW/h	>85
Threshing efficiency, per cent	>99
Cleaning efficiency, per cent	>96
Total losses, per cent	<5
Cracked grain, per cent	<2

Sudajan *et al.* (2002) conducted a study to develop a threshing unit for a sunflower thresher. The performance was evaluated in terms of output capacity, threshing efficiency, grain damage, grain losses, grain and material other than grain (MOG) separation, power requirement and specific energy consumption against different drum types, drum speeds and feed rates. The sunflower threshing capacity of a rasp bar drum was higher than peg tooth type, both with open and closed threshing drums. The threshing efficiency was found to be higher than 99%. Visible grain damage increased with an increase in threshing drum speed and feed rate for each threshing drum. The minimum specific energy consumption could be achieved with the rasp bar drum at all speeds and feed rates.

Based on the review presented in this section it is noticed that the spike tooth type threshers are popular among the farmers because of their simplicity in design, low cost and their ability to make fine straw in case of wheat. Such threshers working on axial-flow principle can thresh different crops if the cylinder speed can be regulated independently. For maize crop the cylinder speed has been found to be varying from 500-700 r/min and concave clearance from 20-35mm.

2.4 Performance of Threshers

Majumdar *et al.* (1981) conducted research on performance of various commercial threshers and drawn following conclusions.

- Uniformity of spike distribution over cylinder periphery is more important for better performance.
- Power consumption and grain damage increase with the increase in spike length and thickness.
- Power consumption and broken grains increase and unthreshed grains decrease with the increase in the cylinder speed.
- Quality of straw is better at higher cylinder speeds, low concave clearance and concave gap.

Varshney *et al.* (2004) has suggested the design values for a power thresher in terms of power requirement, concave perforation area and sieve perforation as given in Table 2.5.

Table 2.5 Performance of different Types of Threshers

Power threshers (spike-tooth type)	Power kW	Threshing area per kg feed rate mm^2	Concave perforation area per kg feed rate mm^2	Sieve perforation area per kg feed rate mm^2
Sherpur(Commercial)*	3.7	1000	300	71
Jyoti(Commercial)**	2.6	860	400	59
Shankar(Commercial)***	3.7	880	250	62
CIAE Multi crop	3.7	990	380	70
CIAE Axial Flow Multi crop	5.6	990	400	80
CIAE High Capacity Multi crop	15.0	1000	400	100
Recommended Value, minimum	10	950	350	70

* M/S Sherpur Agro Industries, Ludhiana, Punjab
** M/S Jyoti Industries, Vadora, Gujarat
*** M/S Shankar Industries, Bhopal, Madhya Pradesh

According to Pandey *et al.* (1997), the efforts were made by a number of research organizations to develop stationary power threshers to thresh maize besides other crops. The important features of these designs are highlighted below and their specifications as well as performance values are given in Table 2.6.

- CIAE during 1981-85 developed a multi-crop thresher suitable for wheat, maize, sorghum, paddy, gram and soybean. It consists of spike tooth cylinder, aspirator type blower and sieve shaker. It saves 26-39 per cent labour and operating time and 22 per cent on cost of operation compared to threshing by single crop thresher. The output capacity is reported to be 1635 kg/h for maize.

- CIAE during the year 1984-87 developed a semi-axial flow multi crop thresher suitable for wheat, soybean, sorghum, maize, pigeon pea, rice, sunflower and safflower crops. It consists of spike-tooth cylinder, aspirator type blower and sieve shaker. It can be operated with 7.5 hp electric motor. It saves 27-40 per cent labour and operating time and 19 per cent on cost of operation compared to conventional spike-tooth thresher. The output capacity is 1350 kg/h for maize.

- CIAE during 1989-94 developed a high capacity multi-crop thresher suitable for wheat, maize, grain, soybean, pigeon pea and sunflower. It consists of a spike-tooth cylinder, three aspirated blowers, cleaning sieves and automatic feeding and bagging system. It is provided with accessories such as extra pulley, concaves and sieves for threshing different crops. It saves 50 per cent labour and operating time and 54 per cent cost of operation compared to conventional spike tooth thresher. The output capacity is reported as 2890 kg/h for maize.

- TNAU has developed a maize thresher suitable for maize crop. The machine is used for dehusking and shelling of maize cob. It uses an axial flow mechanism with spike tooth cylinder for axial movement of cobs while shelling. The machine runs with 10 hp motor. The output capacity of the machine is 1500-2000 kg/h.

- PAU has developed a spike- tooth thresher suitable for separating the grains from panicles, cob and pod. It consists of spike tooth cylinder, aspirator, cleaning sieves and feeding system. The concave clearance, sieve clearance, screen slope and speeds of cylinder and aspirator can be adjusted according to the crop requirements.

- TNAU has developed a multi-crop thresher suitable for threshing paddy, ragi, jowar, maize, sunflower and wheat. It consists of threshing cylinder, oscillating box, straw walker and winnowing and cleaning attachment. The output of the machine ranges from 600-1000 kg/h depending on the type of crops.

- PAU has developed an axial flow type maize dehusker-cum-sheller for dehusking and shelling of maize cob simultaneously. The developed machines are of two types, namely spike tooth type and axial flow type. In axial flow type, thresher pegs are provided on cylinder and louvers are provided on the upper periphery of the drum to convey the crop to the outlet. The threshing capacity is reported in the range of 1200-2800 kg/h.

- MPUAT has developed a number of power driven machines such as maize dehusker, maize sheller and maize dehusker sheller. The output capacity of power operated maize dehusker sheller is reported 1300 kg/h.

Akubuo (2002) worked on the performance evaluation of a locally fabricated maize sheller. Cob breakup, shelling efficiency, kernel damage and separation loss were measured for three varieties of local maize over three harvest dates. Harvest date was found to have significant effects on most of the variables studied because of the variations in moisture contents. The kernel damage and cob breakup decreased significantly with later harvest date. The shelling efficiency was not significantly affected by changes in the harvest date for 'Nsukka Super' and 'Nsukka Local' maize varieties but the effects on the 'Agbuda Special' maize variety were more variable. The shelling capacity was not significantly influenced by harvest date or maize variety.

Mahal *et al.* (2007) developed a high capacity axial flow maize thresher to thresh the corn cobs along with the husk. The machine is equipped with a spike tooth axial flow type thresher and can be operated by a 35 hp tractor through PTO. The performance of the machine was evaluated at cylinder speeds of 400 to 500 r/min. Grain damage and threshing efficiency were acceptable even the maize moisture content was 24%. The total grain loss was less than 2%. The machine was found to thresh grain up to 2500 kg/h.

The material presented in this section indicates that there is a growing consciousness among the scientists and engineers to develop threshers which can be effectively used to remove husk and grain from maize cobs in a single operation. A few designs have been commercialized but they have not been fully accepted by a large number of farmers because of their high cost. There is, therefore, a need to have an optimum design of various components of such a machine in order to make it more efficient and cost effective.

Many researchers have evaluated the performance of maize threshers for a wide range of crop-cylinder-system variables. It is apparent that there is no specific cylinder-concave configuration that can be recommended for the best threshing effectiveness. Conversely, for the same cylinder-concave configuration, more than one crop can be effectively threshed following necessary adjustments within the threshing system. Therefore, for a thresher, proper adjustments of peripheral velocity, concave clearance, and number of rows of threshing elements will be necessary to thresh a wide variety of dried crops. A large number of researchers have advocated the use of peg type threshing element working on axial flow principle for dehusking and shelling of maize crop. According to Chakraverty *et al.* (2003), in evaluating a thresher, energy input and peak power requirements are given less weight than its characteristic performance for obtaining a maximum quantity of sound grains or seeds from cereal and pulse crops. These findings have been kept in view while designing and testing a maize dehusker-cum-sheller in the present study.

Table 2.6 Performance of Power Operated Maize Threshers/Dehusker-cum-Shellers Developed at various Research Organizations in India

S. No.	Equipment	Organization	Power source (hp)	Total weight (kg)	Cylinder size (diameter, mm x length, mm)	Beater size (LxTxB) (mm)	Type of threshing element	Blower size, dia. (mm) and type	Threshing efficiency (%)	Cleaning efficiency (%)	Output capacity (kg/h)
1.	Multi-crop thresher	CIAE, Bhopal	5	450	500 x 584	25 x 8 x 80	Spike tooth	672 Aspirated- 4 blade	99.9	99.3	1635
2.	Semi axial flow multi crop thresher	CIAE, Bhopal	7.5	550	540 x 740	1.6 dia x 80	Spike tooth	600 Aspirated- 6 blade	99.5-99.8	99.3-99.6	1350
3.	High capacity multi crop Thresher	CIAE, Bhopal	11	1200	700 x 1100	40 x 10 x 180	Spike tooth	600 Aspirator- 4 blade	100	99.9	2890
4.	Maize sheller	PAU, Ludhiana	3-7.5	80-123	300-900	Stud or flat	Spike tooth	NA	NA	NA	NA
5.	Maize thresher	TNAU, Coimbatore	10	600	NA	NA	Spike tooth	NA	NA	NA	1500-2000
6.	Multi crop thresher	TNAU, Coimbatore	7.5	NA	415 x 1460	NA	Rasp bar	NA	NA	NA	600-1000 (multi crop)
7.	Maize dehusker-cum-sheller	PAU, Ludhiana	10	NA	495 x 1460	NA	Spike tooth	Centrifugal	NA	NA	1200-2800
8.	Dehusker-cum-maize sheller	MPUAT, Udaipur	NA	NA	NA	NA	NA	NA	95	NA	1300

2.3 Mathematical Modeling

Simone *et al.* (2000) developed a mathematical model to explain the threshing and separation of beans (*Phaseolus Vulgaris L)* in order to predict the parameters of regulation and design in a conventional combine thresher. The whole procedure was divided into three different and linked steps: the detachment of beans from the pod, the penetration of beans through the straw mat, and the passage of beans through the concave grate. The model included classical mechanics and probabilistic concepts. The model proposed was able to fit the experimental data and predict new results with remarkable good accuracy.

A mathematical model using dimensional analysis was used to characterize the cleaning process in a stationary sorghum thresher (Simonyan *et al.,* 2006). The analysis was used to obtain a functional relationship between cleaning efficiency and independent variables such as grain moisture content (θ_g), straw moisture content (θ_s), bulk density of grain (β_g), bulk density of straw (β_s), feed rate (f_r), frequency of sieve oscillation (α), threshing cylinder speed (V_t), sieve hole diameter (D), air velocity (V_a) and particle density (ρ_p). The functional equation involving dimensionless term is given below:

$$\eta = f_e\left(\frac{\beta_g V_t D^2}{f_r}, \frac{\beta_s V_t D^2}{f_r}, \frac{\alpha D}{V_t}, \frac{V_a}{V_t}, \frac{\rho_p D^2 V_t}{f_r}, \theta_g, \theta_s\right)$$

Where η = Cleaning efficiency, per cent,

θ_g = Grain moisture content (wb), per cent,

θ_s = Straw moisture content (wb), per cent,

β_g = Grain bulk density, kg/m^3,

β_s = Straw bulk density, kg/m^3,

f_r = Feed rate, kg/s,

α = Sieve oscillating frequency, 1/s,

V_t = Threshing speed, m/s,

D = Diameter of sieve hole, m,

V_a = Air velocity, m/s and

ρ_p = Particle density, kg/m^3.

The developed cleaning efficiency model was verified by comparing the predicted with measured experimental results from a sorghum thresher test rig. Results showed a good agreement between the predicted and experimental results at 5 per cent level of significance.

It is seen from the past studies that the moisture content of the crop is one of the main parameters which can be controlled for efficient and safe handling of grain. High levels of moisture tend to reduce some of the physical properties of the grain while low moisture levels make the grain brittle and more prone to damage causing them unfit for seed purpose. The behavior of grain to different methods of handling in a thresher has conclusively been established that optimum level of clearance, speed of operation and moisture content are of paramount importance to obtain clean undamaged grain. Therefore, for each crop being threshed, the property of different varieties, moisture content at the time of threshing and the design of threshing element have to be carefully considered.

CHAPTER III

PHYSICAL AND MECHANICAL PROPERTIES OF MAIZE

This chapter deals with the determination of various physical and mechanical properties of maize husk and grain. These properties are essential for the design of machines for processing and handling the grains and their products. The accurate estimate of the shape, size and surface of each kernel is needed for the design of concave, sieves, cleaners and graders. These properties are influenced to a great extent by the moisture content. The chapter has been presented under the following heads.

- Structure of corn kernel
- Measurement of physical properties of maize grain
- Determination of mechanical properties
- Results and discussion

3.1 Structure of Corn Kernel

Corn or maize (*Zea mays L.*) is an important cereal crop in North America. Maize within a few weeks develops from a small seed to a plant, typically 2 to 3.5 m tall. Corn apparently originated in Mexico and spread northward to Canada and southward to Argentiana. A typical longitudinal section of a kernel of corn is shown in Fig. 3.1. The corn seed is a single fruit called the kernel. It includes an embryo, endosperm, aleurone, and pericarp. The pericarp is a thin outer layer that has a protection role for the endosperm and embryo. Pericarp thickness ranges from 25 to 140 μm among genotypes. Pericarp adheres tightly to the outer surface of the aleurone layer and is thought to impart semipermeable properties to the corn kernel. All parts of the pericarp are composed of dead cells that are cellulosic tubes. The innermost tube-cell layer is a row of longitudinal tubes pressed tightly against the aleurone layer. This layer is covered by a thick and rather compact layer, known as the mesocarp, composed of closely packed, empty, elongated cells with numerous pits. A waxy cutin layer that retards moisture exchange covers an outer layer of cells, the epidermis. The endosperm usually comprises 82-84 per cent of the kernel dry weight and 86-89 per cent starch by weight. The outer layer of endosperm or the aleurone layer is a single layer of cells of an entirely different appearance. This layer covers the entire starchy endosperm. The germ is composed of the embryo and the scutellum. The scutellum acts as the nutritive organ for the embryo, and the germ stores nutrients and hormones that are necessary for the initial stage of germination (Chakraverty *et al.*, 2003).

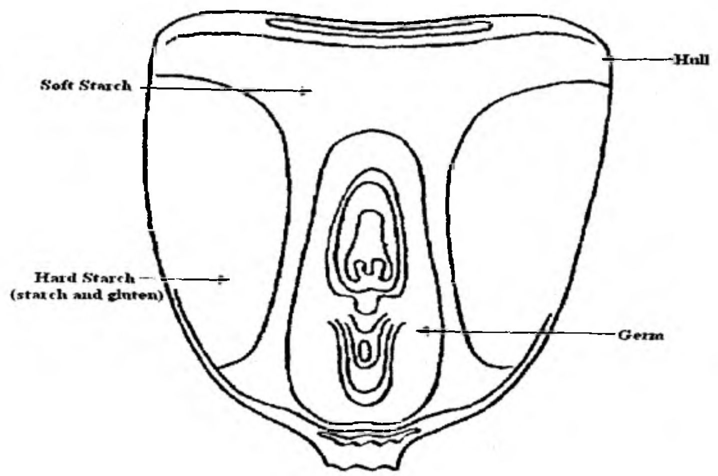


Fig. 3.1 Structure of a Maize Kernel (Potter, 1986)

3.2 Measurement of Physical Properties of Maize Grain

The common varieties of maize commonly grown in the State of Andhra Pradesh are DHM 103, Harsha, Madhuri, BH 2187, Kargil 9000 and DHM 109 (Fig 3.2). The physical properties of maize grain of these varieties were studied and used in the subsequent design of the maize dehusker-cum-sheller.

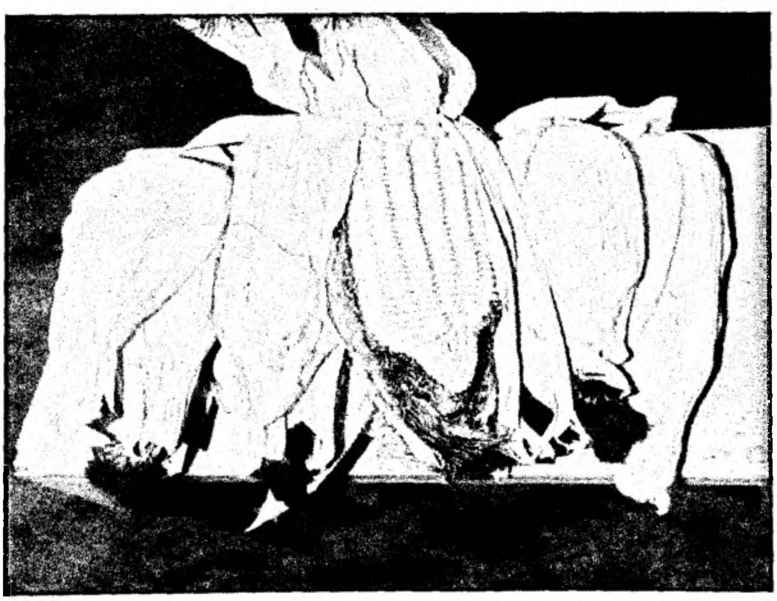


Fig 3.2 Maize Varieties Used

3.2.1 Spatial dimensions

The dimensions of a typical maize cob and a maize grain are shown in Figs. 3.3 (a) and 3.3 (b). Spatial dimensions such as length, width and thickness of a maize grain were determined using a micrometer with least count of 0.001mm. These dimensions could be obtained by measuring the total length / width of 10 seeds (randomly chosen) that were arranged in a line tip to tip / touching along with width or maximum diameter. This measurement was then divided by 10 to obtain an average seed length / width. The longest dimension, L is called length, second longest dimension, B perpendicular to L is called width and the third longest dimension, T perpendicular to both is called thickness of grain.

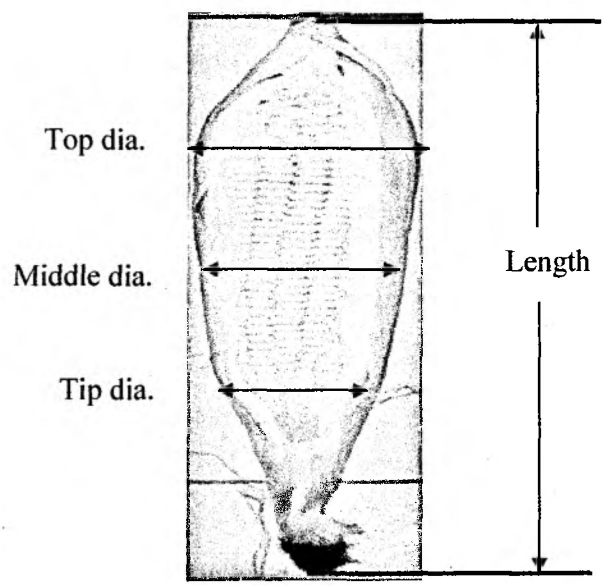


Fig. 3.3(a) Dimensions of a Typical Maize Cob with Husk

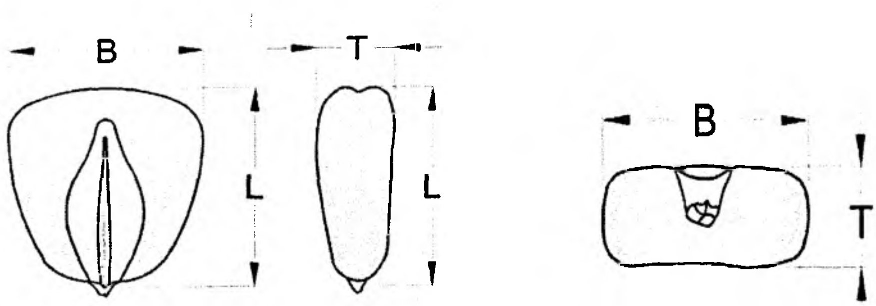


Fig. 3.3(b) Dimensions of a Maize Grain

3.2.2 Size or equivalent diameter

This dimension is the geometric mean of the three dimensions, namely length, width and thickness. Size can be calculated using the following expression.

$$\text{Size} = (\text{length x width x thickness})^{1/3} \quad \cdots (3.1)$$

3.2.3 Sphericity

It is defined as the ratio of surface area of a sphere having same volume as that of the grain to the surface area of the grain. According to Kachru *et al.* (1994), the sphericity (Fig. 3.4) is defined as

$$\text{Sphericity} = \frac{di}{dc} \quad \cdots (3.2)$$

where di = diameter of the largest inscribed circle, and

dc = diameter of the smallest circumscribed circle.

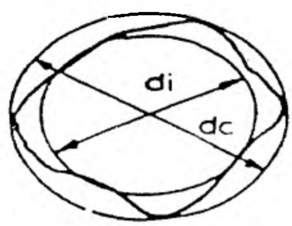


Fig. 3.4 Sphericity of Grain

3.2.4 Moisture content

The moisture content of the grain on dry weight basis was determined using oven dry method. A Maize grain sample weighing 25 gram was kept in air-oven at 100°c for 72 h. The weight of oven dried sample was taken with an electronic balance and the per cent moisture content was calculated using the following formula.

$$M_c(db) = \frac{W_s - W_d}{W_d} x100 \quad \cdots (3.3)$$

where W_s = weight of sample, g, and

W_d = weight of dried sample, g

The same procedure was also used to determine the moisture content of the husk on dry weight basis.

3.2.5 Terminal velocity

The terminal velocity of the grain in air was measured by using a vertical air tunnel as shown in Fig. 3.5. The range of different air velocities could be obtained by an adjustable speed motor attached with a blower. The air velocity at which the grain remained in suspension was measured and termed as terminal velocity.

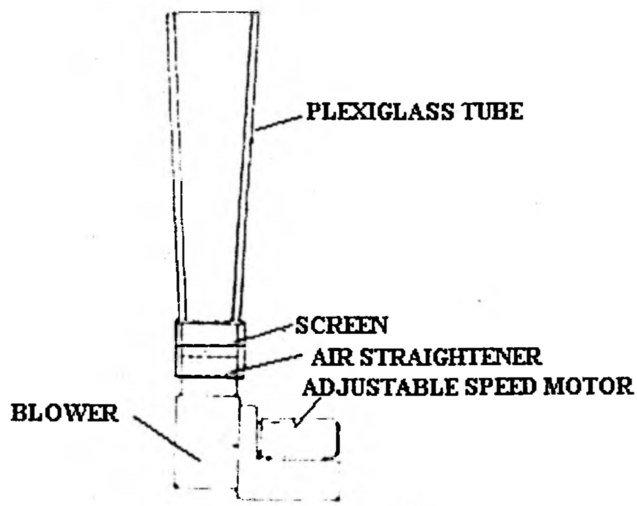


Fig. 3.5 Vertical Air Tunnel for Terminal Velocity

3.2.6 Bulk density

The bulk density of the grain was determined by measuring the weight of known volume of grain sample at given moisture content. The following formula was used to calculate the bulk density of grain in g/cm^3.

$$BD = \frac{W_s}{V_s} \quad \cdots (3.4)$$

where W_S = weight of sample, g, and

V_S = volume of sample, cm^3

The bulk density of maize cob with husk and the bulk density of core without grain and husk were determined on wet weight basis using the following formula.

$$BD_{cob} = \frac{W_{cob}}{V_{cob}} \quad \cdots (3.5)$$

$$BD_{core} = \frac{W_{core}}{V_{core}} \quad \cdots (3.6)$$

where W_{cob} = wet weight of cob samples, g,

V_{cob} = volume of wet cob samples, cm^3,

W_{core} = wet weight of core samples, g, and

V_{core} = volume of wet core samples, cm^3

3.2.7 Angle of Repose

When a granular material is allowed to flow free from a point into a pile, the angle which the side of the pile makes with the horizontal plane is called angle of repose. The angle of repose of grain was determined by the following formula.

$$\text{Angle of repose,} \quad \phi = \tan^{-1}\left(\frac{h_p}{r_{bp}}\right) \qquad \cdots(3.7)$$

where h_p = height of grain pile on a circular plate, cm, and

r_{bp} = radius of circular plate, cm.

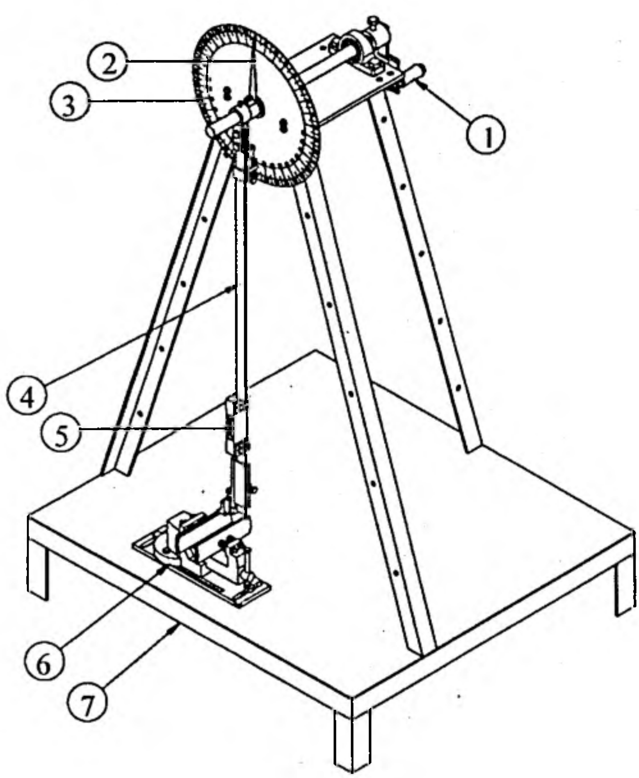
3.3 Determination of Mechanical Properties

The force required for detachment of husk and grain from a cob depends upon the direction in which the impact force is applied, the extent of maturity of the grain, the variety of the crop and the biological properties associated with the crop. Due to the fibrous structure of the plant material the strength parameters vary in different directions. The facilities used to determine the force required for detachment of husk and kernel from a maize cob is discussed below.

3.3.1 Test Set-up:

The force required to detach husk and single kernel from the maize cob of two varieties, namely DHM-103 and Harsha was determined using a pendulum type device. The device was developed specifically for this purpose as shown in Fig. 3.6. The device consists of a frame, pendulum arm, tool cob holding device, a single ended beam type load cell and a Data logger.

The frame is made of M.S. angle iron to support the pendulum type device. The pendulum arm is made of M.S. flat of size 25 x 5 mm. The effective length of the pendulum arm is 670 mm. A weight of 10 kg is mounted on the pendulum arm at a distance from the axis of rotation. The position of the weight could be altered easily by means of fasteners used for this purpose. A dial with graduation from 0 to 180 degree on both sides of the equilibrium position of the pendulum was fixed on top end of the pendulum arm. The dial is fitted with an indicator pointer which indicates the maximum position reached by the driving pointer after the pendulum arm is released. The tool holding device consists of a box section (32 x 25 x 12 mm) made of 3 mm thick M.S sheet, on which suitable tools were mounted for separation of grain or husk from the maize cob. The tool holding device is further attached to a box section (105 x 32 x 12 mm) made of 3 mm thick M.S. sheet to facilitate vertical adjustment of tool holding device. The platform for cob holding device consists of a frame made of M.S. flat of size 300 x 150 x 8 mm mounted on 3 mm M.S. sheet. The cob holding device was mounted on this platform by fasteners. A suitable spring was provided for proper holding of cob in the holder. The maize cob holder could be moved in horizontal and lateral direction.



1. Handle Assembly
2. Indicating Needle
3. Indicating Dial
4. Pendulum Assembly
5. Load Cell
6. Vice Assembly
7. Frame Assembly

Fig. 3.6 Test Set-up for Measurement of Force for Separation of Husk and Grain

A single ended beam type load cell of 300 N capacity was used for measuring the force required for separation of grain and husk from the maize cob. The load cell (Fig. 3.8) was connected between tool holding device and pendulum arm. The specification of the load cell is given in Appendix A. A portable battery operated Ethernet data logger DT800 was used to measure the force sensed by the load cell. Before mounting in the setup the load cell has been calibrated (Fig. 3.9) to check its sensitivity and accuracy. The load cell was integrated with DT 800 data logger and programming of the data logger has been done as per the specification of the load cell so as to get the readings of the load directly in N.

3.3.2 Test procedure

The moisture content of husk and grain was determined on dry weight basis. The tests were conducted by setting the pendulum arm at 30°, 60° and 90° from the vertical plane. The purpose of selecting the three positions was just to assess at what position detachment of husk and grain takes place so that the force required could be measured conveniently. The experimental set up (Fig 3.7) had provision for holding the maize cob in desired orientation to help detachment of grain and husk by specially made tool. The tool was mounted in the tool holder and vertical adjustment was possible to fix the tool in proper position convenient for removal of grain and husk.

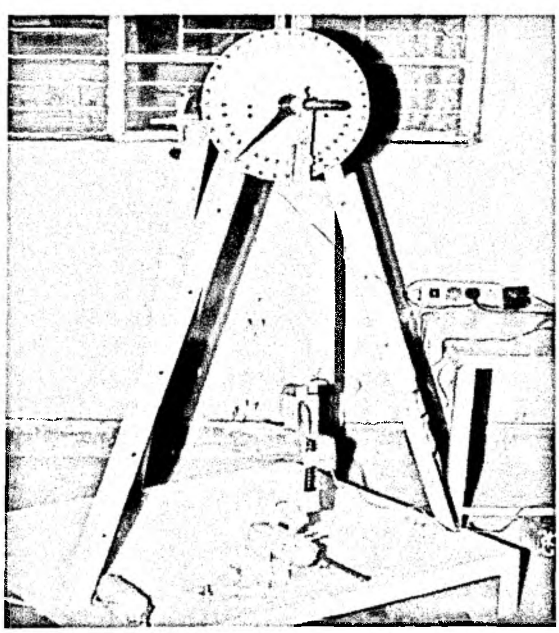
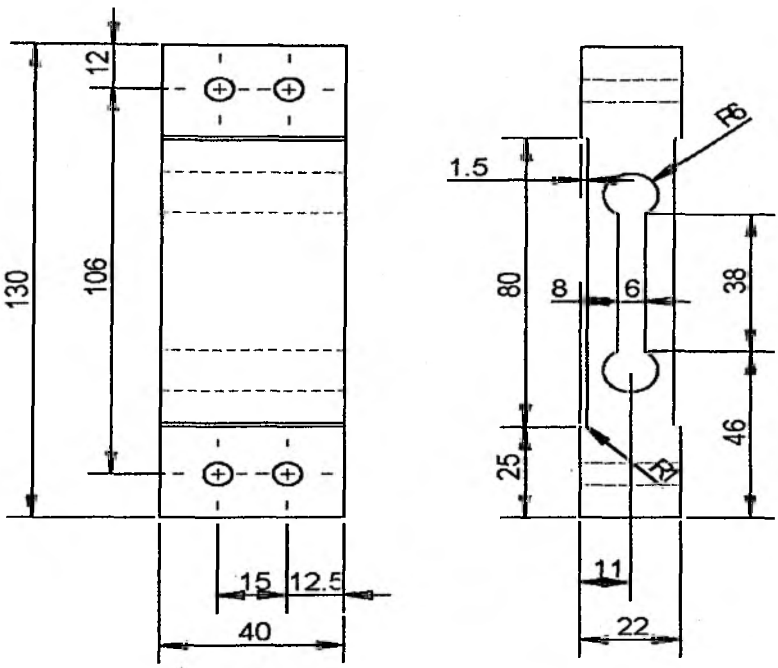


Fig. 3.7 Experimental Test Set-up

Initially the maize cob of a particular variety was fixed in position and the force required to detach husk from the cob was determined by setting pendulum arm at 3 positions. The same cob with husk removed was used at later stage to determine the force required to detach the grain at the same three positions of the pendulum arm. Three replications were made for each measurement. The signal received from the load cell was initially captured in internal memory of the data logger. Stored data was in replay format which was further converted in Excel format for analysis. The results were finally expressed in N after statistical analysis.



Dimensions in mm

Fig. 3.8 Single Ended Beam type Load Cell

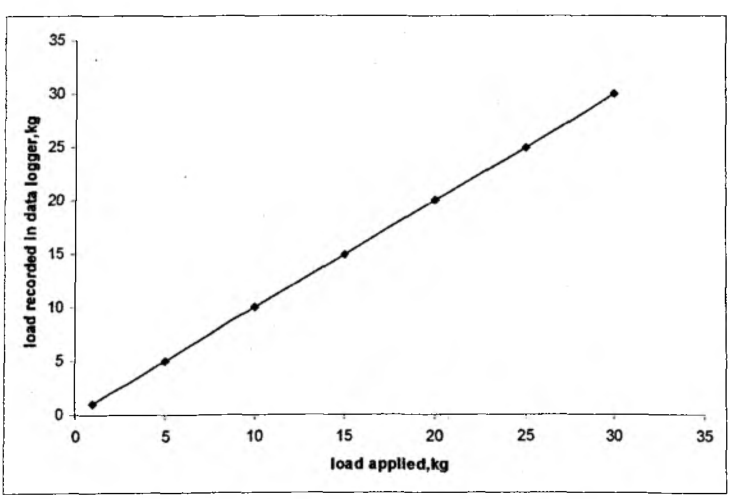


Fig. 3.9 Calibration of Load Cell

3.3.3 Research plan

A Independent parameters

- Crop variety : 2 (DHM103 and Harsha)
- Moisture content : 2
  - Husk (DHM103 - 21.11 % and Harsha – 10.50 %)
  - Grain (DHM103 – 18 % and Harsha – 9.50 %)
- Position of pendulum arm : 3 (90°, 60° and 30°)
- Replications : 3

B Dependant parameters

- Force required to detach husk
- Force required to detach grain

3.4 Results and Discussion

3.4.1 Physical properties

Size of maize cob

The lengths of the maize cobs with husk of six different varieties were found to vary from 328 to 362 mm. The top diameters of these varieties were found in the range of 56-78 mm, while the middle diameters were in the range of 42-57 mm and the tip diameters were in the range of 26-34 mm (Table 3.1).

Bulk density of maize cob and maize core

The bulk densities of maize cob with husk and maize core (after removing the grain and husk) were found in the range of 0.421-0.441 g/cm^3 and 0.236-0.262 g/cm^3 on wet weight basis (Table 3.1).

Grain size

The results are presented in the Table 3.2. The length of the grain of the six varieties has been found to vary from 8.67 to 12.12 mm. Similarly the values of width and thickness were in the range of 7.07-9.37 mm and 3.91-5.57 mm respectively. Based on these three dimensions, the size of the grain was worked out and it was found in the range of 6.94-7.93 mm. These results are in line with those reported by Varshney *et al.* (2004) except for some variations which could be attributed to varietals differences.

Grain sphericity

The sphericity of the maize grain for the six selected varieties varied between 0.63 and 0.80 (Table 3.2).

Grain bulk density and terminal velocity

The bulk density of the maize grain for the six selected varieties, determined in the moisture range of 8.7 to 12.4 per cent, varied between 0.684 and 0.836 g/cm^3. The terminal velocity of grains varied between 13.10 and 14.15 m/s (Table 3.2).

Angle of repose

The angle of repose for maize variety (Kargil 9000) was measured and found within the range of 27 – 35^0.

Grain-to-non grain ratio

The average values of grain-to-non grain ratio found for different varieties are shown in Table 3.3. It is noticed that the grain constitutes about 75 per cent, while the weight of the husk and core constitutes about 25 per cent of the total weight of the cob.

Table 3.1 Physical Properties of Maize Cob with Husk

Variety	Length mm	Top diameter mm	Middle diameter mm	Tip diameter mm	Bulk density of cob g/cm^3	Bulk density of core g/cm^3
DHM 109	362	78	57	34	0.441	0.253
Kargil 9000	355	75	53	32	0.435	0.251
BH 2187	348	66	48	29	0.431	0.262
Madhuri	335	63	46	28	0.428	0.247
Harsha	330	59	44	28	0.426	0.236
DHM 103	328	56	42	26	0.421	0.248

Table 3.2 Physical Properties of Maize Grain

Variety	M_c (db) %	Length mm	Width mm	Thickness mm	Size mm	Sphericity	Bulk density g/cm^3	Terminal Velocity m/s
DHM 103	8.7	8.67	7.07	5.45	6.94	0.80	0.684	13.10 - 14.15
Harsha	12.4	8.84	7.14	5.57	7.06	0.80	0.750	
Mudhuri	8.7	10.47	8.44	3.91	7.02	0.67	0.747	
BH 2187	12.4	10.8	9.37	4.05	7.43	0.69	0.740	
Kargil 9000	8.7	11.99	8.36	4.97	7.93	0.66	0.833	
DHM 109	12.4	12.12	8.52	4.21	7.28	0.63	0.836	

Table 3.3 Grain-to-Non Grain Ratio of different Varieties of Maize

Variety	Weight of whole cob g	Weight of husk g	Weight of grain g	Weight of core g	Grain-to-non grain ratio	Grain percentage %
DHM 103	148.4	17.1	107.6	23.7	2.64	72.5
Harsha	152.2	11.4	110.6	30.2	2.66	72.7
Madhuri	173.7	12.8	129.0	31.9	2.90	74.3
BH 2187	182.4	14.7	136.4	31.3	2.96	74.8
Kargil 9000	208.3	16.7	156.6	35.4	3.0	75.2
DHM 109	223.8	5.8	181.9	36.1	4.34	81.3

The physical properties of the grain such as size of the grain, bulk density and terminal velocity were used in the design of separating and cleaning units of the machine. Similarly the physical properties of cob with husk and core were used for the design of feeding hopper, separating and cleaning units. The grain-to-non grain ratio was used for the performance evaluation of the developed machine.

3.4.2 Mechanical properties

The results are presented in Table 3.4. The data indicate that the force required to detach husk from the maize cobs varied in the range of 5.83 to 23.26 N within the moisture range of 10.5 to 21.11 per cent and force required to detach a single kernel from the maize cob varied from 3.89 to 17.33 N in the moisture range of 9.5 to 18.0 per cent. These data have been considered for the design of cylinder pegs in the present study.

Table: 3.4 Force Required to Detach Husk and Grain from Maize Cob

Variety	M_c (db) per cent	Angle degree	Force required			Mean	SD	CV
			R_1^* N	R_2 N	R_3 N	N	N	per cent
(A) HUSK								
DHM 103	21.11	90	10.31	8.87	7.85	9.01	1.23	13.72
DHM 103	21.11	60	8.97	23.00	10.10	14.02	7.79	55.58
DHM 103	21.11	30	13.00	11.90	2.17	9.02	5.96	66.06
Harsha	10.50	90	25.01	23.60	21.19	23.26	1.93	8.30
Harsha	10.50	60	11.80	10.50	9.75	10.68	1.03	9.71
Harsha	10.50	30	6.81	6.05	4.65	5.83	1.09	18.77
(B) GRAIN								
DHM 103	18.00	90	6.19	1.31	14.60	7.36	6.72	91.25
DHM 103	18.00	60	1.36	1.01	9.32	3.89	4.70	120.61
DHM 103	18.00	30	5.60	8.24	11.50	8.44	2.95	34.98
Harsha	9.50	90	13.60	23.90	7.57	15.02	8.25	54.96
Harsha	9.50	60	5.56	12.80	14.70	11.02	4.82	43.76
Harsha	9.50	30	11.50	18.10	22.40	17.33	5.49	31.67

*R_1, R_2 and R_3 are replications

The physical and mechanical properties of the maize cob and maize kernel presented in this chapter have been utilized to some extent in the design of the maize dehusker-cum-sheller in the present study. These data will also help the engineers in developing effective design of maize threshers.

CHAPTER IV

DESIGN OF MAIZE DEHUSKER-CUM-SHELLER

This chapter deals with the theoretical design considerations and the mechanical design of maize dehusker-cum-sheller under the following heads.

- Theoretical Considerations
- Major Design Requirements
- Mechanical Design of Critical Components of Maize Dehusker-cum- sheller

4.1 Theoretical Considerations

4.1.1 Working principle of an axial-flow type thresher

Threshing/detaching the kernels from the ears or pods is accomplished by a combination of impact and rubbing actions. While the conventional tangential threshing unit threshes mostly by impact, other threshing devices like rotary threshing units act more by rubbing (Fig. 4.1). Rotary threshing units in which the crop is fed axially or tangentially into the rotor are becoming more popular.

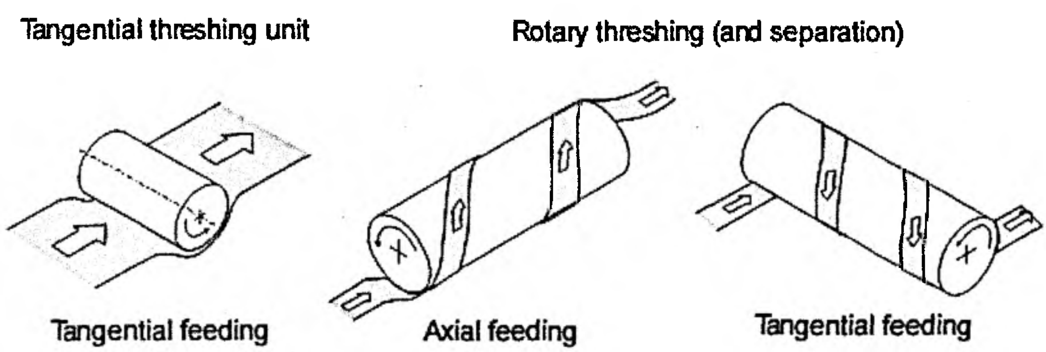


Fig. 4.1 Tangential and Rotary Feeding to Threshing Cylinders

Axial-flow type spiked drum threshers are widely used to thresh corn cobs. A typical spiked drum thresher with cylindrical screen concave is shown in Fig.4.2. Such threshers consist of the spiked drum and the cylindrical mesh concave without spikes. The spikes on the drum are in a helical arrangement. The cobs enter through the feeding hopper and are drawn in by the spikes provided on the threshing drum. They move in a helical path over the drum. The corn is shelled from the cob partly due to the friction between the cobs and concave and the cobs themselves and partly due to the impact of the drum spikes, wherein squeezing, rubbing, combing, and tearing actions are also associated between the threshing elements and concave grating. The impact and combing actions also help in breaking the leftover cobs during their flow axially against the louvers provided on the inner surface of the cylinder cover. The efficiency of grain threshing increases with increase in the number of impacts and decrease in the threshing gap. The number of impacts can be regulated by adjusting the speed of the drum. For this purpose, the drive shaft of the drum has a speed regulator or change pulleys. The gap between the concave and the drum is altered by adjusting the position of the concave. The thresher has a regulating mechanism for this purpose also. Proper selection of the position of the concave relative to the drum depends upon type and condition of the crop being threshed.

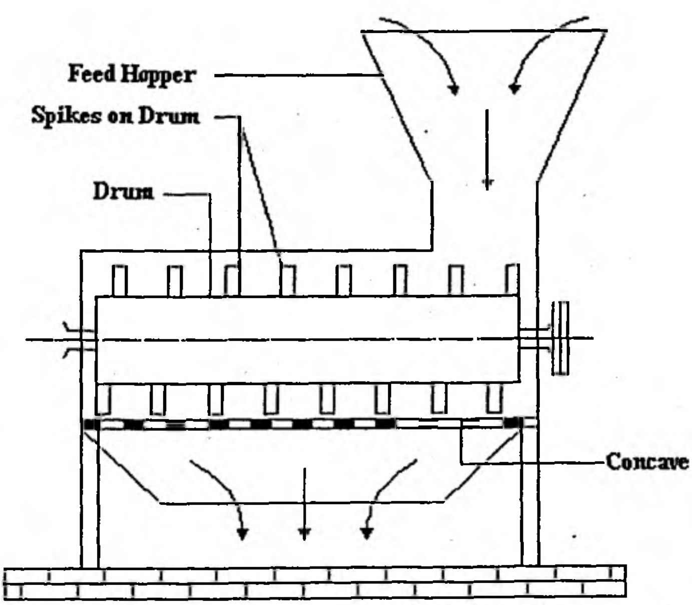


Fig. 4.2 Spiked Drum Thresher with Cylindrical Screen Concave

4.1.2 Power requirement for threshing cylinder

The threshing action of the drum on the plant mass is accompanied by repeated impact on the latter and its deformation in the inter space of the drum and the concave. The total tangential force (P) on the beaters or spikes on the drum consists of the impact force (P_1) and the extensive force (P_2), that is,

$$P = P_1 + P_2 \qquad \cdots(4.1)$$

According to Klenin *et al.* (1985), the force 'P_1' may be determined by equating the impulse force 'P_1' with the change in momentum of the plant mass, that is,

$$P_1 \Delta t = \Delta q \times (u_2 - u_1)$$

or $$P_1 = q \times (u_2 - u_1) \quad \cdots(4.2)$$

where q = feed rate of the plant mass, kg/s,

Δt = duration of impact, s,

Δq = quantity of plant mass which suffers the impact, kg,

u_2 = speed of the plant mass after impact, m/s, and

u_1 = speed of the plant mass before impact, m/s.

The force 'P_2' accounts for the resistance to shifting of the plant mass. Drawing in of the plant mass through the gap between the drum and the concave is a complex process. For a maize crop, it is accompanied by friction between the cobs and the components of the thresher unit, break up of the kernels, rupture and bending of the cobs. It is difficult to consider all these factors. Goryachkin (1936) assumed that the force 'P_2' can be approximated by making it proportional to the total resistance at the drum periphery 'P', that is,

$$P_2 = f \times P \quad \cdots(4.3)$$

where 'f' is a proportionality coefficient called the wear coefficient.

The wear coefficient considers all the resistance occurring as the plant mass is pulled through the thresher. The coefficient 'f' lies between 0.65 and 0.75 for a rasp bar thresher, and 0.7 and 0.9 for a peg tooth thresher.

Substituting P_1 and P_2 in eqn. (4.1) gives,

$$P = \frac{q(u_2 - u_1)}{1 - f} \quad \cdots(4.4)$$

Multiplying both sides of the equation by the peripheral velocity of the pegs 'u', the following equation is obtained for 'N_1', the power required to thresh by impact and elongation of the plant mass (power required for the sequence of operations):

$$N_1 = \frac{q(u_2 - u_1)u}{1-f} \qquad \cdots(4.5)$$

Goryachkin (1936) assumed that ($u_2 - u_1$) may be taken equal to the drum's peripheral speed 'u' for inelastic impact. Hence eqn. (4.5) is replaced with

$$N_1 = \frac{qu^2}{1-f} \qquad \cdots(4.6)$$

Apart form the energy required for threshing, a certain amount of energy is expended in overcoming bearing friction and air resistance.

The power required to overcome friction at the drum bearings is directly proportional to the tangential speed and that for overcoming air resistance varies as its cube, that is,

$$N_2 = Au + Bu^3 \qquad \cdots(4.7)$$

where 'A' and 'B' are the respective proportionality coefficients for friction and windage of the thresher drum.

According to Pustygin (1948), the coefficient 'A' is 5 to 5.5 N for a peg tooth drum and 0.85 to 0.9 N for a rasp bar drum per 100 kg weight of the drum.

The significant difference between the values of the coefficient 'A' for the rasp bar and for the peg tooth type thresher drums is because for the peg tooth drum, in addition to the friction at the supports, the coefficient includes the air resistance acting at the peg teeth, the thresher bars and the end plates of the drum, which is proportional to the tangential speed.

Coefficient 'B' represents air resistance which depends on the geometry of the rotating parts of the drum, their size and density and other properties of the air.

The magnitude of coefficient *'B'* per meter length of a drum of 550 mm diameter may be taken to be 0.045 N-s^2/m^2 for a peg tooth drum and 0.065 N-s^2/m^2 for a rasp bar drum.

The total power required to run the thresher drum would then be equal to

$$N_t = N_1 + N_2 = \frac{qu^2}{1-f} + Au + Bu^3 \qquad \cdots(4.8)$$

4.2 Major Design Requirements

According to Varshney *et al.* (2004) and Kepner *et al.* (1978), the major design requirements for maize threshers are given as follows.

4.2.1 General requirements

The prime objective of the threshing process for maize crop is to detach sound or undamaged grain kernels from the dehusked cobs. A thresher should perform maximum threshing with minimum breakage, grain loss and input power. Different systems of thresher should match the power and capacity for which the thresher is designed. The design should be safe for operation and the thresher body should be rigid for safe transport.

4.2.2 Cylinder type

The type of thresher is generally designated according to the type of threshing cylinder fitted with the machine. The major types of threshers commercially available in India have been discussed in Chapter II. Out of the various types, the spike-tooth type axial flow threshers have been found to be quite suitable for maize crops because of its simplicity in design and low cost. The power requirement varies from 6 to 9 kW/t of crop.

4.2.3 Energy requirement

The energy requirement for threshing maize crop is 2-3 kW-h/t of crop and 3-4 kW-h/t of grain. Average percentage of grain in maize cobs (including husk) varies from 65 to 85 per cent depending upon the moisture content of the grain. Based on a typical study performed in this project, the grain-to-non grain ratio by weight was found to be 3 (75 per cent grain in the maize cob) as reported in Chapter III.

4.2.4 Power requirement

As shown in Table 2.4, the power requirement for operating a cylinder in 11-15 kW thresher is 50-60 per cent and for aspirator blower it is 30-35 per cent. The shaker requires only 3-5 per cent of the total power available to the thresher.

4.2.5 Cylinder speed requirement and operational settings

Thresher operational parameters for maize crop are presented in Table 4.1.

Table 4.1 Cylinder Peripheral Speeds and Operational Settings of Spike-Tooth Thresher

Threshing parameters	Recommended
Cylinder speed, m/s	9
Aspirator blower speed, m/s	< 30
Concave clearance, mm	20-29
Gap between two axial square bars of concave, mm	25
Sieve shaker stroke length, mm	26-30
Sieve hole size, mm	12
Sieve slope, degrees	2.0-3.5

The design of a multi crop thresher should permit independent drive to cylinder and blower so that speed can be varied independently as per the crop requirement. The concave gap is very important for threshing at lower speeds.

4.2.6 Performance requirement

According to BIS code *IS:6320-1985*, the permissible limits for different performance parameters are given in Table 4.2.

Table 4.2 Permissible Limits of Performance Parameters

Performance parameters	Permissible limits
Capacity, kg (grain) $kW^{-1}h^{-1}$	>85
Threshing efficiency, %	>99
Cleaning efficiency, %	>96
Total loss, %	<5
Cracked grain, %	<2

4.2.7 Recommended thresher size based on land holding

The recommended thresher size based on land holding capacity is given in Table 4.3.

Table 4.3 Recommended Thresher Size Based on Land Holding

Average land holding ha	Thresher size kW	Power source required kW
10	3.7	3.7 (Electric motor); 5.5 (Engine)
20	7.5	7.5 (Electric motor); 15.0-18.5 (Engine)
30	11.2	15.0-22.5 (Tractor)
40	15.0	22.5-26.0 (Tractor)

4.2.8 Cylinder, concave and sieve design data

Research studies have revealed that higher feed rates in larger cylinder diameter of spike tooth threshers have lower specific power requirement than smaller ones. Uniformity of spike distribution over cylinder periphery is more important for better performance. Power consumption and grain damage increase with increase in spike length and thickness.

Power consumption and broken grains increase and decrease respectively with the increase in the cylinder speed. Design data obtained for cylinder, concave and sieve are given in Table 4.4.

Table 4.4 Cylinder, Concave and Sieve Design Data Adopted in Spike-Tooth Type Commercial Threshers in India.

Parameter	Adopted range	Recommended minimum value
Power, kW	2.6-15	-
Threshing area per kg feed rate, mm^2	860-1000	950
Concave perforation area per kg feed rate, mm^2	240-400	350
Sieve perforation area per kg feed rate, mm^2	59-100	70

4.2.9 Blower design data

Studies at CIAE, Bhopal (Varshney *et al.*, 2004) have revealed that centrifugal straight blade type aspirator blowers are suitable for spike tooth threshers for conveying fine materials to a longer distance. The number of blades should be 3 to 4 for uniform discharge and blade width should be one-quarter of blower diameter. Blower tip speed should not be more than 30 m/s. Five to eight kg of air is required for separation and conveying one kg of straw. Aspirator blowers consume 30 to 40 per cent of available power. Straight-blades with backward tilt should be used for thrower type blower. Design data for blower are given in Table 4.5.

Table 4.5 Blower (aspirator) Design Data Adopted in Spike Tooth Type Commercial Threshers in India

Parameter	Adopted range
Power, kW	2.6-15
Air required per kg of straw, kg	5.4-7.8
Air velocity, m/s	16.6-28.8
Blower diameter, mm	470-720
Blade width, mm	135-175
Number of blowers	1-3
Number of blades on blower	3-4

4.2.10 Proportion of different constituents in maize cob

Based on the data reported in Chapter III, the average percentage of grain, core and husk in the maize cobs may be taken as 75, 17 and 8 per cent respectively. Hence the following values of the total feed rate may be assumed as handling capacity of the different components.

Thrower-cum-blower = 15 %

Sieves = 75 %

Main blower = 10 %

4.3 Mechanical Design of Critical Components of Maize Dehusker-cum-Sheller

4.3.1 Size of dehusker-cum-sheller

A power operated maize dehusker-cum-sheller is required by a farmer with holding size not less than 10 ha. Normally a farmer owning such a thresher uses not only to thresh his own crop but also earns additional revenue by making it available on custom hiring service. Considering the size of land holding as 15-20 ha for medium to large size farmers located in maize growing regions, the size of the power source may be taken as 25 to 35 Ps (18 to 26 kW) based on the common size of tractors available in most parts of the country. The design of the thresher is, therefore, based on 20 kW power available at PTO of such tractors.

4.3.2 Threshing Cylinder

Based on available literature, an axial flow, peg type cylinder is selected for shelling maize cobs with husks.

Diameter of threshing cylinder

The term threshing cylinder used in the thesis includes the cylindrical drum and the pegs mounted on the drum. The recommended peripheral speed of threshing cylinder for maize crop is 9 m/s by Varshney *et al.* (2004) and 13 to 20 m/s by Kepner *et al.* (1978). Based on these values the average value for design of threshing cylinder is adopted as 13 m/s.

Considering the minimum required breakage of grains and low power requirement the cylinder speed adopted in commercial maize threshers ranges from 300 to 750 r/min. Based on this the cylinder speed is selected as 530 r/min, which is equal to standard PTO speed 540 ± 10 r/min less 2 per cent slip in belt transmission.

The power is transmitted from PTO shaft to cylinder shaft by using a universal joint and a pair of V-pulleys, each having a diameter of 30 cm.

The peripheral speed, u is given by

$$u = \frac{\pi D_c N_c}{60} \qquad \cdots(4.9)$$

where D_c = diameter of the cylinder, m, and

N_c = cylinder speed, r/min

For u = 13 m/s, the diameter of cylinder comes out to be

$$D_c = \frac{60 \times u}{\pi \times N_c}$$

$$= \frac{60 \times 13}{\pi \times 530}$$

$$= 0.470 \text{m}$$

$$= 470 \text{mm}.$$

Selected cylinder diameter = 480 mm. This includes the drum diameter without pegs = 360 mm and peg length =60 mm.

For 480 mm diameter of cylinder the design peripheral velocity comes to

$$u = \frac{\pi \times 0.48 \times 530}{60} = 13.32 \text{ m/s}$$

Maximum permissible feed rate

For a PTO power of 20 kW and taking the transmission efficiency as 90%, the power available to the thresher is 20 x 0.9 = 18 kW. This power is utilized for running the cylinder as well as for operating the blower and sieve system. The power required to operate the cylinder may be taken as 80 per cent of the available power, that is 18 x 0.8 = 14.4 kW.

According to Varshney *et al.* (2004), the energy required to thresh maize cobs by mechanical means is 2 to 3 kW-h/t. Taking factor of safety 1.2 for overloading, energy required to thresh the maize cobs = 3 x 1.2 = 3.6 kW-h/t.

The maximum permissible feed rate,

$$q = \frac{\text{Power available (kW)} \times 1000}{3600 \times \text{Energy required (kW h/t)}} \quad \cdots(4.10)$$

$$= \frac{14.4 \times 1000}{3600 \times 3.6}$$

$$= 1.11 \text{ kg/s}$$

Number of pegs

The throughput or handling capacity of a peg tooth drum is directly proportional to the number of peg teeth 'z' and the permissible feed per tooth 'q_0', that is,

$$q = q_0 \times z \quad \cdots(4.11)$$

According to Bosoi *et al.* (1990) the permissible feed 'q_0' is assumed to be 0.020 to 0.025 kg/s per tooth. Taking q_0 = 0.020 kg/s per tooth,

$$z = \frac{q}{q_0}$$

$$= \frac{1.11}{0.020}$$

$$= 55.5 \approx 56.$$

Length of cylinder

The working length l_c of the cylinder may be determined using the following expression.

$$l_c = a_p \times \left(\frac{z}{m_p} - 1 \right) \qquad \cdots(4.12)$$

where m_p = number of pitch of the helix over which teeth are located, and

a_p = distance between adjacent paths of teeth, mm.

Usually m_p is equal to half the number of cross bars M. If M = 8 then m_p = 4. The value of a_p is used equal to 92 mm based on the values available in commercial design. Substituting the values of the parameters in eqn. (4.12) yields.

$$l_c = 92 \times \left(\frac{56}{4} - 1 \right)$$

$$= 1196 \text{ mm} \approx 1200 \text{ mm}$$

Arrangement of teeth on the threshing cylinder

The development of a peg type cylinder with eight cross bars and a four-pitch helical line over which the teeth are located is shown in Fig. 4.3. The teeth are placed at the points of intersection of the helical lines with the cross bars. When the drum rotates, each tooth moves in a particular plane which is indicated by the lines *AA, BB, CC* and so on the development of the drum. As the figure shows, the number of adjacent planes in which the teeth move are

$$n_p = \frac{l_c}{a_p} + 1 \qquad \cdots(4.13)$$

The number of teeth which lie in the same plane of rotation is equal to the number of pitches of the helical path, which is equal to four in this design.

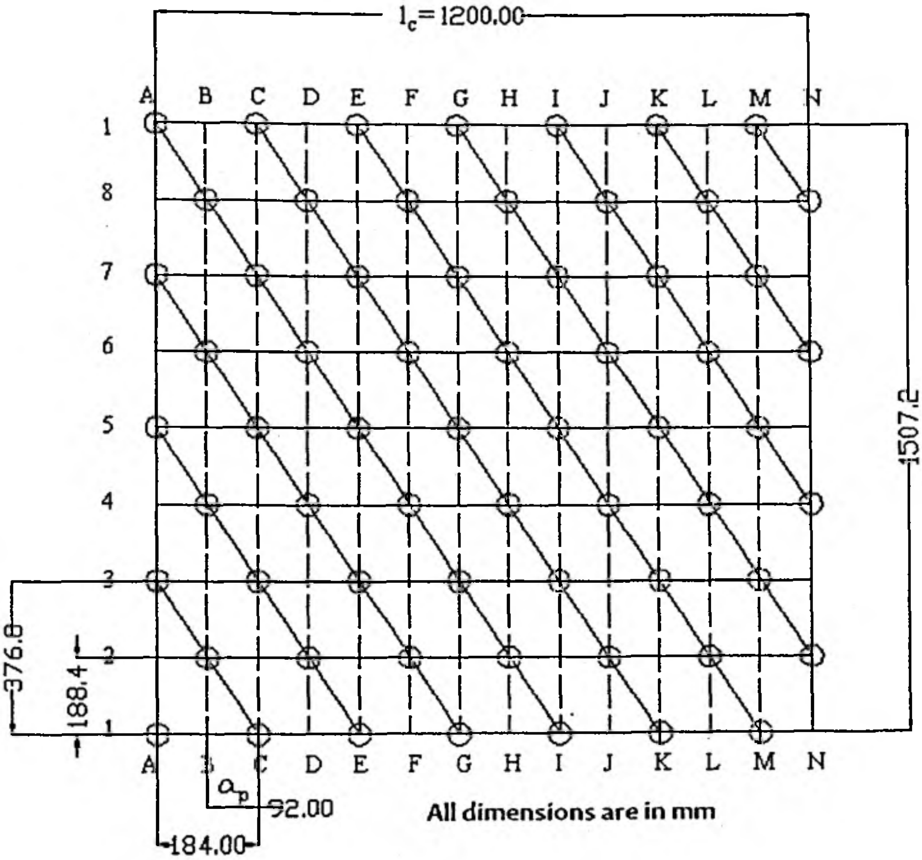


Fig 4.3 Development of a Peg-Tooth Cylinder with Eight Cross Bars and Four-Pitch Helical Line

Helix angle maintained for placing the pegs on cylinder periphery
$= \tan^{-1}(376.8/184) = 64^0$.

Design of peg cross-section

A peg attached to the threshing cylinder is subjected to different kinds of forces while engaged in threshing action. The predominant forces are caused due to bending and twisting moments. The effect of these forces is considered here to determine the section of a peg for the design of the threshing cylinder. From the available literature, a square section of peg is selected for its effective threshing of maize crop.

Impact force experienced by a peg during threshing

According to Goryachkin drum theory (1936), the power required to thresh by impact is given by

$$N_1 = \frac{q \times u^2}{(1-f)} \qquad \cdots(4.14)$$

where q = feed rate, kg/s,

u = peripheral speed, m/s, and

f = wear coefficient (0.7 – 0.9)

Impact force, $P_I = \frac{N_1}{u}$

$$= \frac{1.11 \times 13.32}{(1-0.9)}$$

$= 148$ N

This force is assumed to be increased 5 times more to take into account the force required to detach husk and grain from more than one cob at a time as well as for breaking them into pieces. Hence the design impact force is

$P_I = 148 \times 5$

$= 740$ N

Bending and twisting moments

The bending and twisting moments experienced by the peg (Fig. 4.4) are given as

Bending moment, $M_p = P_I \times l_p$ (peg length $l_p = 60$ mm as determined above)

$= 740 \times 0.06$

$= 44.4$ N.m

Twisting moment, $T_p = P_I \times \frac{a}{2}$ (where a is square section dimension in m).

$$= 740 \times \frac{a}{2}$$

$= 370a$ N.m

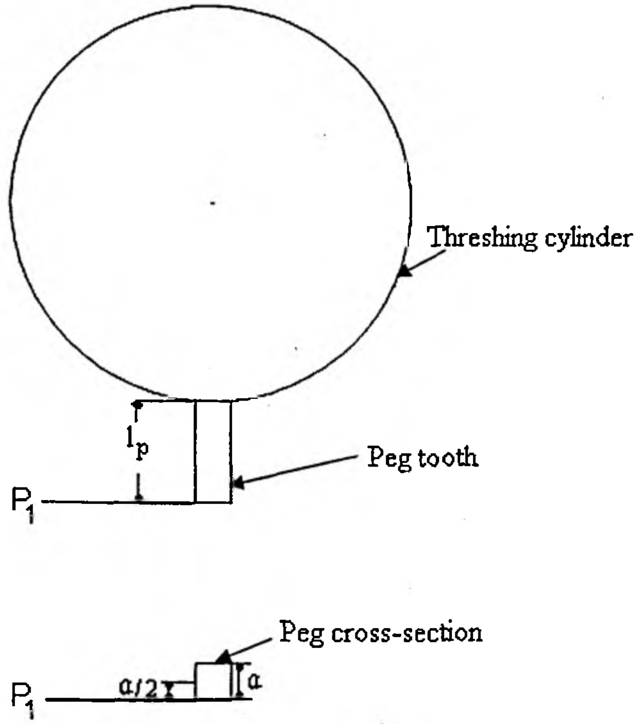


Fig. 4.4 Bending and Twisting Moments acting at Cylinder Peg

As per BIS code *IS: 11691-1986,* the material used for designing the peg section is mild steel St 42 having yielding stress σ_y = 250 N/mm^2 and ultimate stress σ_{Ult} = 410 N/mm^2.

The allowable shear stress for combined bending and twisting moments is given by

$$\tau_p = \frac{3}{a^3} \times FS \times \sqrt{(C_m \times M_p)^2 + (C_t \times T_p)^2} \qquad \cdots(4.15)$$

where C_m and C_t are the combined shock and fatigue factors(C_m = 2.0 and C_t = 2.0 for sudden loading) and FS is factor of safety equal to 2.5.

Allowable shear stress based on yielding stress is

$$\tau_p = 0.3 \times \sigma_y$$

$$= 0.3 \times 250$$

$$= 75 \text{ N/mm}^2$$

Or, allowable shear stress based on ultimate stress is

$\tau_p = 0.18 \times \sigma_{Ut}$

$= 0.18 \times 410$

$= 74\ \text{N/mm}^2$

The smaller of the two values is 74 N/mm^2, hence, τ_p= 74 N/mm^2.

Substituting τ_p= 74 x 10^6 N/m^2, C_m = 2, C_t = 2, M_p = 44.4 N-m, T_p = 370a N-m and FS = 2.5 in eqn. (4.15) yields a= 18 mm.

Hence the peg having square cross-section of 25 x 25 mm is chosen.

4.3.3 Design of louver

The louver is provided on the top cover of the cylinder to move the material, mostly threshed husk, axially toward the thrower-cum-blower. The shape of the louver is different for different crops. In maize dehusker-cum-shellers the louver is provided by fixing bolts along the longitudinal axis of the cover keeping the same helix pitch as that maintained for placing the pegs on the cylinder.

The bolts have to pass in between the pegs of the cylinder. So, the spacing of the bolts is equal to the spacing between the pegs, which is also equal to the helix pitch, that is 184 mm as shown in Fig. 4.5.

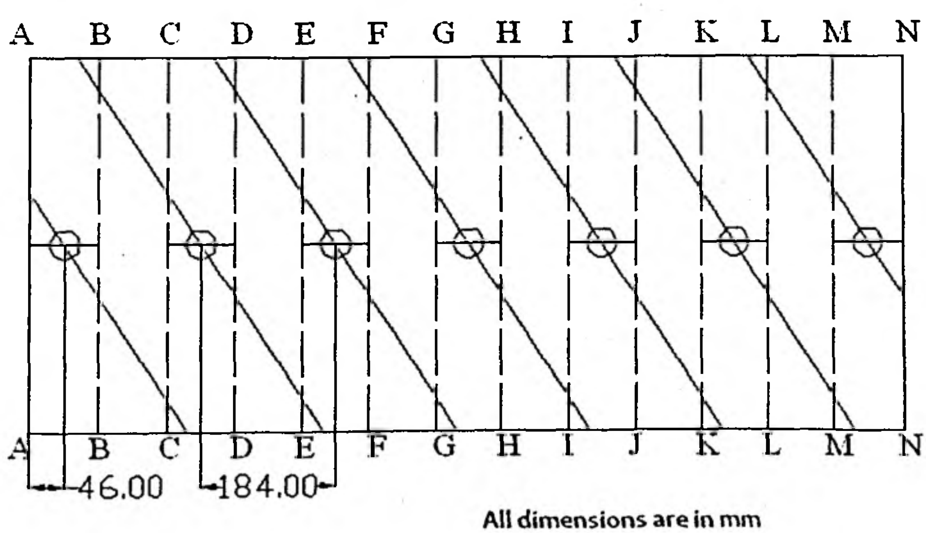


Fig. 4.5 Arrangement of Bolts on Louver Surface

4.3.4 Design of concave

The length of the concave is same as the length of the cylinder, that is 1.2m. According to Chakraverty *et al.* (2003), the peripheral width of the concave in spike tooth type cylinders should be equal to one-third to five-twelfth of drum periphery. Based on this recommendation peripheral width comes to

$$\text{Peripheral width} = 0.4 \times \pi \times D_c \qquad \cdots(4.16)$$

$$= 0.4 \times \pi \times 0.48$$

$$= 0.603 \text{ m} \approx 600 \text{ mm.}$$

The radius of curvature of the concave should be equal to the radius of the cylinder, that is 240 mm as shown in Fig. 4.6.

The concave clearance is made adjustable varying from 40-48 mm based on the values adopted in commercial threshers, even though the values quoted in Table 4.1 are lower than this range.

Area of concave surface is given by

$$A_c = 0.6 \times 1.2$$

$$= 0.72 \text{ m}^2$$

According to Varshney *et al.* (2004), threshing area per kg feed rate is 950 mm^2 and concave perforated area per kg feed rate is 350 mm^2 (Table 4.4).

$$\text{Percent perforation of concave} = \frac{350}{950} \times 100 = 37\ \%$$

Perforated area of concave = 0.37 x 0.72 = 0.27 m^2.

This perforated area can be closely achieved by fixing 12 mm diameter rods along the length of the concave at an interval of 20 mm and 6 mm square rods along the width of the concave at an interval of 150 mm.

$$\text{The actual percent perforation of concave} = \frac{(20-12)\times(150-6)}{20\times150} \times 100$$

$$= 38.4\%$$

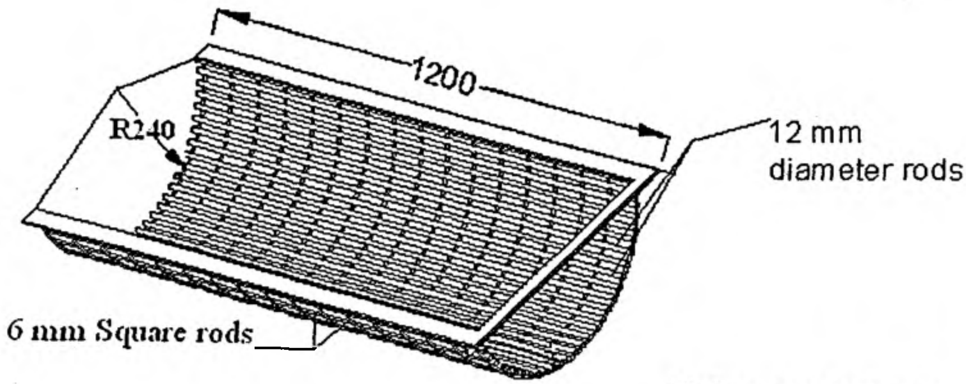


Fig. 4.6 Design Dimensions of Concave

4.3.5 Design of thrower-cum-blower (Aspirator)

Power available for thrower-cum-blower is assumed to be 10 per cent of the total power (18 kW) available to operate the maize dehusker-cum-sheller.

Therefore, power available to operate thrower-cum-blower is

$P_a = 0.1 \times 18 = 1.8$ kW = 1800 W

The power required by the thrower-cum-blower to impart kinetic energy to air at air velocity 'v_a' is given by

$$P_a = \frac{\gamma_a \times A_a \times i_a \times V_a^2}{2 \times \eta_c} \times u_a \quad \cdots(4.17)$$

where P_a = power required by the thrower-cum-blower, W,

γ_a = bulk density of air, kg/ m^3,

≈ 1.2 kg/m^3;

i_a = number of blades,

= 3 to 4,

u_a = peripheral velocity of thrower-cum-blower, m/s,

A_a = surface area of each aspirator blade, m^2, and

η_c = conversion efficiency in decimal = 0.3.

Recommended peripheral velocity of aspirator is less than 30 m/s (Table 4.2). Hence, selected $u_a = 25$ m/s.

According to Kanfojski (1976), the air velocity, 'v_a' imparted by the frontal surface of rasp-bar is given by

$$v_a = \varepsilon\, u_a \qquad \cdots(4.18)$$

where ε = coefficient of proportionality and is approximately equal to 0.55.

Using the above expression and assuming the same value of coefficient 'ε' as recommended by Kanfojski (1976), the desired air velocity from thrower-cum-blower can be calculated as shown below.

$$v_a = 0.55 \times 25$$
$$= 13.75 \text{ m/s}$$

Substituting the values P_a = 1800 W, γ_a = 1.2 kg/m^3, η_c = 0.3, i_a = 3, v_a = 13.75 m/s and u_a = 25 m/s in eqn. (4.17) yields the frontal area of each blade of aspirator A_a = 0.063 m^2.

Hence a blade with dimensions 200 x 300 mm (frontal surface area 0.06 m^2) is selected.

The thrower-cum-blower is mounted on the same shaft as that of the threshing cylinder. Hence speed of thrower-cum-blower with peripheral velocity 25 m/s is N_a= 530 r/min.

Effective radius of the thrower-cum-blower,

$$R_{te} = \frac{25 \times 60}{2 \times \pi \times 530}$$
$$= 0.45 \text{ m}$$
$$= 450 \text{ mm.}$$

The effective radius 'R_{te}' and blade width 'w_t' of the thrower-cum-blower (Fig. 4.7) is given by

$$R_{te} = \frac{R_o + R_i}{2} \quad \cdots(4.19)$$

$$w_t = R_o - R_i \quad \cdots(4.20)$$

where R_o = outer radius of the thrower-cum-blower, mm, and

R_i = inner radius of the thrower-cum-blower, mm

Substituting R_{te} = 450 mm and w_t = 200 mm in eqns. (4.19) and (4.20) yields R_o = 550 mm and R_i = 350 mm.

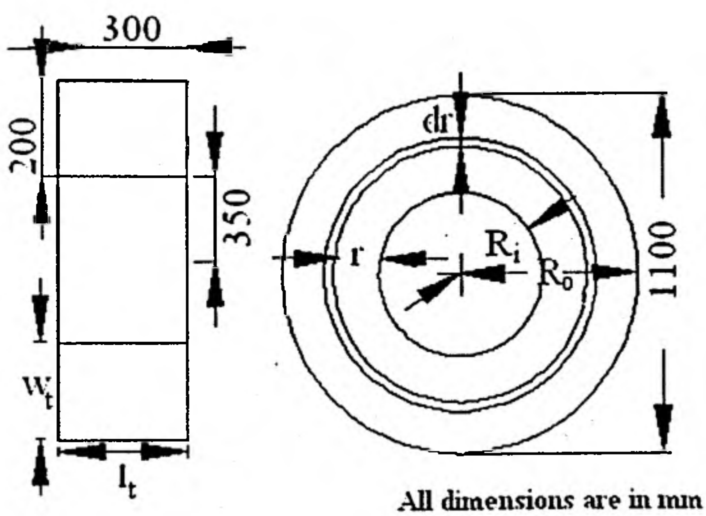


Fig. 4.7 Design Dimensions of Thrower-cum-Blower

Consider an element of *'dr'* thickness at a distance *'r'* from the center of the thrower-cum-blower (Fig. 4.7). The volume flow rate of air from the thrower-cum-blower is given by

$$Q_t = \left(\int_{R_i}^{R_o} 2 \times \pi \times r \times l_{tb}.dr\right) \times N_a$$

$$= \pi \times (R_o^2 - R_i^2) \times l_{tb} \times N_a \quad \cdots(4.21)$$

where l_{tb} = length of thrower-cum-blower (blade length), m.

Substituting $R_o = 0.55$ m, $R_i = 0.35$ m, $l_{tb} = 0.3$ m and $N_a = 530$ r/min in eqn. (4.21) yields,

$$Q_t = \pi \times (0.55^2 - 0.35^2) \times 0.3 \times 530$$
$$= 90 \text{ m}^3/\text{min}$$
$$= 1.5 \text{ m}^3/\text{s}.$$

Maize cobs have 75 per cent grain and 25 per cent chaff and core pieces by weight as reported in Chapter III. It is assumed that 15 per cent of the total material (mostly chaff) is handled by the thrower-cum-blower and 10 per cent by the blower as given in section 4.2.10. Based on this assumption, the material handled by the thrower-cum-blower is 1.1 x 0.15 = 0.167 kg/s.

According to Varshney *et al.* (2004) 5-8 kg of air is required for separation and conveying of one kg of straw and chaff. Based on this value the minimum air flow rate required from thrower-cum-blower is calculated as follows

$$\textit{Air flow rate required } \left(\frac{m^3}{s}\right) = \frac{\textit{Feed rate handled by the thrower (kg)} \times \textit{Amount of air needed per kg of chaff } \left(\frac{kg}{kg}\right)}{\textit{Density of air, } \left(\frac{kg}{m^3}\right)}$$

$$= \frac{0.167 \times 8}{1.2}$$

$$= 1.113 \ m^3/s$$

The design flow rate is higher than the required value, hence design of the thrower-cum-blower is safe.

4.3.6 Design of sieves

Based on the data of commercially available maize threshers with the prime mover size of more than 15 kW, three sieves were selected. In the present study the size of the maize kernel for the common varieties of maize was determined and found in the range of 7-8 mm as presented in Chapter III. Based on this dimension the first sieve is selected with 12 mm diameter hole, second sieve with

8 mm diameter hole and third sieve with 6 mm diameter hole. This is also supported by the recommendations given by Varshney *et al.* (2004). The functional requirements of each sieve are given as follows.

- The material coming to the first sieve from the concave has a mixture of threshed grains, chaff, unthreshed grains attached to core pieces and broken core pieces. The top sieve is required to screen the threshed grains and other coarse materials smaller than 12 mm to the second sieve and allow lighter materials bigger than 12 mm diameter travel to the lower end of the sieve and get collected on the ground.

- The middle sieve is required to screen the sound threshed grains smaller than 8 mm in diameter to the third sieve while allowing all other light materials including chaff, core pieces and very light grains to be blown off by the blower and get deposited on the ground towards the blower outlet.

- The material coming to the third sieve includes the sound grains, light chaff particles and some foreign particles including dust. The sieve allows foreign materials smaller than 6 mm diameter to get screened and fall on the ground, while the sound grains and other materials bigger than 6 mm diameter are collected from the lower end of the sieve at the grain outlet.

The design of the sieves has been done keeping their functional requirements in view.

Referring to section 4.2.10, the sieves are required to handle 75 per cent of the total feeding material. Out of this, the grains constitute 65 per cent and core pieces 10 per cent.

Quantity of grain coming to sieves, $q_g = 0.65 \times 1.11$

$= 0.721$ kg/s

$= 43.3$ kg/min

Quantity of core pieces coming to sieves, $q_c = 0.10 \times 1.11$

$= 0.111$ kg/s

$= 6.66$ kg/min

Taking density of grain $\rho_g = 800$ kg/m^3 and density of core pieces $\rho_c = 250$ kg/m^3 (Tables 3.1 and 3.2), the volume flow rate of the material coming to sieves is,

$$Q_s = \frac{q_g}{\rho_g} + \frac{q_c}{\rho_c}$$

$$= \frac{43.3}{800} + \frac{6.66}{250}$$

$$= 0.0807 \text{ m}^3/\text{min}$$

The volume flow rate of material coming to sieves, Q_s is given by

$$Q_s = w_s \times t_s \times v_s \text{ m}^3/\text{min} \qquad \cdots(4.22)$$

where w_s = sieve width, m

t_s = seed bed thickness, m, and

v_s = velocity of seed flow along the sieve length (oscillating velocity of sieve shaker), m/min

The thickness of the bed is assumed to be equal to the thickness of a single maize kernel, that is $t_s = 7$ mm (based on data obtained in the present study, Chapter III).

According to Varshney *et al.* (2004), the stroke length of sieve, $l_s = 30$ mm and number of strokes per min for sieve shaker is $n_s = 400$ strokes/min.

Hence, sieve shaker eccentricity, $e_s = l_s/2 = 30/2 = 15$ mm

Oscillating velocity of sieve shaker, $v_s = \dfrac{l_s \times n_s}{60}$

$$= \frac{0.03 \times 400}{60}$$

$$= 0.2 \text{ m/s}$$

$$= 12 \text{ m/min.}$$

Substituting Q_s = 0.0807 m^3/min, t_s = 0.007 m and v_s = 12 m/min in eqn. (4.22) yields, width of sieve w_s = 960 mm.

Considering the standard width size as 900 mm and taking aspect ratio of 2:1, the selected sieve size is 1900 x 900 mm. All the three sieves are required to be provided with a slope of 3.5 degree as recommended by Varshney *et al.* (2004) for maize crop.

Speed of sieving unit shaft is given by

$$N_e = n_s/2 \qquad \cdots(4.23)$$

Substituting n_s = 400 strokes/ min in eqn. (4.23) yields,

N_e = 200 r/min

This speed can be achieved by giving drive to the eccentric pulley from another pulley mounted on the cylinder shaft (530 r/min) with 2.65: 1 transmission ratio as shown in Fig. 4.10.

4.3.7 Design of main blower

Power available to operate main blower is assumed to be 7 per cent of the total power available to operate the thresher that is 18kW. Taking power transmission efficiency from cylinder shaft to main blower shaft as 90 per cent, power available at blower is

P_b= 0.07 x 18 x 0.9 = 1.134 kW = 1134 W

The terminal velocity of the maize kernel was found to be 13.1-14.1 m/s in the present study (Chapter III). The air velocity required from the main blower should be smaller than the terminal velocity of the kernel to separate the chaff well from the maize seeds. Hence, the selected air velocity from main blower, v_b = 12 m/s.

Using the relationship between air velocity and peripheral velocity (eqn. 4.18) as suggested by Konfojski (1976), the peripheral velocity of the main blower is

$$u_b = \frac{v_b}{\varepsilon} = \frac{12}{0.55} = 22 \text{ m/s}$$

The power required by the blower to impart kinetic energy to air at air velocity v_b, is given by

$$P_b = \frac{\gamma_a \times A_b \times i_b \times v_b^2}{2 \times \eta_c} \times u_b \text{ W} \qquad \cdots(4.24)$$

where P_b = power required by the blower, W,

γ_a = bulk density of air, kg/ m^3,

≈ 1.2 kg/m^3;

i_b = number of blades = 4,

u_b = peripheral velocity of blower, m/s;

A_b = surface area of each blade, m^2, and

η_c = conversion efficiency in decimal = 0.3.

Substituting P_b = 1134 W, γ_a = 1.2 kg/m^3, η_c = 0.3, i_b = 4, v_b = 12 m/s and u_b = 22 m/s in eqn. (4.24) yields frontal surface area of each blade of the blower, A_b = 0.045 m^2.

Hence a blade with dimensions 530 x 70 mm may be selected (Fig. 4.8).

Therefore, length of main blower, l_{mb} = 530 mm.

If the inner radius of the blower R_{bi} is taken as 150 mm, then the outer radius R_{bo} becomes 150+70 = 220 mm.

The speed of the blower shaft, N_b is given by

$$N_b = \frac{u_b \times 60}{2 \times \pi \times R_{be}} \qquad \cdots(4.25)$$

where R_{be} = effective radius of the main blower, m,

$$= \frac{R_{bo} + R_{bi}}{2}$$

$$= \frac{220 + 150}{2} = 185 \text{ mm.}$$

Substituting $u_b = 22$ m/s and $R_{be} = 0.185$ m in eqn. (4.25) yields $N_b = 1136$ r/min

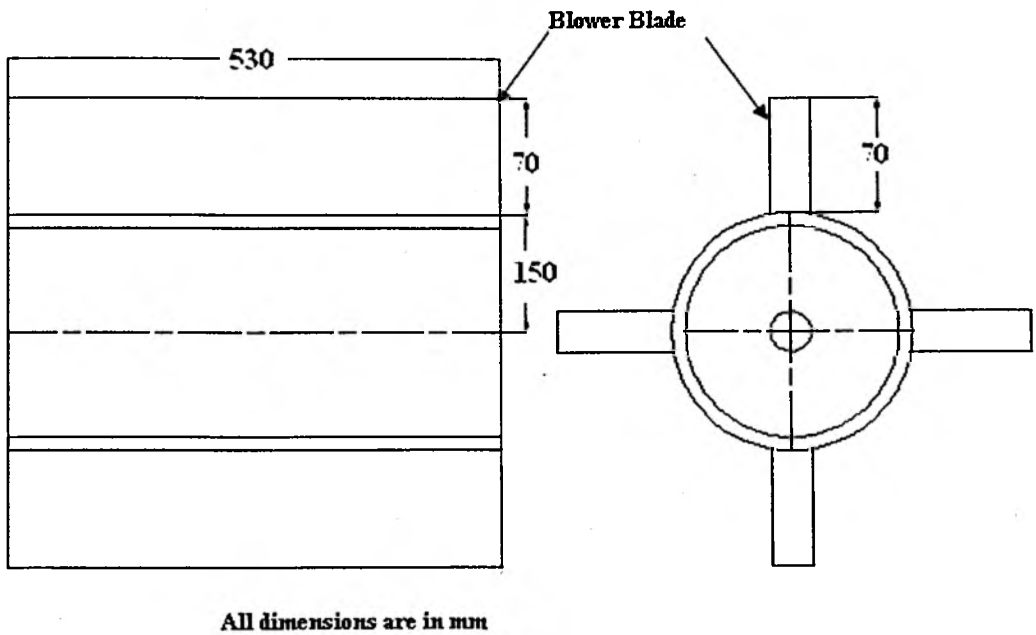


Fig. 4.8 Design Dimensions of Main Blower

This speed can be achieved by using a set of two pulleys, one mounted on sieving unit shaft and another on blower shaft. The speed ratio achieved is 0.17:1 as shown in Fig. 4.10.

Volume flow rate of air from the main blower is

$$Q_b = \pi \times (R_{bo}^2 - R_{bi}^2) \times l_{mb} \times N_b$$

$$= \pi \times (0.22^2 - 0.15^2) \times 0.53 \times 1136$$

$$= 49 \text{ m}^3/\text{min} = 0.82 \text{ m}^3/\text{s}.$$

It is assumed that 10 per cent of the total material is required to be handled by the main blower as given in section 4.2.10. Based on this assumption, the material handled by the main blower is 1.11 x 0.10 = 0.111 kg/s.

According to Varshney *et al.* (2004), 5-8 kg of air is required for separation and conveying of one kg of straw and chaff. Based on this value the minimum air flow rate required from the main blower is 0.74 m^3/s.

Hence the design flow rate is adequate. The geometry of the designed blade is shown in Fig. 4.8.

4.3.8 Design of feeding hopper

It is known that the feed rate of material, q = 1.11 kg/s. The bulk density of maize cobs with husk, ρ_b (determined in the present study) = 435 kg/m^3.

Volume flow rate of maize cobs, $q_v = \frac{q}{\rho_b}$ ...(4.26)

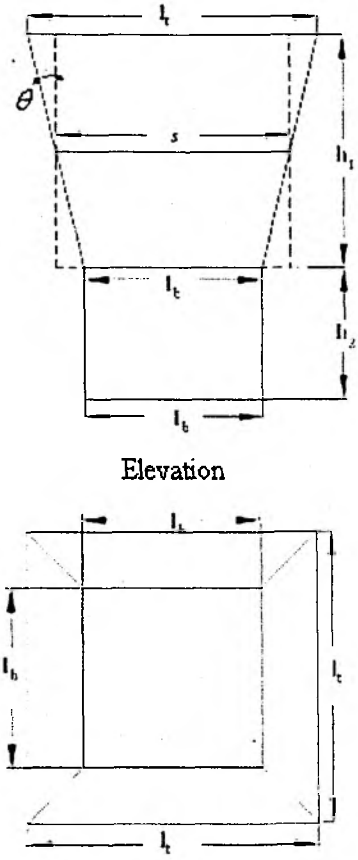
$$= \frac{1.11}{435}$$

$$= 0.0025\ m^3/s$$

$$= 0.15\ m^3/min$$

In this design the feeding of the material is done manually at a constant rate. If the feeding interval is assumed to be one minute , then the volume of feed required to be filled in the hopper is V_f =0.15 m^3.

The hopper is proposed to have a trapezoidal shape at top and rectangular at bottom with square cross-section both at top and bottom as shown in Fig. 4.9. It is assumed that the top trapezoidal portion accounts for 75 per cent and the bottom rectangular portion 25 per cent of the total volume of the hopper.



Elevation

Plan

Fig. 4.9 Feeding Hopper

From the geometry of the figure the volume of feeding hopper, V_f is given by

$$V_f = V_T + V_R \quad \cdots(4.27)$$

where V_T = volume of the trapezoidal portion of the feeding hopper, m^3,

$$= 0.75 \times V_f = s^2 \times h_1 \quad \cdots(4.28)$$

V_R = volume of the rectangular portion of the feeding hopper, m^3.

$$= 0.25 \times V_f = l_b^2 \times h_2 \quad \cdots(4.29)$$

s = middle section dimension of trapezoidal portion, m,

h_1 = height of trapezoidal portion, m,

h_2 = height of rectangular portion, m, and

l_b = bottom section dimension of rectangular portion, m.

Assuming $h_l/s = 1$ and referring to eqn. (4.28), the volume of the trapezoidal portion of the feeding hopper in relation to its height is

$$V_T = 0.75 \times V_f = h_1^3 \qquad \cdots(4.30)$$

Substituting $V_f = 0.15$ m^3 in eqn. (4.30) yields

$h_l = 0.483$ m

≈ 485 mm, and

s = 485 mm

From the geometry of the figure, the top and bottom section dimensions of the trapezoidal portion of the hopper are as follows

$$l_t = s + \frac{h_1}{2}\tan\theta \qquad \cdots(4.31)$$

$$l_b = s - \frac{h_1}{2}\tan\theta \qquad \cdots(4.32)$$

where l_t = top section dimension of trapezoidal portion, m,

l_b = bottom section dimension of trapezoidal portion, m, and

θ = side inclination angle of the trapezoidal portion with vertical plane.

Based on the inclination angle (θ) adopted in commercial threshers the design inclination angle for feeding hopper is taken as 25^0 for easy flow of materials.

Substituting s = 485 mm, h_l = 485 mm and θ = 25^0 in eqns. (4.31) and (4.32) yields

l_t = 598 mm and l_b =372 mm.

Based on the above design values, the top and bottom sections of the trapezoidal portions are adopted as 600 x 600 mm and 370 x 370 mm respectively.

Substituting V_f= 0.15 m^3 and l_b = 0.37 m in eqn. (4.29) yields

h_2 = 274 mm $\approx$ 275 mm.

Total height of the feeding hopper $h_t = h_1 + h_2$

$= 485 + 275 = 760$ mm.

4.3.9 Design of power transmission system

The layout of the designed power transmission system is shown in Fig. 4.10. The power transmission system was designed by using commercially available software, "*MITCalc integrated environment*".

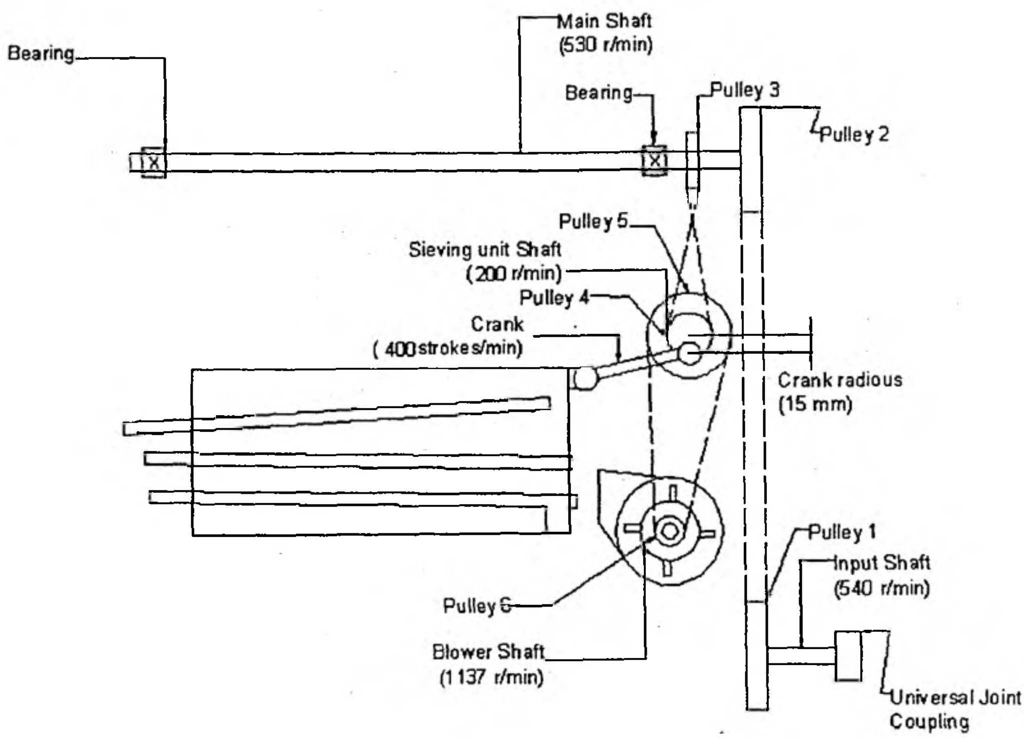


Fig. 4.10 Schematic Representation of Power Transmission from PTO to Different Components of Maize Dehusker-cum-Sheller

Power transmission from Pulley-1 to Pulley-2

PTO power at standard PTO speed is 20 kW. The power is transmitted from PTO shaft to main cylinder shaft through an universal joint and a set of two V-pulleys, Pulley-1 and Pulley-2 as shown in Fig. 4.10. Power transmission efficiency of universal joint is taken as 95 per cent. The operating parameters and the design dimensions of pulleys and belts are mentioned in Table 4.6 and Fig. 4.11.

Table 4.6 Power Transmission from Pulley-1 to Pulley-2

Manner of loading, operational parameters	Pulley 1	Pulley 2
Transferred power/ power distributed to pulleys, kW	19	18
Speed of pulleys, r/min	540	540
Transmission ratio	1:1	
Torque, Nm	331.1	301.2
Type of driving units (loading)	Light shocks	
Type of driven machine (loading)	Light duty	
Daily loading of the transmission	Less than 8 hours	
Belt slip coefficient, %	1.27	1.27
Transmission efficiency, %	91.0	91.0
V-belt type / optimization	CX-ANSI	
Diameter of the pulleys, mm	305	305
Axis distance : optimum value, mm min-max , mm	605 mm 363-1212 mm	
Length of the belt: standardized, mm	>1678	
The angle of wrapping of the pulley, degrees	180.3	180.3
Number of belts (calculated)	2 (2.1)	

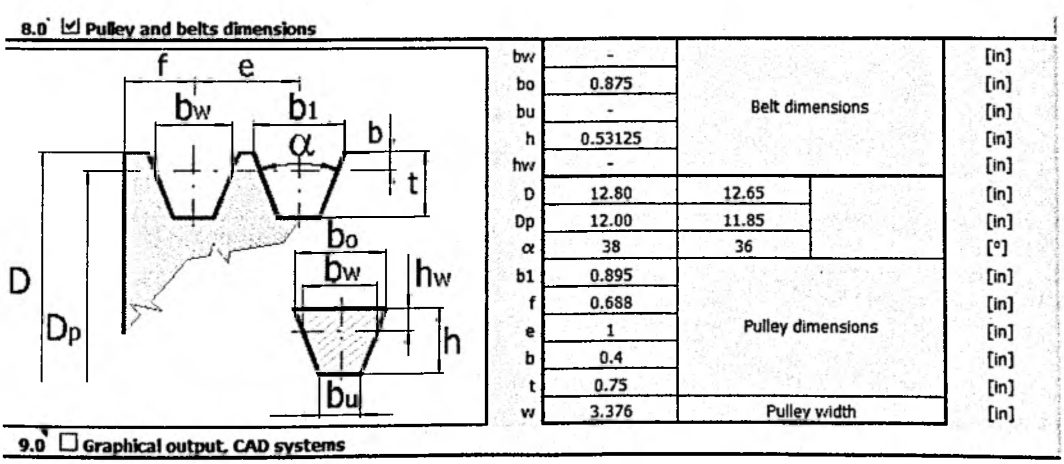


Fig. 4.11 V-Belt and V-Pulley Sizes for Power Transmission from Pulley-1 to Pulley-2

Power transmission from Pulley-3 to Pulley-4

From the total power available to thresher, 7 per cent is required to be transmitted to blower and 3 per cent to the sieves. Thus, 10 per cent of the available power at thresher is to be transmitted through Pulley-3 and Pulley-4 as shown in Fig. 4.10. The operating parameters and the dimensions of pulleys and belt are mentioned in Table 4.7 and Fig. 4.12.

Table 4.7 Power Transmission from Pulley-3 to Pulley-4

Manner of loading, operational parameters	Pulley 3	Pulley 4
Transferred power/ power distributed to pulleys, kW	1.8	1.73
Speed of pulleys, r/min	530	198
Transmission ratio	2.67	
Torque, Nm	32.00	82.23
Type of driving units (loading)	light shocks	
Type of driven machine (loading)	Light duty	
Daily loading of the transmission	Less than 8 hours	
Belt slip coefficient, %	1.09	1.09
Transmission efficiency, %	96.1	96.1
V-belt type / optimization	BX-ANSI	
Diameter of the pulleys, mm	137	363
Axis distance : optimum value, mm min-max, mm	500 mm 300-1000 mm	
Length of the belt: standardized, mm	>1427	
The angle of wrapping of the pulley, degrees	154.2	205.8
Number of belts (calculated)	1 (0.8)	

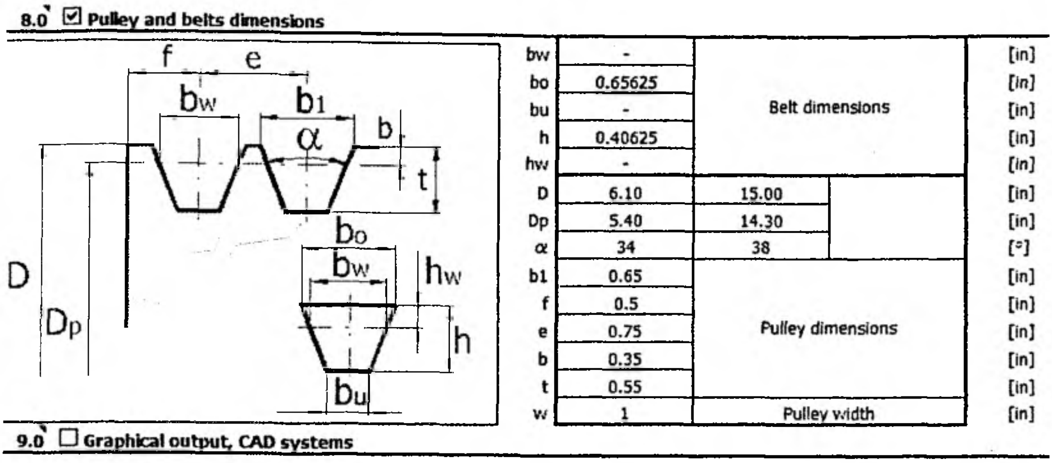


Fig. 4.12 V-Belt and V-Pulley Sizes for power Transmission from Pulley-3 to Pulley-4

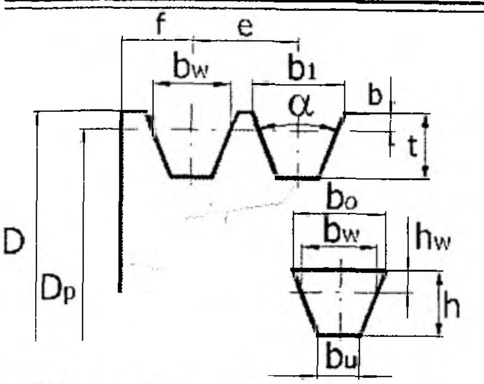
Power Transmission from Pulley-5 to Pulley-6

From the total power available to thresher, 7 per cent is required to be transmitted to blower through V-Pulley (5) and V-Pulley (6) as shown in Fig. 4.10. The operating parameters and the dimensions of pulleys and belt are mentioned in Table 4.8 and Fig. 4.13.

Table 4.8 Power Transmission from Pulley-5 to Pulley-6

Manner of loading, operational parameters	Pulley 5	Pulley 6
Transferred power/ power distributed to pulleys, kW	1.26	1.2
Speed of pulleys, r/min	195	1137
Transmission ratio	0.174 : 1	
Torque, Nm	60.19	10
Type of driving units (loading)	Light shocks	
Type of driven machine (loading)	Light duty	
Daily loading of the transmission	Less than 8 hours	
Belt slip coefficient, %	1.69	1.69
Transmission efficiency, %	95	61
V-belt type / optimization	AX-ANSI	
Diameter of the pulleys, mm	444	76
Axis distance : optimum value, mm min-max , mm	521 mm 312-1041 mm	
Length of the belt: standardized, mm	>1552	
The angle of wrapping of the pulley, degrees	227.3	132.7
Number of belts (calculated)	1(0.8)	

8.0 ☑ Pulley and belts dimensions



bw	-		Belt dimensions	[in]
bo	0.5			[in]
bu	-			[in]
h	0.3125			[in]
hw	-			[in]
D	18.01	3.50		[in]
Dp	17.51	3.00		[in]
α	36	34		[°]
b1	0.504		Pulley dimensions	[in]
f	0.375			[in]
e	0.625			[in]
b	0.25			[in]
t	0.46			[in]
w	0.75		Pulley width	[in]

9.0 ☐ Graphical output, CAD systems

Fig. 4.13 V-Belt and V-Pulley Sizes for Power Transmission from Pulley-5 to Pulley-6

4.3.10 Design of main shaft

The main shaft on which cylinder and thrower-cum-blower are mounted is subjected to torsion loading and bending moment in combination. Hence, according to the maximum shear stress theory (Guest theory), the equivalent twisting moment of the shaft is given by

$$T_e = \sqrt{(K_m \times M_p)^2 + (K_t \times T)^2} \quad \cdots(4.33)$$

$$\text{also } T_e = \frac{\pi \times d^3 \times \tau}{16} \quad \cdots(4.34)$$

where T_e = equivalent twisting moment, N.m,

M_{bm} = bending moment, N.m,

T = torque to be transmitted, Nm,

τ = maximum shear stress of the shaft material, N/m^2,

K_m = combined shock and impact factors for bending moment,

K_t = combined shock and impact factors for twisting moment, and

d = diameter of main shaft, m.

It has been assumed earlier that the power available at cylinder shaft is 90 per cent (80 per cent for cylinder and 10 per cent for thrower-cum-blower) of the total available power for thresher, that is 18 x 0.9 = 16.2 kW.

Hence, torque to be transmitted by the shaft, $T = \dfrac{P_s \times 60000}{2 \times \pi \times N}$ Nm

$$= \frac{16.2 \times 60000}{2 \times \pi \times 530}$$

$$= 292 \text{ Nm.}$$

Let the Pulley-2 be mounted on the main shaft at a distance of x_m=100 mm from the center of bearing as shown in Fig. 4.10. If the diameter of the pulley, D_p = 305 mm (Table 4.6), then

tangential load working on the pulley, $F_t = \dfrac{2 \times T}{D_p}$

$$= \frac{2 \times 292}{0.305}$$

$$= 1915 \text{ N}$$

and bending moment, $M_{bm} = F_t \times x$

$$= 1915 \times 0.1$$

$$= 191.5 \text{ N-m}$$

Substituting K_m =1.5, K_t = 1.5, M_{bm} = 191.5 N.m, T = 292 Nm and $\tau = 45 \times 10^6$ N/m^2 in eqns. (4.33) and (4.34) yields,

$$\sqrt{(1.5 \times 191.5)^2 + (1.5 \times 292)^2} = \frac{\pi \times d^3 \times 45 \times 10^6}{16}$$

or d = 0.039 mm = 39 mm

Hence, the main shaft diameter may be selected as 44 mm ($1\frac{3}{4}$ inch).

4.3.11 Design of main blower shaft

The main blower shaft is also subjected to torsion loading and bending moment in combination. Hence, according to the maximum shear stress theory (Guest theory) the equivalent twisting moment of the blower shaft is given by

$$T_{eb} = \sqrt{(K_m \times M_b)^2 + (K_t \times T_b)^2} \qquad \cdots(4.35)$$

also $T_{eb} = \dfrac{\pi \times d_b^3 \times \tau}{16}$ ···(4.36)

where T_{eb} = equivalent twisting moment of the main blower shaft, N.m,

M_{bb} = bending moment, N.m,

T_b = torque to be transmitted, Nm,

τ = maximum shear stress of the shaft material, N/m^2,

K_m = combined shock and impact factors for bending moment,

K_t = combined shock and impact factors for twisting moment, and

d_b = diameter of main shaft, m.

It has been assumed earlier that the power available at blower shaft is 7 per cent of the total available power for thresher, that is 18 x 0.07 = 1.26 kW.

Hence, torque to be transmitted to the main blower shaft, $T_b = \dfrac{P_b \times 60000}{2 \times \pi \times N_b}$ Nm

$$= \frac{1.26 \times 60000}{2 \times \pi \times 1146}$$

$$= 10.5 \text{ Nm}$$

Let the pulley-6 be mounted on the blower shaft at a distance of x_b=100 mm from the center of bearing. If the diameter of the pulley, D_b =76 mm (Table 4.8), then tangential load working on the pulley, $F_{tb} = \dfrac{2 \times T_b}{D_b}$

$$= \frac{2 \times 10.5}{0.076}$$

$$= 276.3 \text{ N}$$

and bending moment, $M_{bb} = F_{tb} \times x_b$

$= 276.3 \times 0.1$

$= 27.63$ Nm.

Substituting $K_m = 1.5$, $K_t = 1.5$, $M_{bb} = 27.63$ N.m, $T_b = 10.5$ Nm and $\tau = 45 \times 10^6$ N/m^2 in eqns. (4.35) and (4.36) yields,

$$\sqrt{(1.5 \times 27.63)^2 + (1.5 \times 10.5)^2} = \frac{\pi \times d_b^3 \times 45 \times 10^6}{16}$$

or $d_b = 0.017$mm

$= 17$ mm

Hence, the main blower shaft diameter may be selected as 25 mm (1inch).

4.3.12 Design of input shaft and sieving unit shaft

The input shaft and sieving unit shaft are also subjected to torsion loading and bending moment in combination. These shafts were designed following the same principles as adopted for designing main shaft and blower shaft. The design dimensions of these shafts are given below.

Diameter of input shaft = 44.5 mm

Diameter of sieving unit shaft = 25.4 mm

The design dimensions of the major components of the maize dehusker-cum-sheller are given in Table 4.9.

Table 4.9 Design Dimensions of Different Components of Maize Dehusker-cum- Sheller

Component	Design Dimensions
A. Feeding hopper	
• Top section	600 x 600 mm
• Bottom section	370 x 370 mm
• Height	760 mm
B. Threshing cylinder	
• Overall diameter (with pegs)	480 mm
• Drum diameter (with out pegs)	360 mm
• Length of the cylinder	1200 mm
• No. of pegs	56 (8 rows on periphery and 7 pegs per row)
• Peg cross-section	25 x 25 mm
• Peg height	60 mm
• Peg spacing	92 mm between the pegs along the row
C. Thrower-cum-blower	
• Overall diameter	1100 mm
• Hub diameter	700 mm
• No. of blades	3
• Size of blade	300 x 200 mm
D. Concave	
• Concave length	1200 mm
• Concave peripheral width	600 mm
• Concave rods arrangement	6 mm squares at 150 mm spacing along the length of the concave and 12 mm diameter circular rods at 20 mm spacing along peripheral width

Contd...

E. Blower	
• Overall diameter	440 mm
• Hub diameter	300 mm
• No. of blades	4
• Size of blade	530 x 70 mm
F. Sieve system	
• No. of sieves	3
• Size of each sieve (length x width)	1900 x 900 mm
• Hole diameter of top sieve	12 mm
• Hole diameter of middle sieve	8 mm
• Hole diameter of bottom sieve	6 mm
G. Power transmission system	
• PTO to Pulley-1	Power transmission is through Universal joint
• Pulley-1 to Pulley-2	
Pitch diameter of pulley-1	305 mm
Pitch diameter of pulley-2	305 mm
Diameter of pulley-1 shaft	44.5 mm
Diameter of pulley-2 shaft	44.5 mm
No. and belt size	Two CX type belts
• Pulley-3 to Pulley-4	
Pitch diameter of pulley-3	137 mm
Pitch diameter of pulley-4	363 mm
Diameter of pulley-3 shaft	44.5 mm
Diameter of pulley-4 shaft	25.4 mm
No. and belt size	One BX type belt

Contd...

• Pulley-5 to Pulley-6	
Pitch diameter of pulley-5	444 mm
Pitch diameter of pulley-6	76 mm
Diameter of pulley-5 shaft	25.4 mm
Diameter of pulley-6 shaft	25.4 mm
No. and belt size	One AX type belt

Based on the design dimensions arrived in this chapter, the different components were fabricated and assembled. The fabrication and testing procedure are discussed in the next chapter.

CHAPTER V

MATERIALS AND METHODS

This chapter deals with the fabrication of various components of the maize dehusker-cum-sheller based on the design dimensions reported in Chapter IV. The procedure adopted for testing the machine at different operational parameters has also been discussed. The chapter has been presented under the following sub heads.

- Fabrication and assembly
- Working principle of the machine
- Testing methodology

5.1 Fabrication and Assembly

A maize dehusker-cum-sheller to be operated by a 25-35 hp tractor was designed for maize crop based on functional and strength considerations. The machine mainly consists of three units.

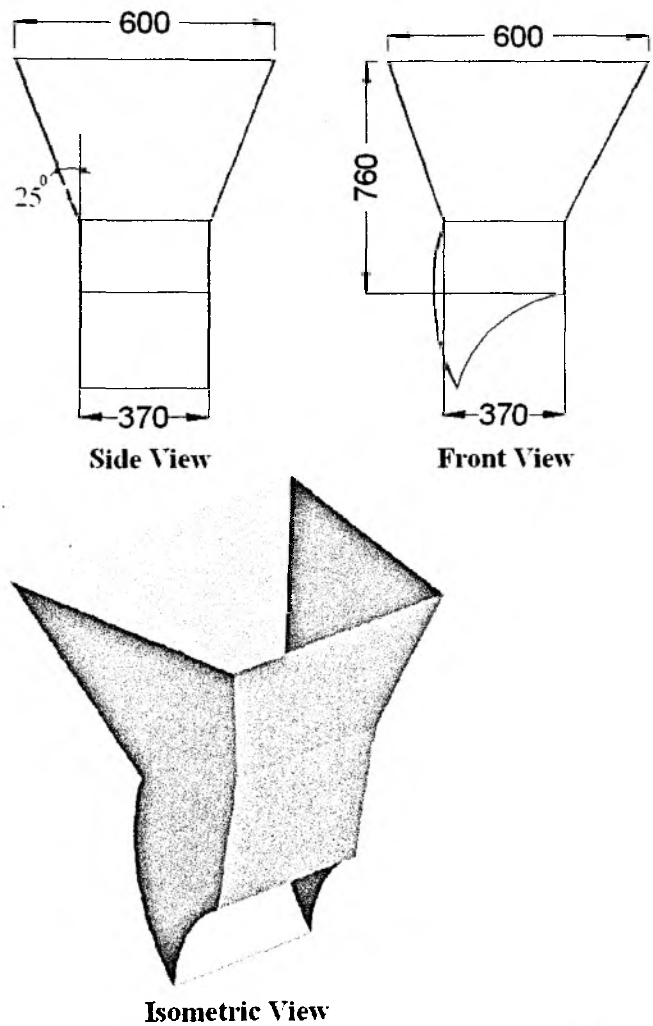
1. Dehusking and shelling unit,
2. cleaning unit, and
3. power transmission unit.

5.1.1 Dehusking and shelling unit

The dehusking and shelling unit consists of feeding hopper, threshing cylinder, louver, concave and thrower-cum-blower. The fabrication of these components is discussed below.

a) Feeding hopper

The constructional details of the feeding hopper are shown in Fig. 5.1. The hopper has a trapezoidal portion at the top and rectangular portion at the bottom. The top and bottom dimensions of the trapezoidal portion are maintained as 600 x 600 mm and 370 x 370 mm respectively, while the rectangular portion attached to the trapezoidal portion at the bottom has a square section of 370 x 370 mm. The height of the feeding hopper is 760 mm. The lower part of the bottom rectangular portion is provided with a slight curvature for easy flow of the material to the threshing cylinder. The material used for the fabrication of the hopper is 16 gauge mild steel sheets. In order to avoid the choking and over loading of the thresher while threshing a crop with high moisture content, a provision has been made to control the feed rate by varying the cross sectional area in side the hopper with a hinged plate.



All dimensions are in mm

Fig. 5.1 Feeding Hopper

b) Threshing cylinder

Initially a 16 gauge mild steel sheet with the size 1130 x 1200 mm was rolled to get a 360 mm diameter drum with 1200 mm length. On both the sides of the drum a circular plate of 360 mm diameter with a 45 mm diameter hole in the centre was welded. A mild steel shaft of 44.5 mm diameter and 1800 mm length was inserted into the drum centre and welded to the two end plates leaving required margin on both the sides as shown in the figure. On the periphery of the drum 56 number of pegs were welded in eight rows maintaining distance between two pegs as 184 mm. The pegs were placed in helical pattern as shown in Fig. 4.3. Each peg had a dimension of 25 x 25 x 60 mm. The fabricated cylinder with pegs on its periphery is shown in Fig. 5.2.

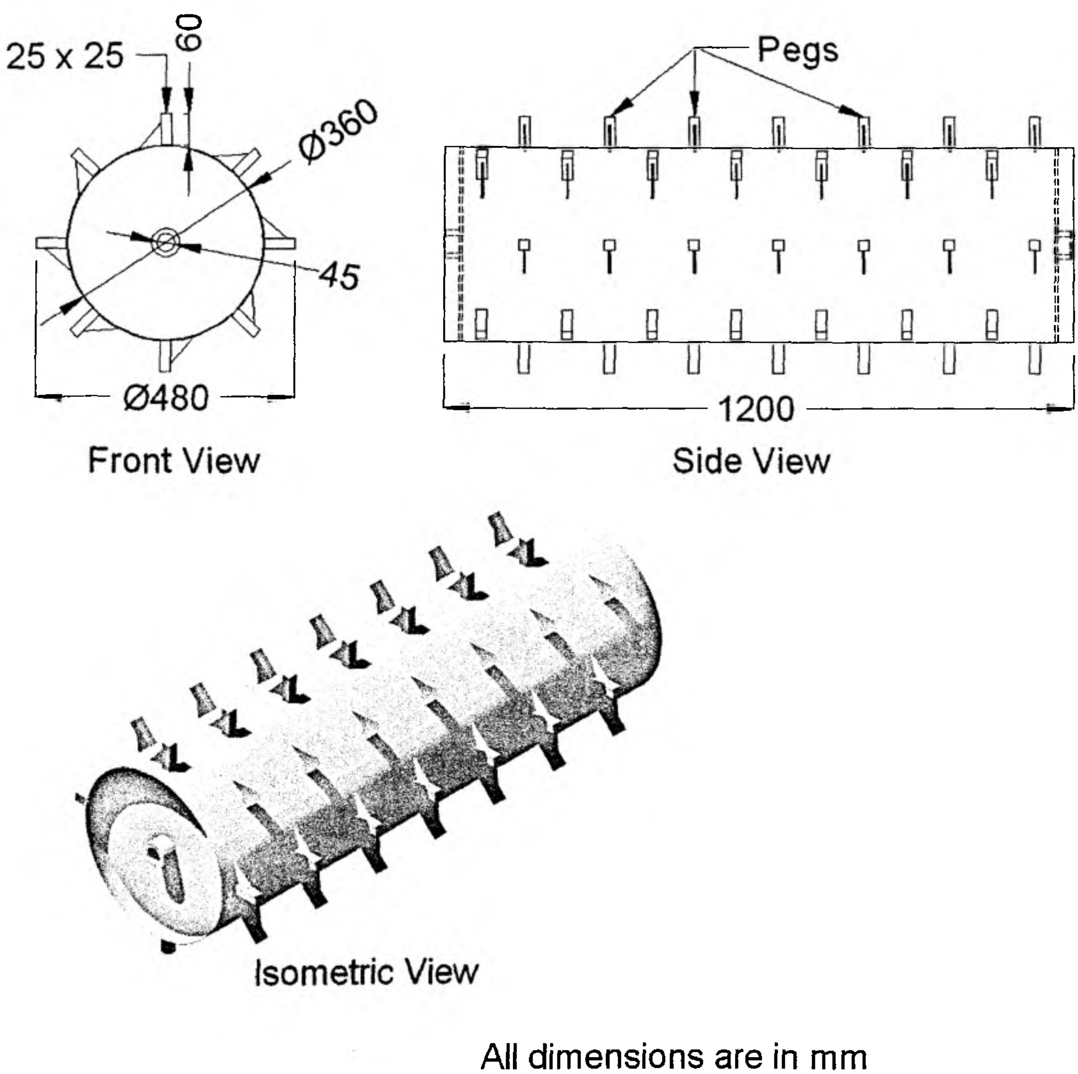


Fig. 5.2 Threshing Cylinder

c) Louver

The upper half of the threshing drum is a blind cover and is made of 16 gauge mild steel sheet. On its inside surface seven adjustable bolts of 12.5 mm size were bolted in a row along its length at 184 mm spacing as shown in Fig. 4.5. The bolts were made adjustable with a view to adjust their length to increase the shelling efficiency. An isometric view of the fabricated louver is shown in Fig. 5.3.

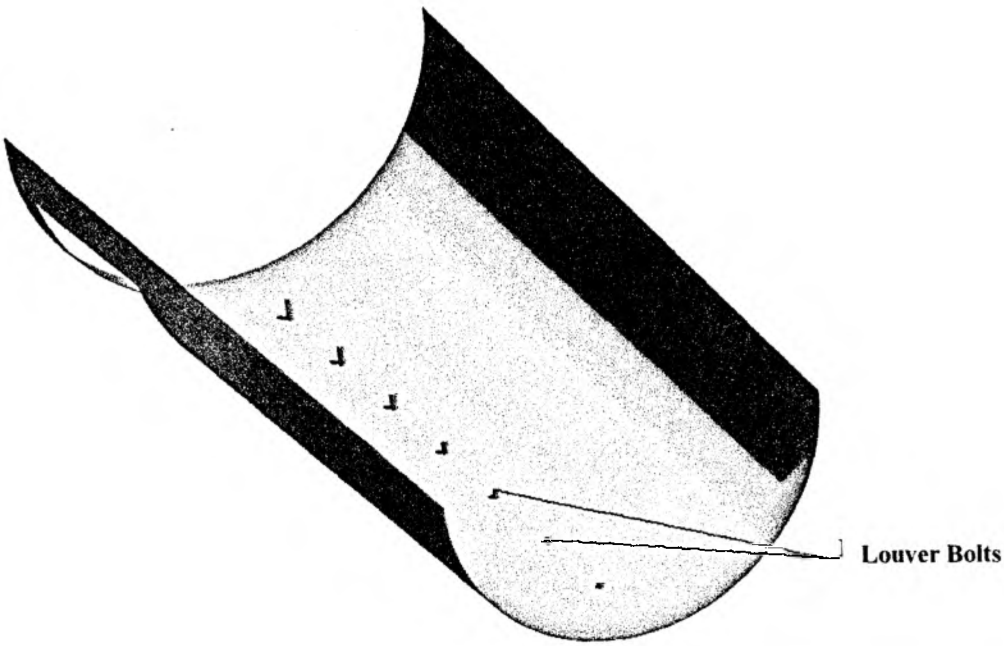


Fig. 5.3 Louver

d) Concave

As per design discussed in Chapter IV, the concave unit has 1200 mm length and 600 mm peripheral width. The concave has been fabricated to maintain the same curvature as that of cylinder, that is 240 mm. The unit was fabricated by fixing 12 mm diameter rods along its length at an interval of 20 mm and 6 mm square rods along its width at an interval of 150 mm. The clearance between concave and tip of the pegs could be varied from 40 to 48 mm with the help of four adjustable bolts fixed on its frame. The details of the concave with the specifications of different components are shown in Fig. 5.4.

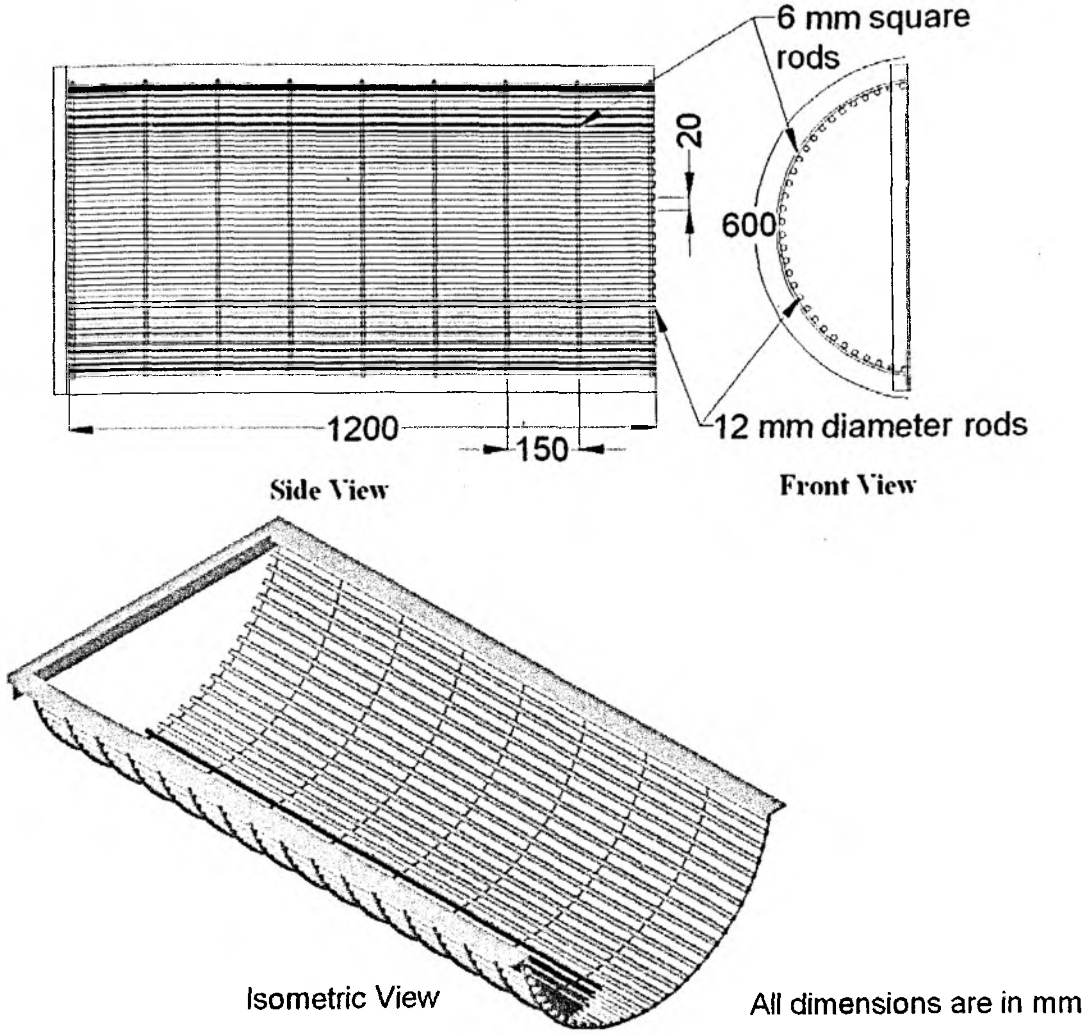


Fig. 5.4 Concave

e) Thrower-cum-blower

On the opposite end of the cylinder a thrower-cum-blower was mounted on the same shaft. This blower has three blades. Each blade was fabricated using a rectangular mild steel sheet of 140 x 300 mm size and welding five pieces of 60 mm length and 12 mm diameter mild steel rods at equal interval on its outer edge. Thus each blade attained a length of 300 mm and width of 200 mm. The blades were welded to the hub having 700 mm outer diameter and 45 mm inner diameter as shown in Fig. 5.5.

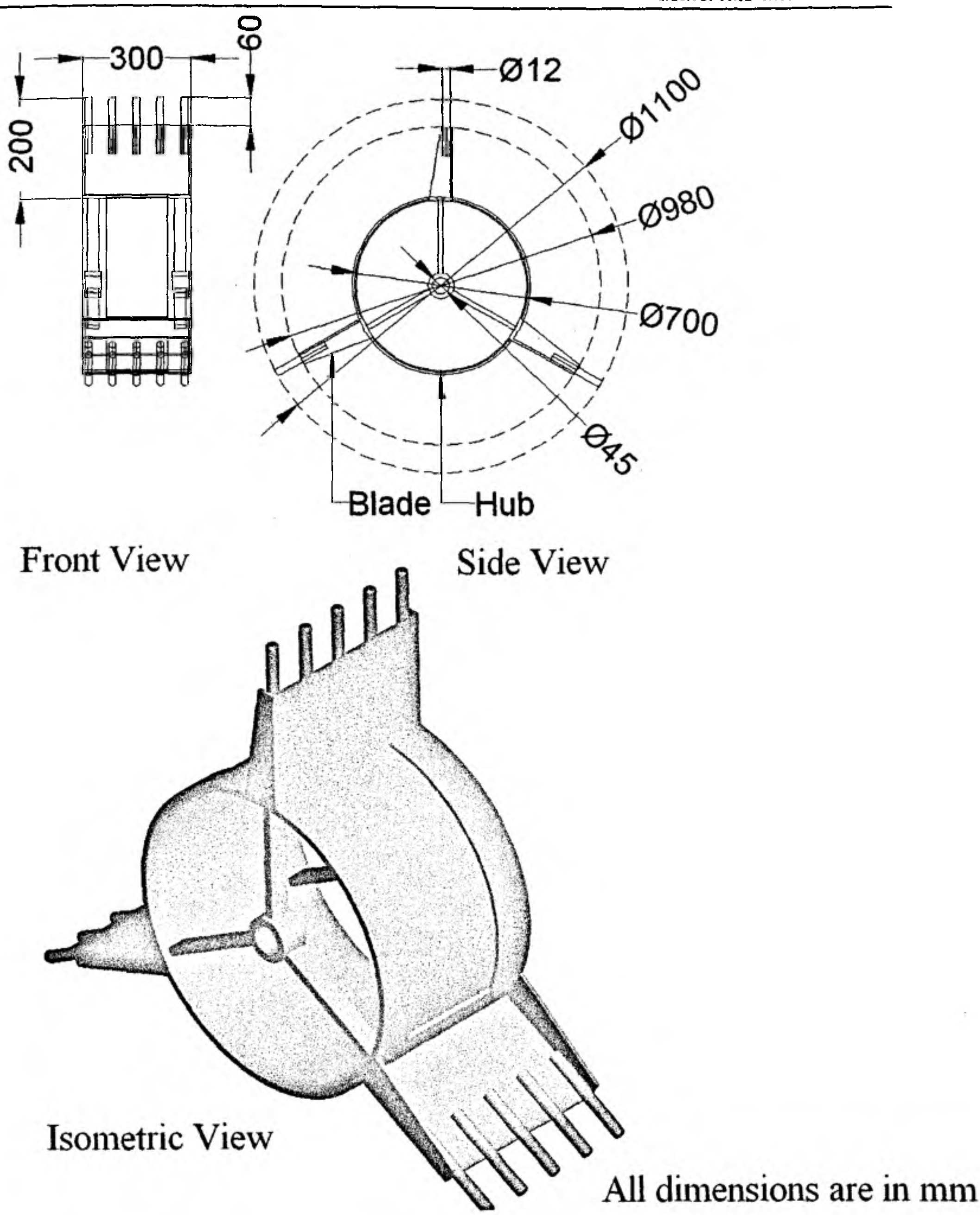


Fig. 5.5 Thrower-cum-Blower

5.1.2 Cleaning unit

The cleaning unit consists of a set of sieves and main blower. The fabrication of these components is discussed bellow

a) Sieves

The sieving unit consists of a set of three sieves. The top sieve has 12 mm diameter holes and is provided to separate large pieces of crushed cobs from the threshed grains. The second sieve has 8 mm diameter holes and the third sieve has 6 mm diameter holes. These sieves are provided for separating foreign materials including broken chaff and small core pieces from the whole grains. Each sieve has 1900 mm length and 900 mm width and was mounted in a rectangular frame made of 39 x 39 x 3 mm MS angle. All the three sieves were provided with an inclination angle of 3.5 degree with horizontal, but the direction of slope for the top sieve was opposite to that of the remaining two sieves. The dimensions of the three sieves with their frame are shown in Fig. 5.6.

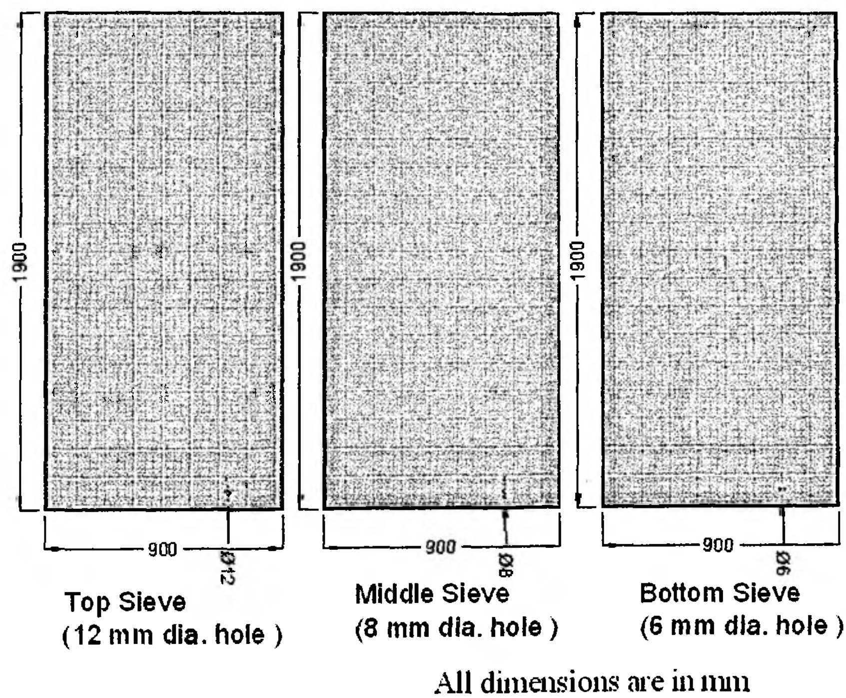


Fig. 5.6 Sieves

The sieves were accommodated in a main sieve frame which could be oscillated at a frequency of 400 strokes/min through an eccentric drive having an eccentricity of 15 mm. The sieve shaking mechanism with specifications of different components is shown in Fig. 5.7.

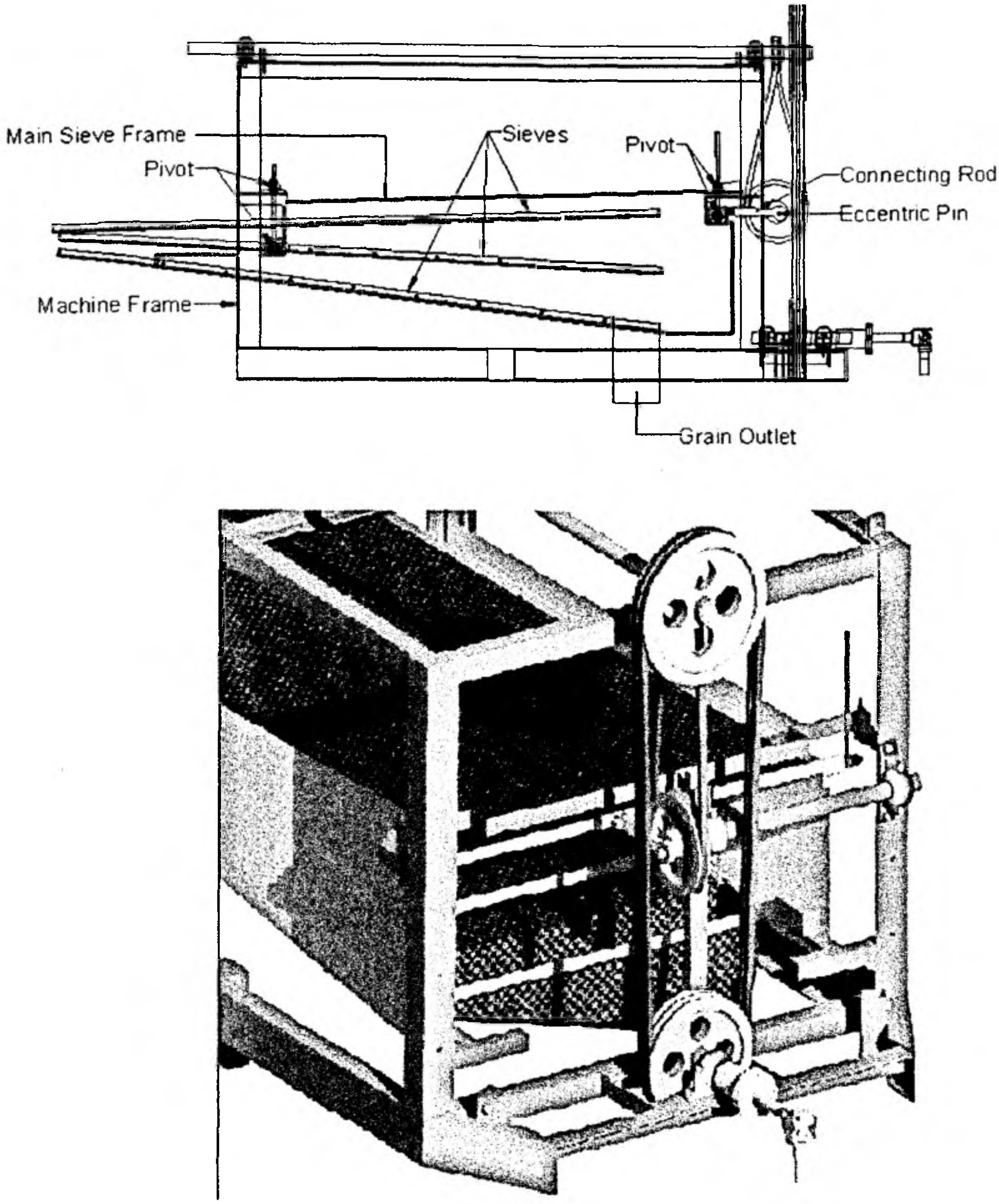
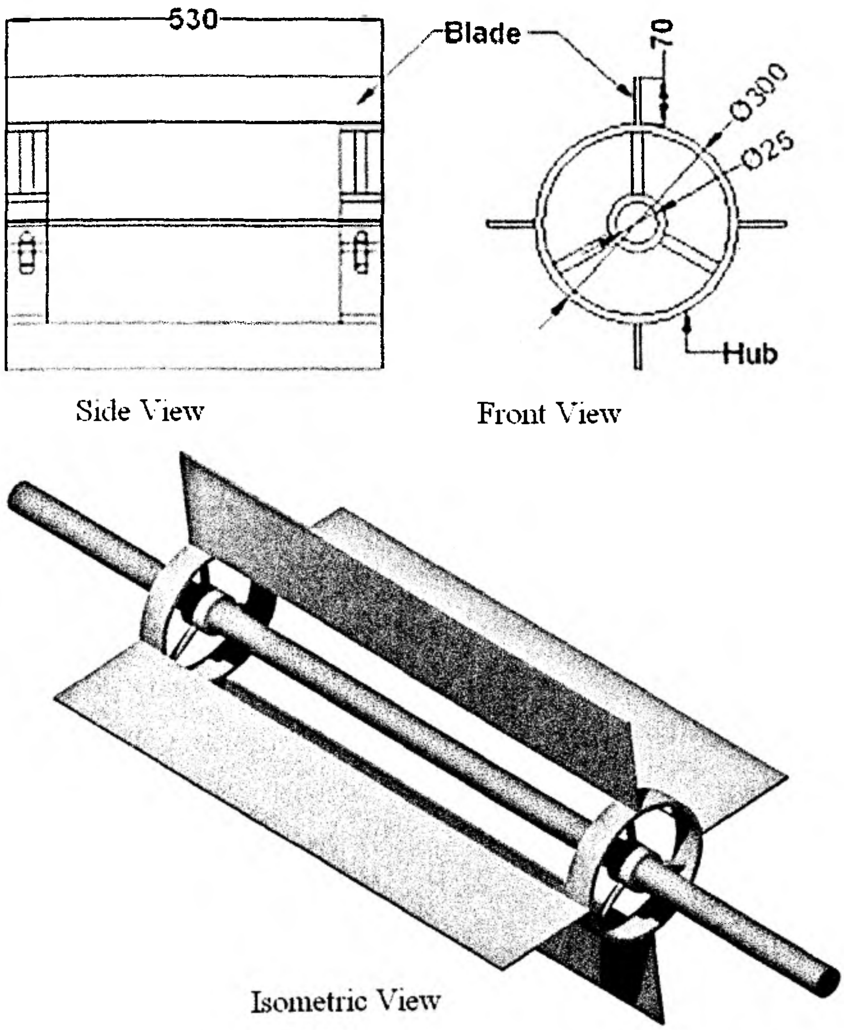


Fig. 5.7 Sieve Shaking Mechanism

b) Main blower

The main blower was provided for blowing off the light chaff particles and broken core pieces from the second and third sieves which could be collected on the ground. As per design the blower consists of four blades, each of 530 x 70 mm size. All the four blades were mounted on a hub of 25 mm inner diameter and 300 mm outer diameter. All the components of the blower were made of 16 gauge mild steel sheet. The fabricated blower with its detailed specifications is shown in Fig. 5.8.



All dimensions are in mm

Fig. 5.8 Main Blower

5.1.3 Power transmission system

A universal joint was used to derive power from tractor PTO shaft to thresher input shaft. The power transmission to threshing cylinder, sieving unit and main blower was provided through belt and pulley arrangement. The different sizes of pulleys and belts were procured from the market as per design requirements. The different sizes of shafts needed to give drive to different components were fabricated using mild steel rod. The specifications of pulleys, belts and shafts in power transmission to different components are given in Table 4.9. The schematic diagram of the transmission system is given in Fig. 5.9.

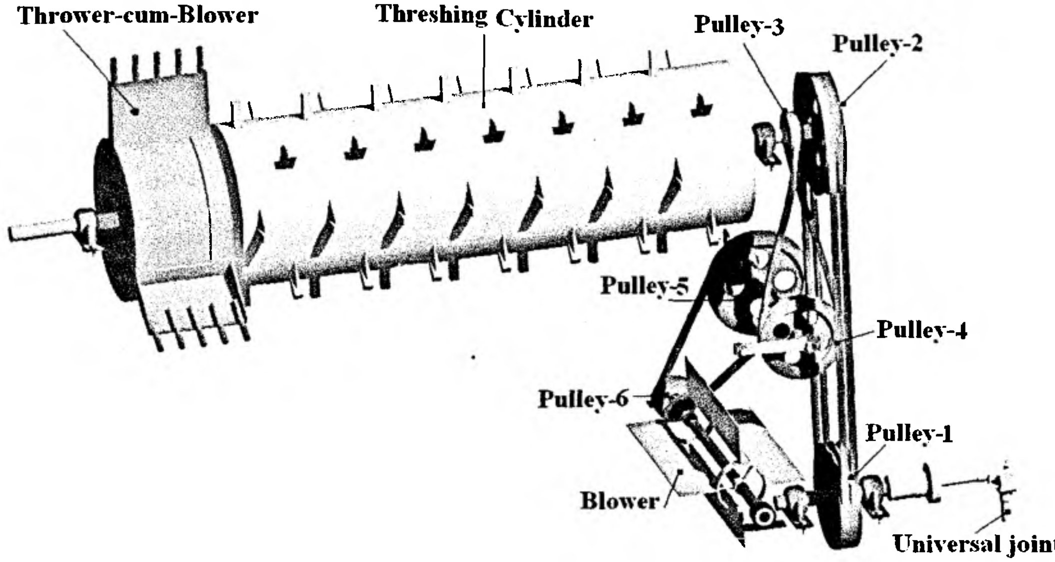


Fig. 5.9 Power Transmission System

5.1.4 Assembly of different components

The exploded view of different components of maize dehusker-cum-sheller is shown in Fig. 5.10. The different components were mounted to the main frame of the machine. The main frame was made of 75 x 75 x 5 mm MS angle. The detailed specifications of the developed machine are shown in Fig. 5.11 and 5.12. The materials used to fabricate the different components are provided in Table 5.1.

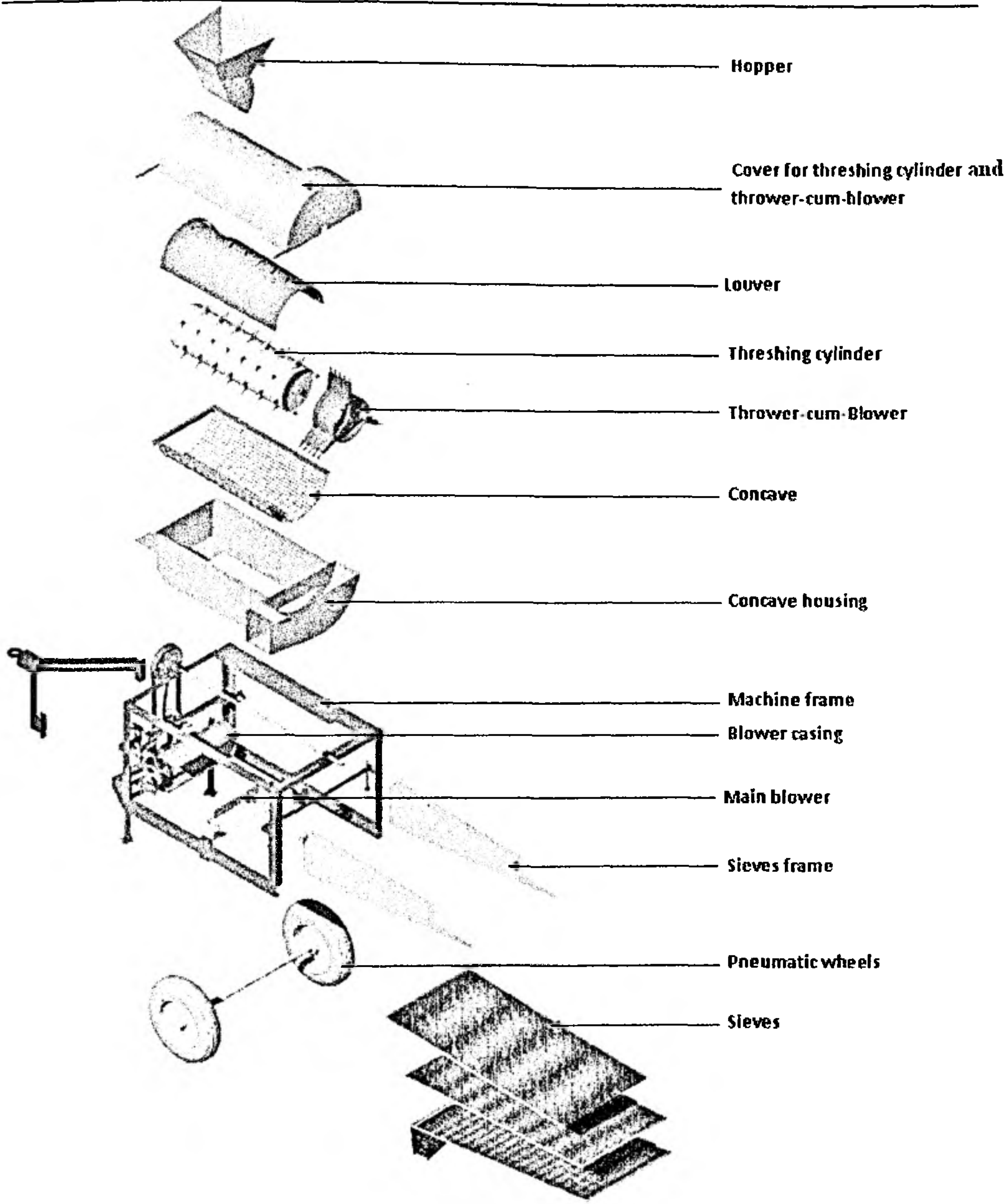


Fig. 5.10 Exploded view of Maize Dehusker-cum-Sheller

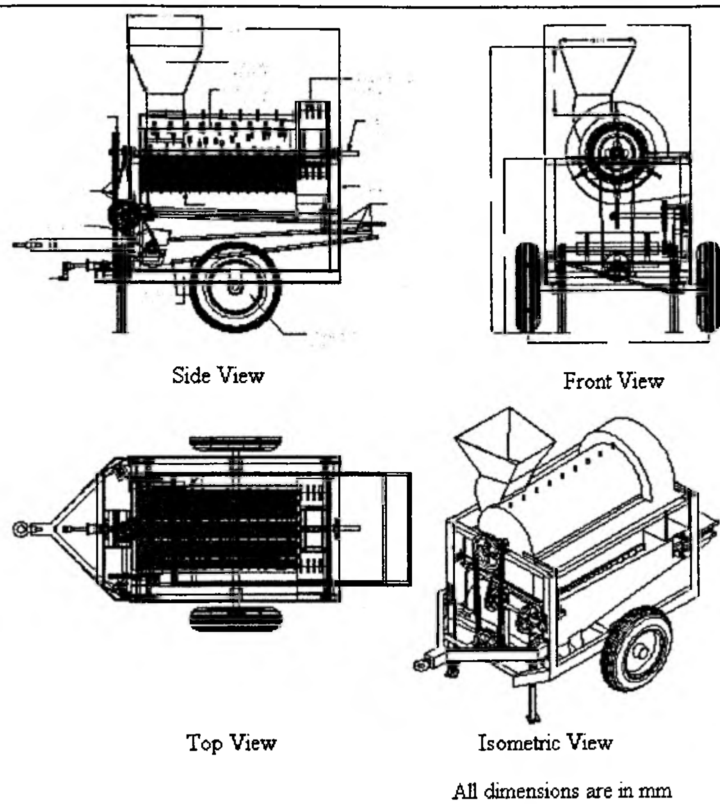


Fig. 5.11 Detailed Specifications of Maize Dehusker-cum-Sheller

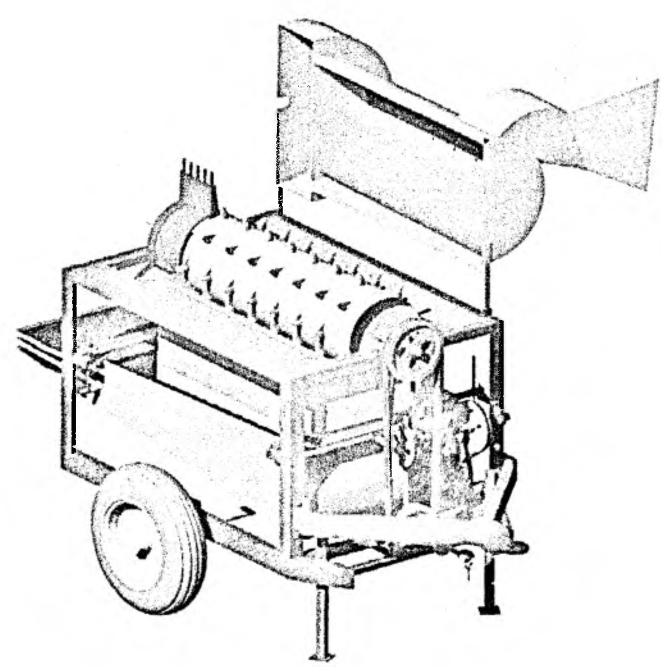


Fig. 5.12 Assembled view of Maize Dehusker-cum-Sheller

Table 5.1 Technical Specifications with Material of Construction of different Components of Maize Dehusker-cum-Sheller

Component	Dimensions mm	Material of construction
1) Dehusking and shelling unit a) Feed hopper (top cross-section x height)	600 x 600 x 760	Mild Steel sheet
b) Threshing cylinder (effective diameter x length)	480 x 1200	Mild Steel sheet and Mild Steel square rods
c) Louver (length)	1200	Mild Steel sheet
d) Concave (peripheral width x length)	600 x 1200	Circular and Square Mild Steel rods
e) Thrower-cum-blower (overall diameter x length)	1100 x 300	Mild Steel sheet and Mild steel circular rods
2) Cleaning unit a) Sieves (length x width)	1900 x 900	Circular and Square Mild Steel sheet
b) Blower (overall diameter x length)	440 x 530	Mild Steel sheet
3) Power transmission unit a) Input shaft (diameter)	44.45	Mild Steel rod
b) Main shaft (diameter)	44.5	Mild Steel rod
c) Sieving unit shaft (diameter)	25.4	Mild Steel rod
d) Blower shaft (diameter)	25.4	Mild Steel rod

Note: Pulleys and belts as per design were procured from the local market.

5.2 Working Principle of the Developed Machine

The maize dehusker-cum-sheller is powered by a 25-35 hp tractor. The drive from tractor PTO to input shaft of the thresher is derived through a universal joint. During operation, maize cobs with husk are fed into the machine through hopper.

The cobs entering through the feeding hopper are drawn in by the spikes provided on the threshing drum and they move in a helical path over the drum. Shelling is accomplished between the rotating cylinder and the stationary concave screen. While in the shelling chamber, the maize cob is subjected to a combination of impact, shear, compressive forces and tangential forces provided by the threshing element, which have impact and rubbing effect on the maize cob thereby shelling the maize. Most of the shelled kernels with broken core pieces and foreign particles pass through the stationary concave screen to the oscillating sieves while the shelled pieces of husk along with some of the shelled kernels and broken cob pieces are discharged by the thrower-cum-blower unit at the thrower outlet. The sieves receive their oscillating action from the crank which imparts reciprocating movement to the sieves. The shelled kernels, chaff and foreign particles smaller than 12 mm in size pass through the first sieve, where as the broken core pieces along with unthreshed grains are collected at the end of the top sieve. From the second and third sieves the sound threshed grain is collected at the grain outlet and chaff from both the sieves is blown away by the blower through the chaff outlet. Very small foreign particles are collected on the ground from the third sieve.

5.3 Testing Methodology

5.3.1 Factors influencing threshing performance

The performance of a thresher is affected by several factors. These factors may be divided into three categories:

1. Crops related factors
    - crop type, and
    - moisture content.
2. Machine related factors
    - type of elements,
    - number of rows of elements,
    - concave length, and
    - cylinder diameter.

3. System related factors
   - feed rate,
   - peripheral velocity, and
   - cylinder concave clearance

5.3.2 Research plan

Based on the factors discussed above the research plan for studying the effect of various operational parameters on threshing performance was outlined as given below.

A) Independent Variables:

• Crop variety	: 1	(Kargil 9000)
• Grain moisture content	: 5	(15.4, 18.0, 20.5, 23.0, & 25.6 per cent)
• Cylinder peripheral speed	: 5	(10.41, 11.20, 11.92, 12.40 & 12.91m/s)
• Concave clearance.	: 3	(40, 44, 48 mm)
• Replications	: 4	
Number of experiments	: 1 x 5 x 5 x 3 x 4 = 300	

B) Dependent Variables:

- Dehusking efficiency
- Shelling efficiency
- Cleaning efficiency
- Thrower loss
- Blower loss
- Grain damage

5.3.3 Measurements of independent and dependent variables

Measurement of different independent and dependent variables included in the research plan are discussed as follows.

A) Independent Variables:

Grain moisture content

The maize cobs were harvested and spread on the floor for sun drying. These cobs were used for testing the developed machine at different moisture contents. The harvested cobs used for testing immediately after harvesting had higher moisture content than those used at later stages due to loss of moisture. An oven dry method was adopted to determine the moisture content of the cobs on different days.

To determine the moisture content, the grains were manually shelled from five randomly selected cobs and 100 g sample was taken. The sample was kept in oven for 72 h at 100 °C and the moisture content on wet basis was determined using the following expression.

$$M_c(wb) = \frac{Ws - W_d}{Ws} x100 \qquad \cdots (5.1)$$

where W_s = weight of sample, g, and

W_d = weight of dried sample, g.

Cylinder Speed

The cylinder speed was varied as discussed in the research plan by using different sizes of pulley as shown below.

Cylinder peripheral speed m/s	Pulley size on input shaft mm (inch)	Pulley size on cylinder shaft mm (inch)
10.41	234 (9.2)	300 (11.8)
11.20	241 (9.5)	290 (11.4)
11.92	246 (9.7)	274 (10.8)
12.40	246 (9.7)	264 (10.4)
12.91	230 (9.0)	254 (10.0)

Concave clearance

Concave clearance was varied from 40 to 48 mm by adjusting the height of concave with the help of adjustable screws.

B) Dependent Variables:

Dehusking efficiency

The efficiency with which the threshing cylinder removes husk from the husked cobs fed into the feeding hopper is termed as dehusking efficiency. It was determined using the following expression.

$$E_d = \left[1 - \frac{W_{hc}}{W_{cf}}\right] \times 100 \qquad \cdots(5.2)$$

where E_d = dehusking efficiency, per cent,

W_{hc} = weight of husked cobs obtained per unit time at thrower outlet, g, and

W_{cf} = total weight of cobs fed into the hopper per unit time, g.

Shelling efficiency

The threshed grain received at all outlets with respect to total grain input is expressed as shelling efficiency in per cent by weight. The following expression was used to determine the shelling efficiency.

$$E_s = \frac{W_t}{W_i} \times 100$$

$$= \left[1 - \frac{W_u}{W_i}\right] \times 100 \qquad \cdots(5.3)$$

where E_s = shelling efficiency, per cent,

W_t = weight of threshed grain obtained per unit time from all outlets, g,

W_i = weight of total grain input per unit time, g, and

W_u = weight of unthreshed grain per unit time obtained from all outlets, g.

Cleaning efficiency

The amount of whole grain received at main grain outlet with respect to grain mixture is expressed as cleaning efficiency in per cent by weight. It was determined by using the following expression.

$$E_c = \frac{W_c}{W_m} \times 100 \qquad \cdots(5.4)$$

where E_c = cleaning efficiency, per cent,

W_c= weight of whole grain per unit time obtained from main grain outlet, g, and

W_m = quantity of whole material per unit time at main grain outlet, g.

Thrower loss

The thrower-cum-blower is supposed to discharge husk pieces removed from the cobs by the threshing cylinder. However along with the husk pieces the thrown material may also include detached grains and unthreshed grains attached to cob pieces. The thrower loss accounts for the detached grains, both sound and broken, available at the thrower outlet. This loss was determined using the following expression.

$$L_t = \frac{W_{gt}}{W_i} \times 100 \qquad \cdots(5.5)$$

where L_t = thrower loss, per cent,

W_{gt} = quantity of detached grain obtained at thrower outlet per unit time, g, and

W_i = weight of total grain input per unit time, g.

Blower loss

The blower is required to remove the light materials such as chaff, broken core pieces, dust and dirt particles transferred from concave on to the different sieve surfaces . However, in cleaning process the blower may also blow sound detached grains and some unthreshed grains attached to core pieces. The blower account for the detached grains lost to the blower outlet and was determined as follows.

$$L_b = \frac{W_{gb}}{W_i} \times 100 \qquad \cdots(5.6)$$

where L_b = blower loss, per cent,

W_{gb} = quantity of detached grain collected at blower outlet per unit time, g, and

W_i = weight of total grain input per unit time, g.

Loss due to visible grain damage

The main grain outlet contains sound grains, damaged grains which are partially and wholly broken and some foreign particles. The loss due to visible grain damage was determined based on sample taken from this outlet using the following expression

$$L_{gd} = \frac{W_{dg}}{W_i} \times 100 \quad \cdots(5.7)$$

where L_{gd} = loss due to visible grain damage, per cent,

W_{dg} = quantity of damaged grain collected at main grain outlet per unit time, g, and

W_i = weight of total grain input per unit time, g.

Collectable grain loss

Collectable grain loss includes the loss due to grain damage which is collected at the main grain outlet. This loss is same as that given by eqn. (5.7)

Non-collectable grain loss

The non-collectable grain loss includes all the detached grains as well as grains attached to cob pieces that are lost at thrower and blower outlets as shown below.

$$NCGL = \frac{W_u + W_{gt} + W_{gb}}{W_i} \times 100 \quad \cdots(5.8)$$

where NCGL = non-collectable grain loss, per cent,

W_u = weight of unthreshed grain per unit time obtained from all outlets, g,

W_{gt} = quantity of detached grains obtained at thrower outlet per unit time, g,

W_{gb} = quantity of detached grains collected at blower outlet per unit time, g, and

W_i = weight of total grain input per unit time, g.

Total grain loss

Total grain loss includes both collectable and non-collectable grain losses.

TGL = NCGL + CGL ···(5.9)

where TGL = total grain loss, per cent,

CGL = collectable grain loss, per cent (as defined by eqn. (5.7)) and

NCGL = non-collectable grain loss, per cent (as defined by eqn. (5.8)).

5.3.4 Test Procedure

1. The crop variety chosen for evaluating the performance of the developed thresher was Kargil 9000 (Fig. 5.13(a)).

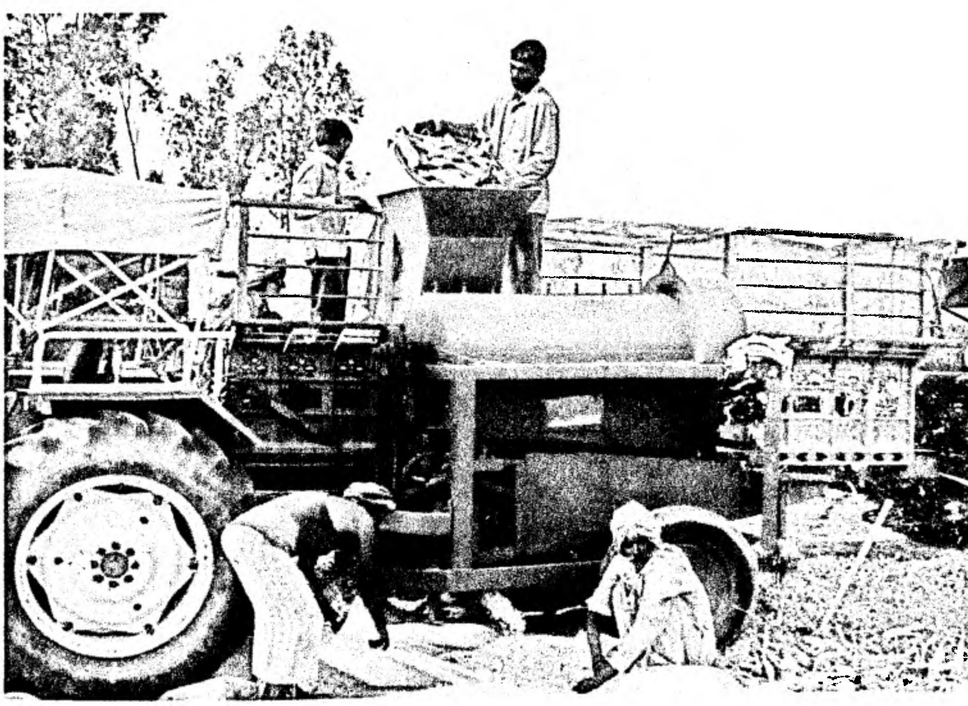
2. After attaining the maturity the cobs were harvested manually when the grain moisture content was around 27 per cent on wet weight basis. The harvested cobs were spread on the threshing floor for sun drying. These cobs were harvested on different dates when their moisture content was equal to the moisture content desired as discussed in the research plan.

3. A 35 hp tractor was used to give drive to the sheller. The tractor PTO shaft was connected to the drive pulley of the sheller with the help of a universal joint.

4. The required size of drive and driven pulleys were mounted on the thresher in order to achieve a peripheral speed as given in the section 5.3.3. The highest peripheral speed obtained with 30 cm diameter pulley mounted on drive and driven shafts was 12.91 m/sec. This speed was slightly lower than the design speed of 13.32 m/sec because the PTO shaft speed at full throttle was reduced to 515 r/min during threshing operation.

5. The machine was set at a particular concave clearance and the tractor engine was started and throttle was set at full position.

(a) Harvested Maize Cobs



(b) Feeding of Maize Cobs in Hopper

Fig. 5.13 Testing of the Developed Maize Dehusker-cum-Sheller

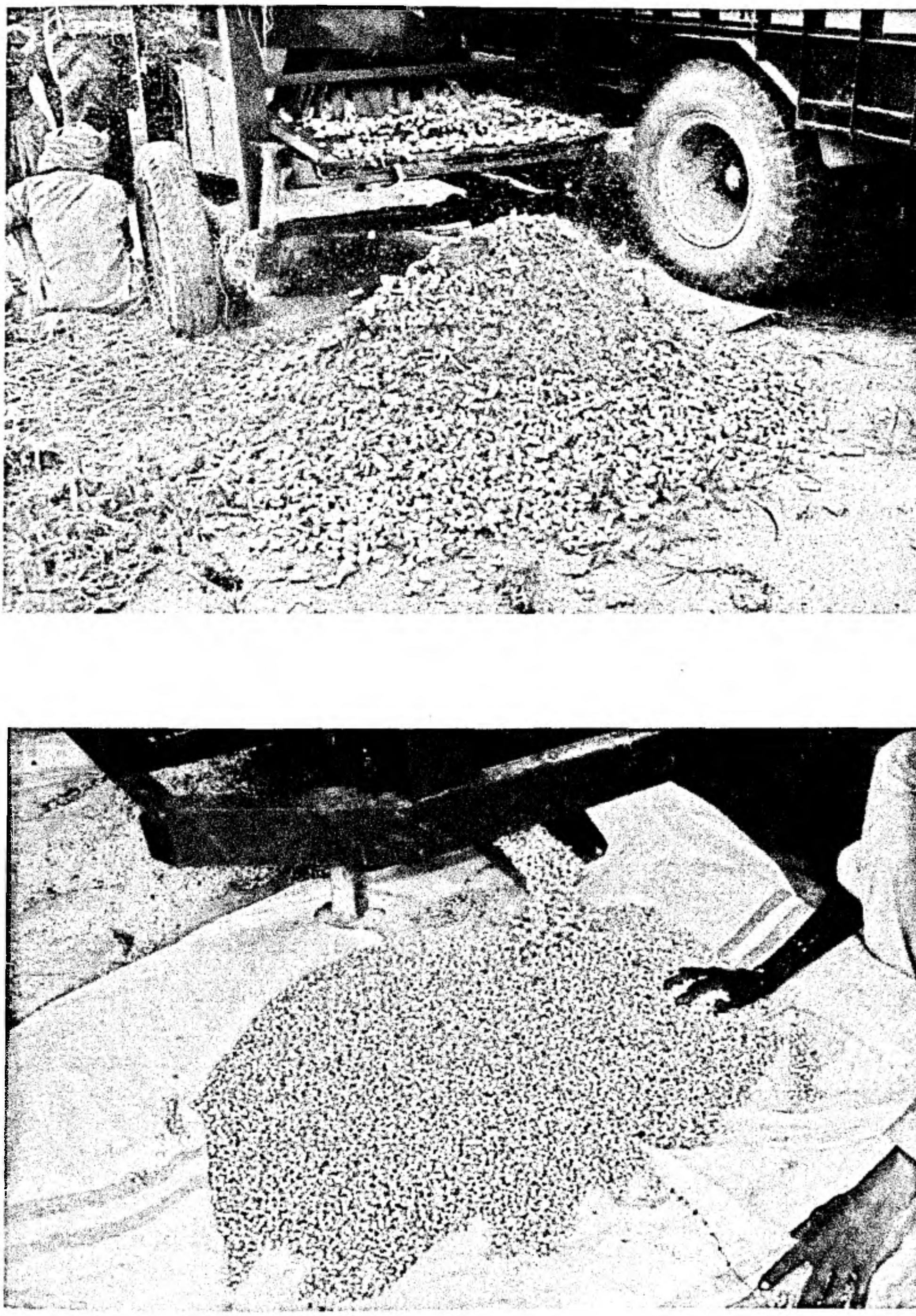


Fig. 5.14 Threshed Grain and Broken Core Pieces obtained during Testing of Maize Dehusker-cum-sheller

6. The husked cobs were fed manually into the hopper as shown in Fig. 5.13(b). Two people were employed for continuously feeding the cobs into the hopper, for which they were trained in initial trial runs. The different materials (threshed, unthreshed, broken cobs, chaff) were discharged by the machine at different locations as indicated below.
   - Outlet of thrower-cum-blower – husk removed from the cobs, broken core pieces, broken core pieces attached with unshelled grain, detached sound and broken grains and foreign particles.
   - Blower outlet – chaff, broken cob pieces, detached sound and broken grains and foreign particles.
   - Main grain outlet – detached sound and broken grains, chaff pieces and foreign particles.

   The materials collected at blower outlet and main grain outlet are shown in Fig.5.14.

7. The machine was operated at a particular setting of peripheral speed and concave clearance for one hour. As per BIS code IS: 6284-1985, the samples were collected for 10 seconds from different outlets after a time lapse of 20, 40 and 60 minutes after the start of threshing operation.

8. The collected samples were analyzed to determine the dehusking efficiency, shelling efficiency, cleaning efficiency and different losses as explained in section 5.2.3.

9. Each experiment was replicated four times.

The test observations at different operational parameters are given in Appendix-B. The results are discussed in the next chapter.

CHAPTER VI

RESULTS AND DISCUSSION

This chapter deals with the results obtained on experimental investigation conducted in the present study. The procedure adopted to optimize the operational parameters of the machine has also been discussed. The chapter includes the following sub topics.

- Effect of operational parameters on performance of developed machine
- Development of the empirical models
- Optimization of operational parameters

6.1 Effect of Operational Parameters on Performance of Developed Machine

According to the research plan presented in Chapter V the experiments were conducted to study the effect of crop moisture content, peripheral speed of threshing cylinder and concave clearance on dehusking and shelling performance of the developed thresher. The moisture content was varied from 15.4 to 25.6 per cent (dry weight basis), the peripheral speed from 10.41 to 12.91 m/s and concave clearance from 40 to 48 mm. These experiments were conducted with a view to study their effect on dehusking and shelling performance of the developed machine and determine their optimum values for the most popular variety (kargil 9000) grown in the southern region of the country for optimum shelling. The average values of the performance parameters of the maize dehusker-cum-sheller are reported in Appendix- B (Table B-1) and the experimental data for four different replications are presented in Tables B-2 through B-7. The results on dehusking and shelling performance have been discussed in terms of dehusking efficiency, shelling efficiency, cleaning efficiency, thrower loss, blower loss and grain damage. The graphs have been prepared to indicate the influence of moisture content on various dependent parameters at different values of peripheral speed and concave clearance. A second degree polynomial has been found to best fit the observed data for each dependent parameter as shown below.

$$y = aM_c^2 + bM_c + c \qquad \cdots (6.1)$$

where y = dependent parameter (E_d, E_s, E_c, L_t, L_b and L_{gd}),

M_c= moisture content, %, and

a, b and c = empirical coefficients.

The values of the coefficients to predict various dependent parameters at different values of independent parameters along with their R^2 values are given in Appendix-C. The experimental data were statistically analyzed using a factorial randomized block design. The analysis of variance for all the dependent parameters is shown in Table 6.1 and the mean values showing the interaction effects of different variables are given in Appendix-C.

6.1.1 Dehusking efficiency

Fig. 6.1 shows the dehusking efficiency as affected by moisture content, cylinder speed and concave clearance. The data indicate that dehusking efficiency decreased with decrease in moisture content up to a certain value beyond which it again increased. This behavior may be attributed to the changes in properties of the sheath at different moisture levels and its corresponding resistance to tearing. The trend also indicates that the dehusking efficiency increased with increase in cylinder speed at different levels of moisture content and concave clearance excepting at the concave clearance of 40 mm where the effect of cylinder speed was not significant. This may be explained on the basis of the fact that increase in cylinder speed increased the frequency of impact of the maize cobs which helped to detach the sheath and increase the dehusking efficiency. With regard to the concave clearance the general trend shows that the efficiency of dehusking decreased with increase in concave clearance. This may be explained as follows. As the concave clearance increased, the resistance to the flow of material decreased leading to higher flow rates. This resulted in reducing the frequency of impact and thereby efficiency of dehusking.

The results indicate that the dehusking efficiency ranged from 98.5 to 100 per cent for the concave clearance of 40 to 48 mm and moisture content of 15.4 to 25.6 per cent. The maximum dehusking efficiency of 100 per cent was observed at moisture contents of 15.4 and 25.6 per cent and at concave clearance of 40 mm and cylinder speed of 12.91 m/sec. This trend is well supported by the past findings in the literature (Mahal et al., 2007).

The statistical analysis indicating the significance level of the different parameters on dehusking efficiency is presented in Table 6.1. The analysis shows that all the three parameters, namely peripheral speed, moisture content and concave clearance are significantly affecting the dehusking efficiency of maize cobs at 1% level. It is also observed that the effect of concave clearance is most significant on dehusking efficiency followed by moisture content and cylinder speed. Among the first order interactions the order of importance is cylinder speed and concave clearance, moisture content and concave clearance and moisture content and cylinder speed. Comparison among treatment means using LSD shows that except in a few cases, the dehusking efficiency differed significantly at different peripheral speeds and concave clearances for each moisture content tested (Table C-2.1).

Table 6.1 Analysis of Variance for Effect of Cylinder Speed, Moisture Content and Concave Clearance on Different Performance Parameters of Maize Dehusker-cum-Sheller

Source of variation	*df*	F- value					
		E_d	E_s	E_c	L_t	L_b	L_{gd}
Replication	3	0.47	0.96	5.43	22.26	10.89	2.62
Cylinder speed (u)	4	373.04**	163.90**	326.24**	1901.68**	7.53**	90.77**
Moisture content (M_c)	4	410.22**	90.75**	21.12**	11239.34**	42.45**	2950.69 **
Concave clearance (C_c)	2	3798.07**	826.12**	49.20**	2459.36**	7.88**	370.13* *
u x M_c	16	10.23**	4.99**	0.09^{ns}	113.24**	1.64^{ns}	2.40**
u x C_c	8	96.51**	27.18**	1.96^{ns}	94.52**	0.45^{ns}	3.20**
M_c x C_c	8	78.67**	12.08**	0.14^{ns}	68.88**	0.53^{ns}	3.87**
u x M_c x C_c	32	10.64**	2.27**	0.18^{ns}	10.98**	0.44^{ns}	2.68**
Error	222						

*significant at 5 per cent level, **significant at 1 per cent level ^{ns} not significant

E_d=Dehusking Efficiency; E_s=Shelling Efficiency; E_c=Cleaning Efficiency; Lt=Thrower Loss; L_b= Blower Loss; L_{gd}=Grain Damage.

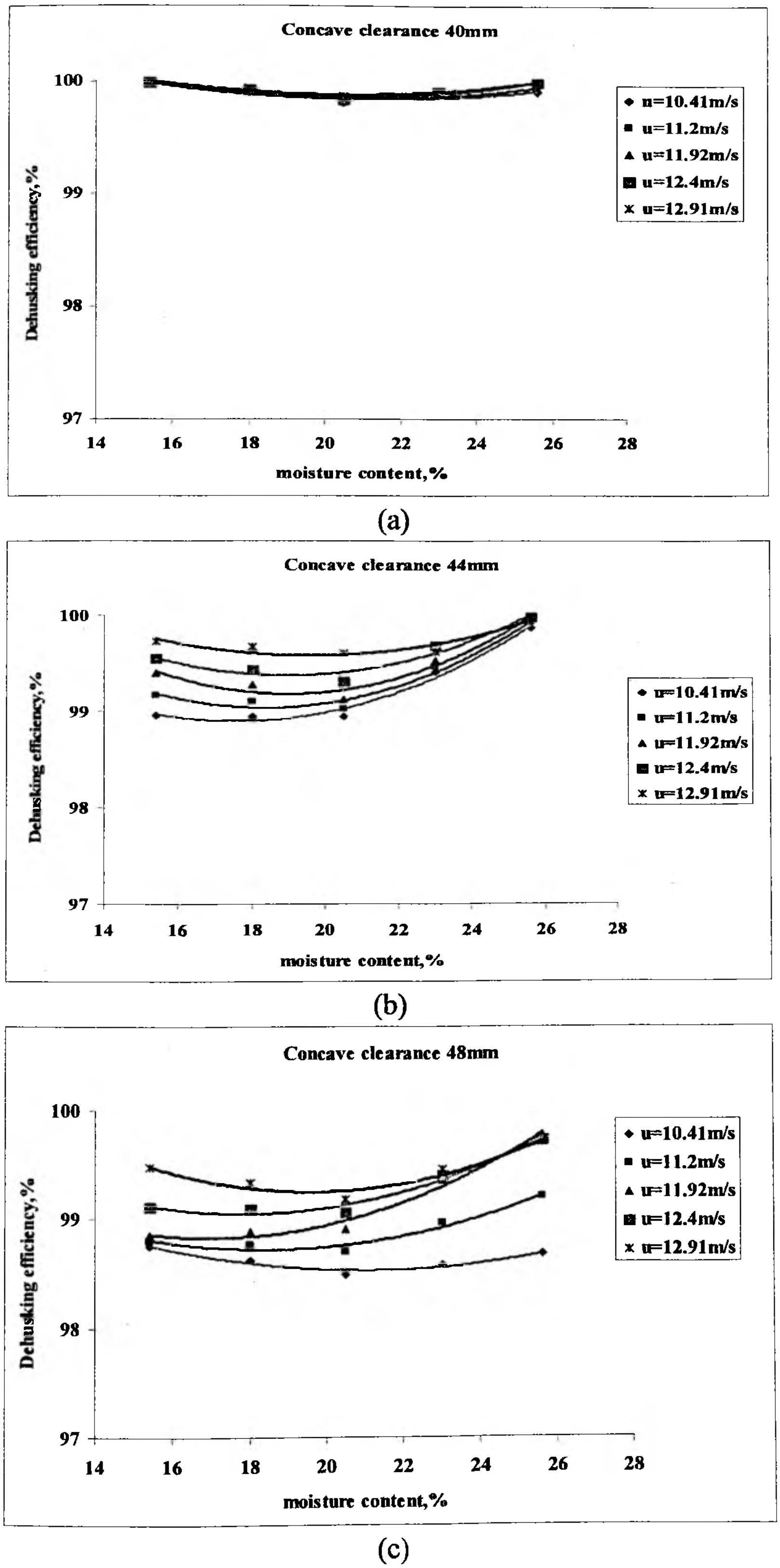


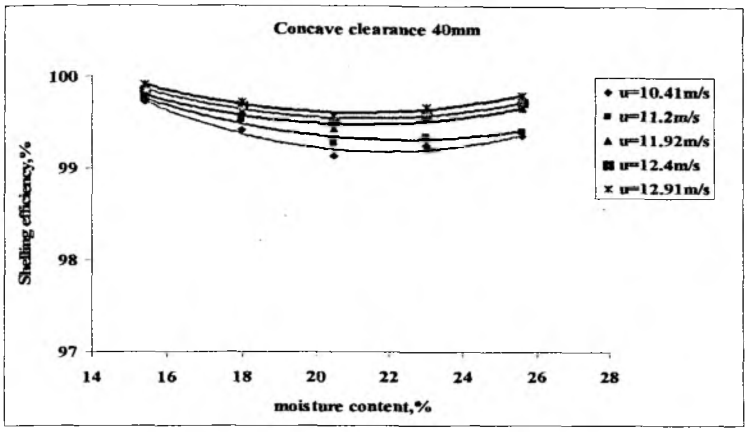
Fig. 6.1 Effect of Moisture Content on Dehusking Efficiency at different Cylinder Speeds and Concave Clearances

6.1.2 Shelling efficiency

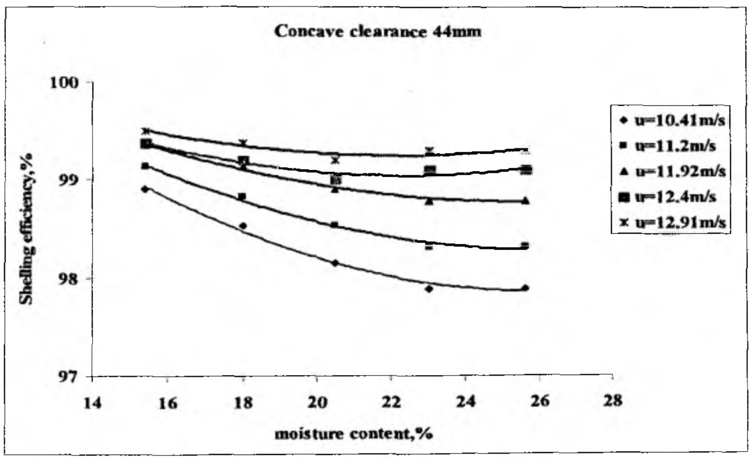
Fig. 6.2 shows the shelling efficiency as affected by moisture content, cylinder speed and concave clearance. In general the shelling efficiency was found to increase with increase in peripheral speed from 10.41 to 12.91 m/s, but decrease with increase in concave clearance from 40 to 48 mm at all the moisture contents studied. This particular trend is quite obvious and true almost with all the crops. Many researchers have found a similar trend in threshing of different crops including maize (Sandhar and Panwar, 1974; Chowdhary and Buchele, 1975; Pandey et al., 1997; Akubuo, 2002 and Mahal et al., 2007). This behavior may be explained as follows. The increase in cylinder speed increases the number of impacts which helps to get the grains detached from the cobs easily. On the other hand the increase in concave clearance decreases the contact of the materials with the rubbing surfaces of the concave which decreases the level of impacts received by the cobs leading to decrease in the shelling efficiency.

With regard to the trend in shelling efficiency with moisture content it is noticed that the shelling efficiency in general improved with decrease in moisture content at all the peripheral speeds and concave clearances studied. Unlike dehusking efficiency, the shelling efficiency was found higher at lower moisture contents than at higher moisture contents. This may be due to the fact that the grains at lower moisture contents require less impact energy to detach as compared to higher moisture contents. It is also interesting to note that the effects of peripheral speed and concave clearance were more pronounced at higher moisture contents than at lower moisture contents. This behavior may be attributed to the fact that low moisture grains due to their poor adhesive strength get detached easily even at lower cylinder speeds compared to high moisture grains which require greater amount of impact energy for detachment.

The data indicate that the shelling efficiency ranged from 96.7 to 99.9 per cent within the range of variables studied. The highest shelling efficiency was achieved 99.9 per cent at lowest moisture content of 15.4 per cent and highest peripheral speed of 12.91 m/s when the machine was set at a concave clearance of 40 mm.



(a)



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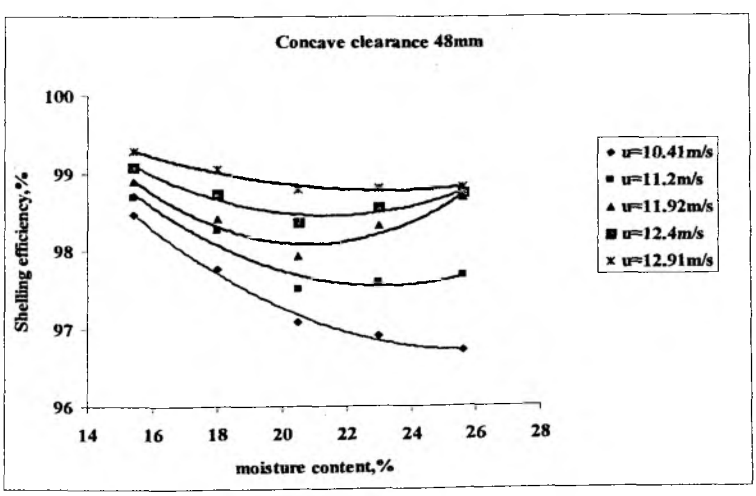


(c)

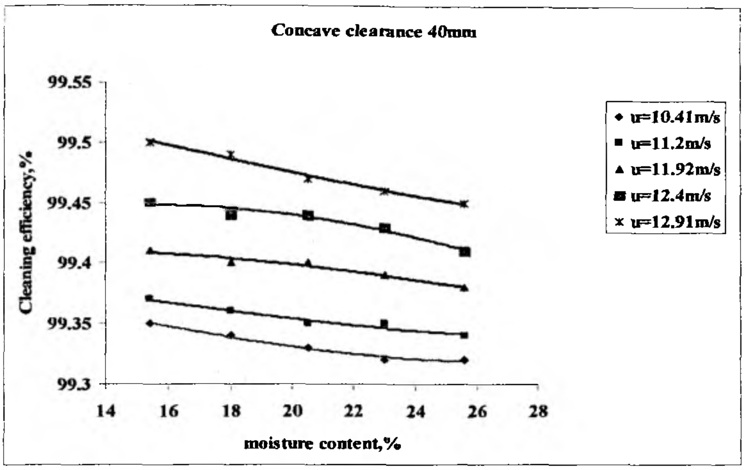
Fig. 6.2 Effect of Moisture Content on Shelling Efficiency at different Cylinder Speeds and Concave Clearances

The analysis of variance (Table 6.1) shows that the cylinder speed, moisture content and concave clearance significantly affected the shelling efficiency at 1 per cent level. The concave clearance was found to be the most significant parameter followed by the cylinder speed and moisture content. Among the first order interactions, cylinder speed and concave clearance followed by moisture content and concave clearance, and cylinder speed and moisture content showed highly significant on shelling efficiency. Comparison among treatment means using LSD shows that the shelling efficiency differed significantly at different concave clearances for each peripheral speed and moisture content tested. However, the cylinder speed in the range of 11.92 to 12.91 m/s did not bring significant differences in shelling efficiency at various moisture contents (Table C-2.2).

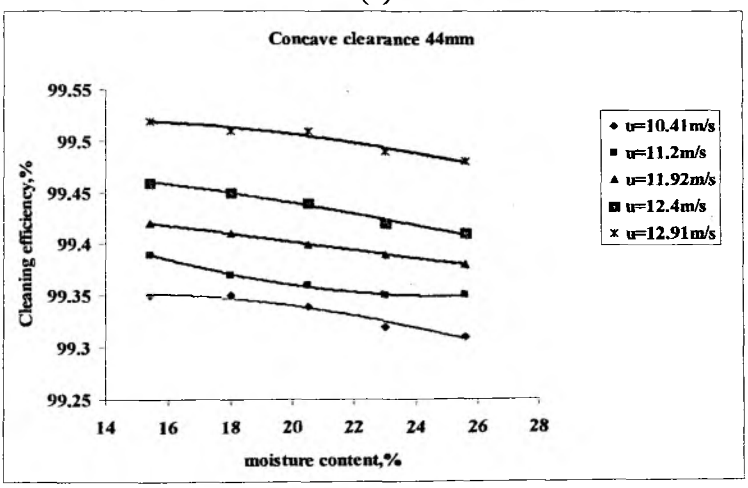
6.1.3 Cleaning efficiency

The cleaning efficiency as affected by the cylinder speed, moisture content and concave clearance is illustrated in Fig. 6.3. The trend shows that the cleaning efficiency decreased with increase in moisture content while it increased with increase in peripheral speed and concave clearance. This is explained as follows.

The better cleaning efficiency at higher peripheral speeds is an obvious trend, because higher peripheral speed produces fine chaff particles which get easily blown away by the blower while traveling along the sieves. This action is also enhanced due to increase in the blower speed at higher cylinder peripheral speeds (the blower shaft gets drive from the cylinder shaft). The better cleaning efficiency obtained at higher concave clearances was perhaps due to smaller amount of material handled by the blower because of poor shelling of the crop. Similarly the poor cleaning efficiency at higher moisture contents might have been due to higher bulk density of the threshed material which is not easily blown away by the blower. A similar trend was also observed by Sandhar and Panwer (1974) and Mahal (2007).



(a)



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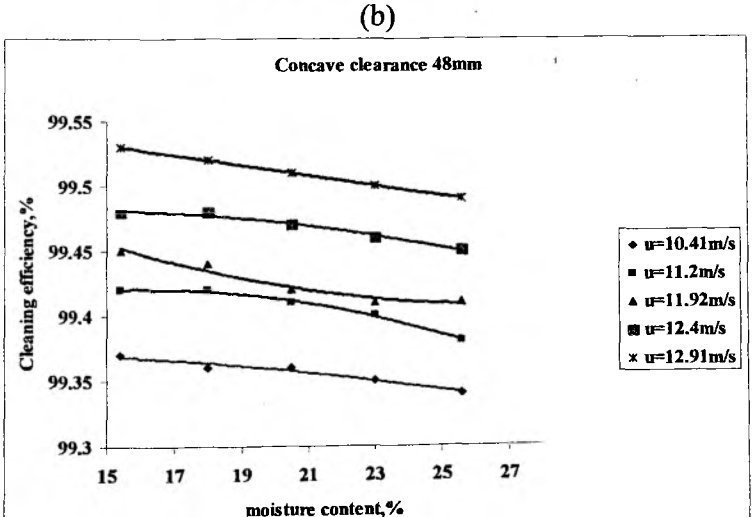


(c)

Fig. 6.3 Effect of Moisture Content on Cleaning Efficiency at different Cylinder Speeds and Concave Clearances

The analysis of variance presented in Table 6.1 shows that the main effects of all the independent variables were highly significant on cleaning efficiency at 1 per cent level. However its interaction effects were insignificant. Treatment means presented in Table C-2.3 also indicate the same behavior except in a few cases.

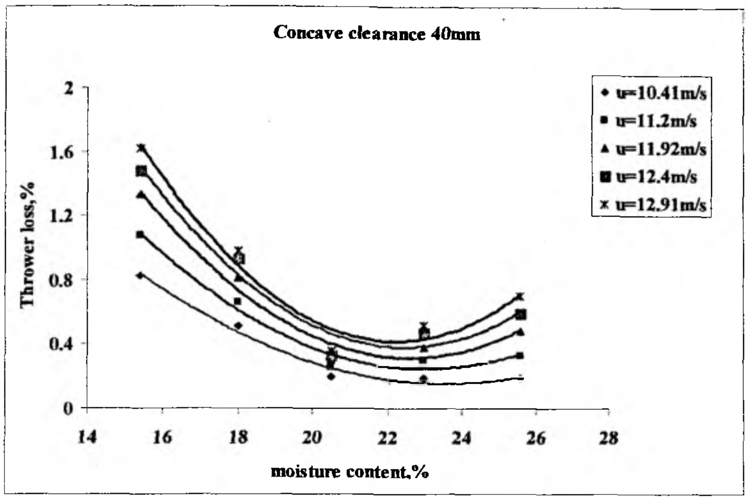
The cleaning efficiency obtained was very high and it was more than 99 per cent in all the cases. The highest cleaning efficiency was observed at the lowest moisture content of 15.4 per cent accompanied with the peripheral speed of 12.91 m/s and concave clearance of 48 mm.

6.1.4 Thrower loss

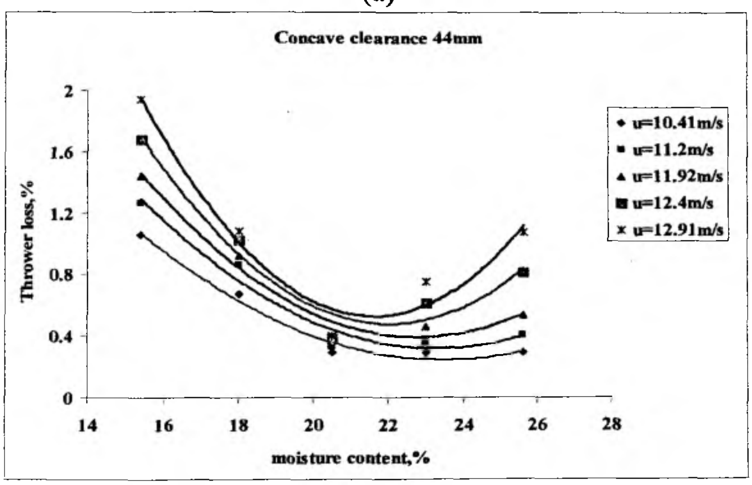
The thrower loss as affected by the cylinder speed, moisture content and concave clearance is illustrated in Fig. 6.4. The trend shows that the thrower loss decreased with decrease in the moisture content from 25.6 to 23 per cent, but it again increased rapidly with further decrease in moisture content up to 15.4 per cent. The data also indicate that the thrower loss increased with increase in peripheral speed at all the moisture contents. However, the same was not true with concave clearance where the minimum loss was found at 40 mm. The observed trend for all the three variables is explained as follows.

The higher thrower loss at lower moisture contents is presumably due to high shelling efficiency observed. This behavior is also true at higher peripheral speeds where shelling efficiency was high. When shelling is better the thrower may receive more threshed grains along with the husk pieces to be discharged during threshing operation. On the other hand the higher thrower loss at extremely high moisture content might have been due to blowing of some threshed grains adhered to the detached husk particles by thrower-cum-blower. However, no definite explanation can be offered with regard to the trend observed at different concave clearances.

The experimental data indicate that the minimum thrower loss was 0.13 per cent obtained at $u = 10.41$ m/s; $M_c = 25.6$ per cent and $C_c = 48$ mm, while maximum loss was 1.94 per cent at $u = 12.91$ m/s; $M_c = 15.4$ per cent and $C_c = 44$ mm.



(a)



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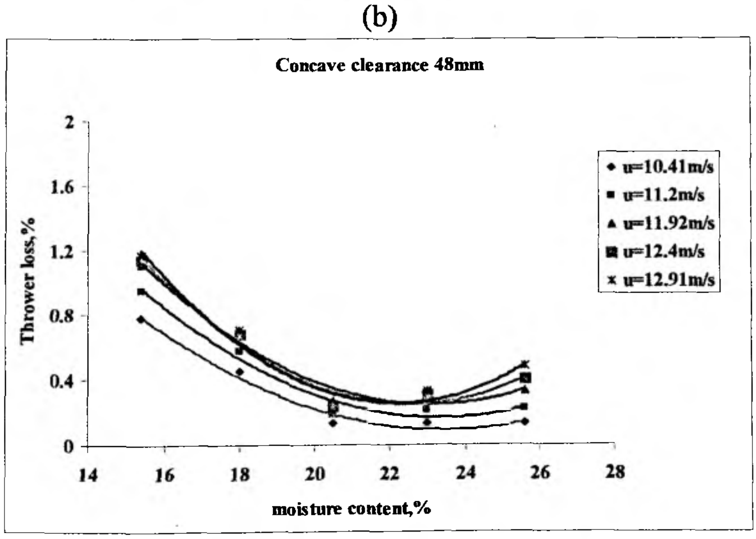


(c)

Fig. 6.4 Effect of Moisture Content on Thrower Loss at different Cylinder Speeds and Concave Clearances

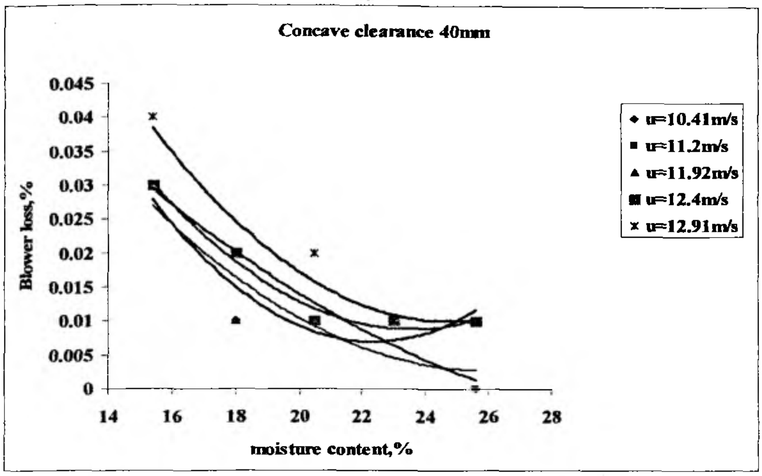
Based on analysis of variance presented in Table 6.1, it is noticed that the thrower loss was significantly affected by all the three independent parameters at 1 per cent level. The moisture content of the crop appeared to have the most significant effect on this loss followed by concave clearance and cylinder peripheral speed. Among the first order interactions the effect of peripheral speed and moisture content was most significant followed by peripheral speed and concave clearance, and moisture content and concave clearance. Comparison among treatment means using LSD shows that except in a few cases, the thrower loss differed significantly at different peripheral speeds and concave clearances for each moisture content tested (Table C-2.4).

6.1.5 Blower loss

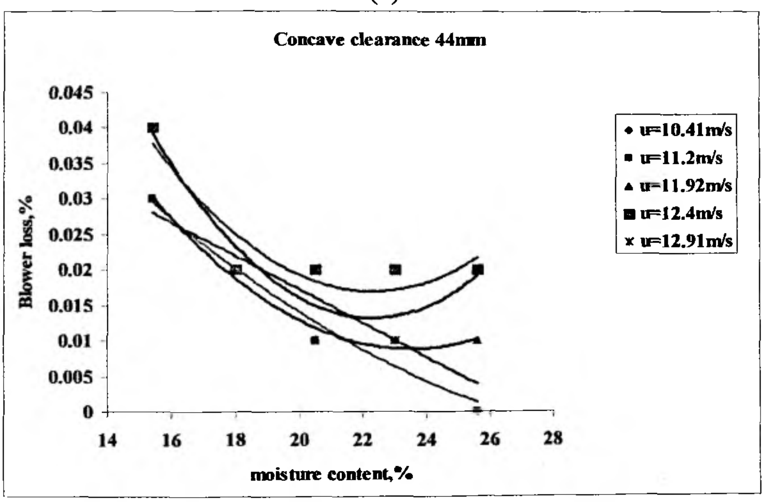
The blower loss as affected by the cylinder speed, moisture content and concave clearance is illustrated in Fig. 6.5. The data indicate that the blower loss in general decreased with increase in moisture content from 15.4-25.6 per cent. It is also observed that the increase in cylinder speed and concave clearance increased the blower loss in most of the cases. The increase in blower loss due to decrease in moisture content might be due to the reason that as the moisture content decreases the grains become lighter in weight and get easily blown away by the blower. The reason for increased blower loss with increase in cylinder speed was due to increase in corresponding blower speed as well as higher shelling efficiency. However, the exact reason for getting higher blower loss at higher concave clearance is not understood.

According to the results of ANOVA presented in Table 6.1, it is observed that the blower loss was significantly affected by cylinder speed, moisture content and concave clearance at 1 per cent level. However, its first order and second order interaction effects were insignificant.

The data indicate that the minimum value of blower loss was zero per cent and maximum 0.04 per cent.



(a)



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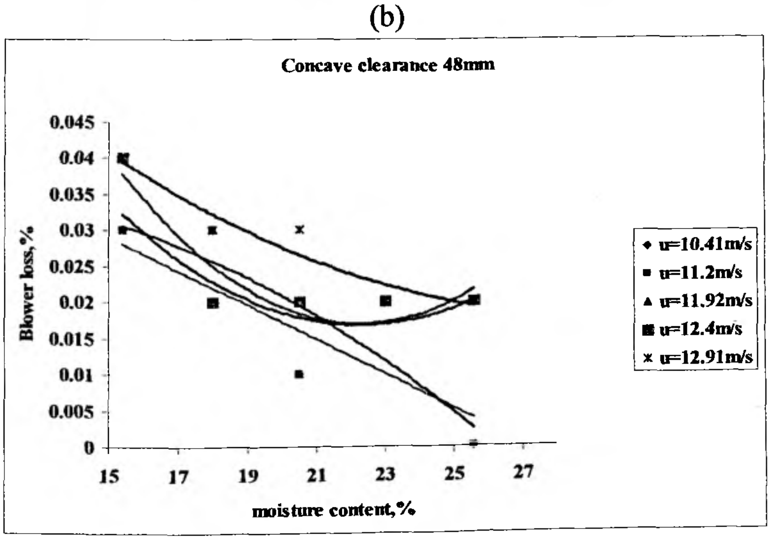


(c)

Fig. 6.5 Effect of Moisture Content on Blower Loss at different Cylinder Speeds and Concave Clearances

6.1.6 Grain damage

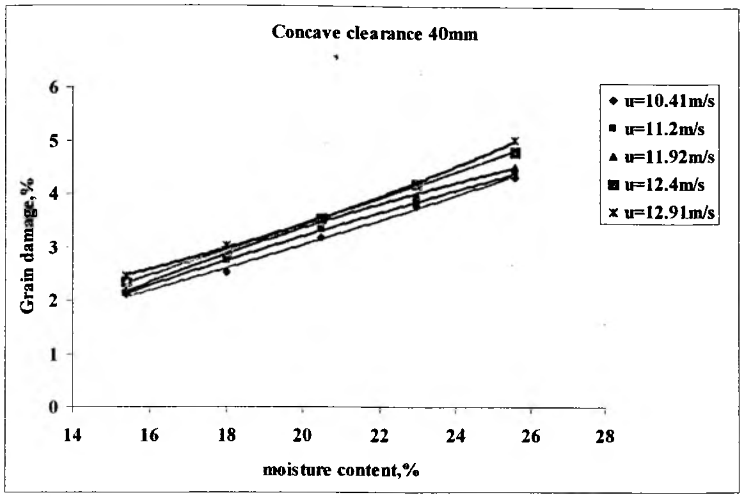
The grain damage as affected by the cylinder speed, moisture content and concave clearance is illustrated in Fig. 6.6.

The trend shows that the grain damage increased with increase in moisture content at all the peripheral speeds and concave clearances tested. It is also noticed that the grain damage increased with increase in peripheral speed from 10.41 to 12.94 m/s. However, an opposite trend was noticed with increase in concave clearance from 40 to 48 mm. This behavior is explained as follows.

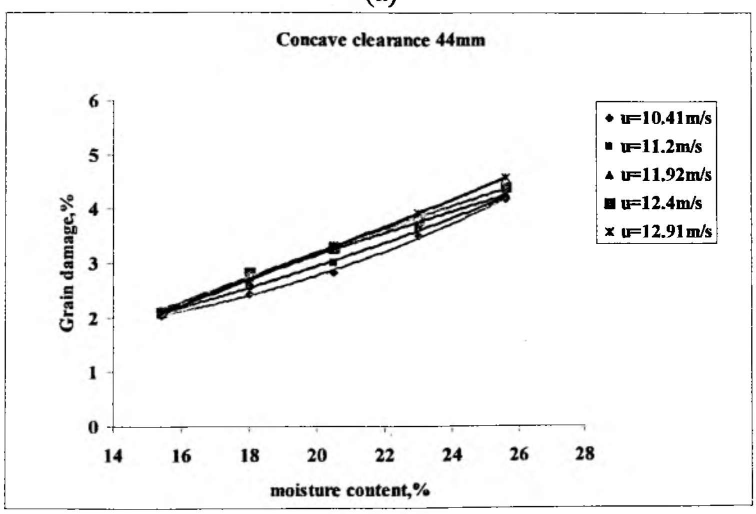
The increase in visible grain damage with increase in moisture content might be due to the fact that the wet grains swell and offer less resistance to deformation caused by the impact forces and hence get compressed and crushed with smaller impact forces. Sandhar and Panwar (1974) also observed a similar trend for maize crop. The increase in visible grain damage due to increase in cylinder speed and decrease in concave clearance might be due to higher level of impacts experienced on grains. This behavior is well supported by many researchers including Chowdhary and Buchele (1978) for maize, Gupta et al. (1985) for maize, Majumdar (1985) for soybean, Saxena and Ojha (1988) for soybean, Sudajan et al.(2002) for sunflower, Vejasit and Salokhe (2002) for soybean and Mahal et al. (2007) for maize.

The grain damage varied from a minimum value of 1.71 per cent observed at u = 10.41 m/s; M_c =15.4 per cent and C_c = 48 mm to a maximum value of 5.04 per cent observed at u = 12.91 m/s; M_c = 25.6 per cent and C_c = 40 mm.

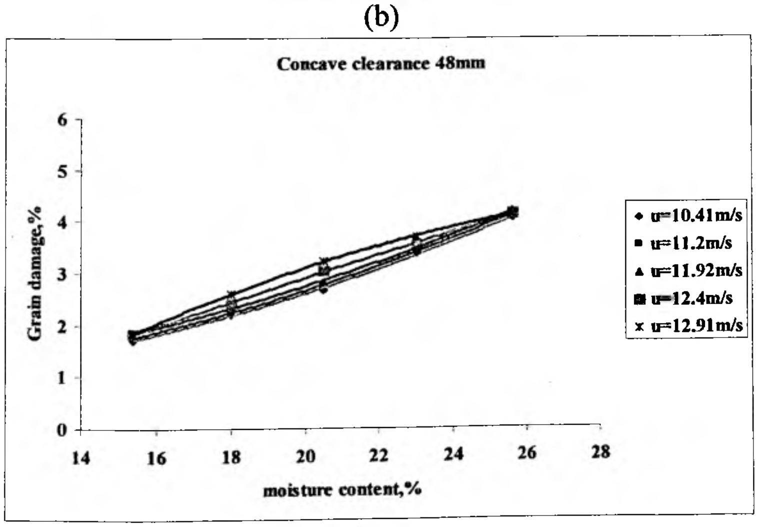
The ANOVA presented in Table 6.1 shows that all the independent parameters significantly affected the grain damage at 1 per cent level. The most significant parameter was moisture content followed by concave clearance and cylinder speed.



(a)



(b)



(c)

Fig. 6.6 Effect of Moisture Content on Grain Damage at different Cylinder Speeds and Concave Clearances

Among the first order interactions the moisture content and concave clearance had the most significant effect followed by cylinder speed and concave clearance, and peripheral speed and moisture content. Comparison among treatment means using LSD shows that the grain damage differed significantly at different peripheral speeds and concave clearances for each moisture content tested (Table C-2.6).

6.1.7 Total loss

As explained in Chapter-V, the total grain loss can be put under two categories: a) Collectable, and b) Non collectable. The loss due to grain damage is considered under collectable loss, while all other losses are considered under non collectable loss. The reason for considering the loss due to grain damage under collectable loss is that the grains collected at the main grain outlet other than the sound grains can still be used as human and animal feed, except that they are not suitable for seeding purposes. However, the grains that are thrown away by the thrower and blower units are non recoverable and hence are put under non collectable losses.

Table 6.2 shows all the grain losses arranged under two different categories as stated above. The data indicate that the collectable grain loss ranges from 1.7-5 per cent whereas the non collectable grain losses range from less than 1 per cent to as high as 3.4 per cent. In other words, of the total grain loss, the collectable grain loss constitutes about 50-80 per cent, whereas non collectable grain losses constitute about 20-50 per cent. These losses put together account for 3.25-6 per cent of the total material fed to the thresher. It is desirable that the operational parameters associated with crop and machine be manipulated to bring the total losses within 4 per cent by restricting the non collectable losses to less than 30 per cent so that the productivity of the developed machine could be increased. The total grain loss observed with this machine at different operational parameters is at par with that observed by Mahal *et al.* (2007) for maize crop. They indicated that the loss due to grain damage was about 2 per cent and the loss due to shelling, cleaning and throwing operations was more than 3 per cent.

Table 6.2 Collectable and Non Collectable Grain Losses Observed at different Operational Parameters.

Peripheral speed, u	Moisture content, M_c	Concave clearance, C_c	Collectable grain loss, CGL	Non-collectable grain loss, NCGL				Total grain loss
				Shelling	Thrower	Blower	Total	
(m/s)	(%)	(mm)	(%)	(%)	(%)	(%)	(%)	(%)
10.41	15.4	40	2.11	0.28	0.83	0.03	1.14	3.25
10.41	18	40	2.52	0.58	0.51	0.01	1.1	3.62
10.41	20.5	40	3.19	0.87	0.2	0.01	1.08	4.27
10.41	23	40	3.79	0.75	0.19	0.01	0.95	4.74
10.41	25.6	40	4.34	0.64	0.19	0	0.83	5.17
11.2	15.4	40	2.14	0.25	1.08	0.03	1.36	3.5
11.2	18	40	2.75	0.47	0.66	0.02	1.15	3.9
11.2	20.5	40	3.34	0.72	0.26	0.01	0.99	4.33
11.2	23	40	3.84	0.65	0.3	0.01	0.96	4.8
11.2	25.6	40	4.41	0.59	0.33	0	0.92	5.33
11.92	15.4	40	2.18	0.21	1.33	0.03	1.57	3.75
11.92	18	40	2.86	0.39	0.81	0.01	1.21	4.07
11.92	20.5	40	3.51	0.57	0.3	0.01	0.88	4.39
11.92	23	40	4	0.46	0.38	0.01	0.85	4.85
11.92	25.6	40	4.52	0.34	0.48	0.01	0.83	5.35
12.4	15.4	40	2.35	0.15	1.48	0.03	1.66	4.01
12.4	18	40	2.93	0.32	0.93	0.02	1.27	4.2
12.4	20.5	40	3.54	0.5	0.33	0.01	0.84	4.38
12.4	23	40	4.2	0.4	0.47	0.01	0.88	5.08
12.4	25.6	40	4.81	0.28	0.59	0.01	0.88	5.69
12.91	15.4	40	2.46	0.09	1.62	0.04	1.75	4.21
12.91	18	40	3.03	0.28	0.98	0.02	1.28	4.31
12.91	20.5	40	3.57	0.43	0.36	0.02	0.81	4.38
12.91	23	40	4.17	0.33	0.52	0.01	0.86	5.03
12.91	25.6	40	5.04	0.2	0.7	0.01	0.91	5.95

Contd...

Peripheral speed, u	Moisture content, M_c	Concave clearance, C_c	Collectable grain loss, CGL	Non-collectable grain loss, NCGL				Total grain loss
				Shelling	Thrower	Blower	Total	
(m/s)	(%)	(mm)	(%)	(%)	(%)	(%)	(%)	(%)
10.41	15.4	44	2.04	1.09	1.06	0.03	2.18	4.22
10.41	18	44	2.44	1.47	0.67	0.02	2.16	4.6
10.41	20.5	44	2.82	1.85	0.29	0.01	2.15	4.97
10.41	23	44	3.5	2.11	0.29	0.01	2.41	5.91
10.41	25.6	44	4.18	2.11	0.29	0	2.4	6.58
11.2	15.4	44	2.08	0.87	1.26	0.03	2.16	4.24
11.2	18	44	2.57	1.17	0.86	0.02	2.05	4.62
11.2	20.5	44	3.01	1.47	0.33	0.01	1.81	4.82
11.2	23	44	3.63	1.69	0.36	0.02	2.07	5.7
11.2	25.6	44	4.21	1.69	0.4	0	2.09	6.3
11.92	15.4	44	2.13	0.65	1.44	0.03	2.12	4.25
11.92	18	44	2.74	0.86	0.92	0.02	1.8	4.54
11.92	20.5	44	3.25	1.09	0.38	0.01	1.48	4.73
11.92	23	44	3.74	1.21	0.46	0.01	1.68	5.42
11.92	25.6	44	4.26	1.21	0.53	0.01	1.75	6.01
12.4	15.4	44	2.11	0.62	1.68	0.04	2.34	4.45
12.4	18	44	2.83	0.8	1.02	0.02	1.84	4.67
12.4	20.5	44	3.28	1	0.39	0.02	1.41	4.69
12.4	23	44	3.8	0.9	0.61	0.02	1.53	5.33
12.4	25.6	44	4.4	0.9	0.81	0.02	1.73	6.13
12.91	15.4	44	2.09	0.5	1.94	0.04	2.48	4.57
12.91	18	44	2.68	0.62	1.08	0.02	1.72	4.4
12.91	20.5	44	3.32	0.8	0.4	0.02	1.22	4.54
12.91	23	44	3.91	0.7	0.75	0.01	1.46	5.37
12.91	25.6	44	4.57	0.7	1.07	0.02	1.79	6.36

Contd...

Peripheral speed, u	Moisture content, M_c	Concave clearance, C_c	Collectable grain loss, CGL	Non-collectable grain loss, NCGL				Total grain loss
				Shelling	Thrower	Blower	Total	
(m/s)	(%)	(mm)	(%)	(%)	(%)	(%)	(%)	(%)
10.41	15.4	48	1.71	1.54	0.78	0.03	2.35	4.06
10.41	18	48	2.19	2.23	0.45	0.02	2.7	4.89
10.41	20.5	48	2.67	2.92	0.13	0.01	3.06	5.73
10.41	23	48	3.37	3.1	0.13	0.02	3.25	6.62
10.41	25.6	48	4.05	3.29	0.13	0	3.42	7.47
11.2	15.4	48	1.76	1.32	0.95	0.03	2.3	4.06
11.2	18	48	2.26	1.74	0.58	0.03	2.35	4.61
11.2	20.5	48	2.74	2.49	0.2	0.01	2.7	5.44
11.2	23	48	3.42	2.41	0.21	0.02	2.64	6.06
11.2	25.6	48	4.13	2.32	0.22	0	2.54	6.67
11.92	15.4	48	1.83	1.11	1.11	0.03	2.25	4.08
11.92	18	48	2.35	1.59	0.69	0.03	2.31	4.66
11.92	20.5	48	2.83	2.07	0.27	0.01	2.35	5.18
11.92	23	48	3.48	1.68	0.29	0.02	1.99	5.47
11.92	25.6	48	4.19	1.31	0.33	0.02	1.66	5.85
12.4	15.4	48	1.83	0.92	1.14	0.04	2.1	3.93
12.4	18	48	2.42	1.27	0.68	0.02	1.97	4.39
12.4	20.5	48	3.05	1.64	0.23	0.02	1.89	4.94
12.4	23	48	3.55	1.44	0.31	0.02	1.77	5.32
12.4	25.6	48	4.15	1.25	0.4	0.02	1.67	5.82
12.91	15.4	48	1.84	0.72	1.17	0.04	1.93	3.77
12.91	18	48	2.6	0.95	0.71	0.03	1.69	4.29
12.91	20.5	48	3.23	1.21	0.19	0.03	1.43	4.66
12.91	23	48	3.7	1.2	0.33	0.02	1.55	5.25
12.91	25.6	48	4.13	1.18	0.48	0.02	1.68	5.81

6.2 Development of Empirical Models

A multiple regression analysis, utilizing the data obtained in the present study was carried out to develop empirical equations to predict the performance of the maize dehusker-cum-sheller in terms of various operational parameters, such as cylinder peripheral speed, moisture content and concave clearance. The developed best fit equations are as follows.

$$E_d = 130.327 - 1.509\,u - 0.626\,M_c - 0.669\,C_c + 5.412E\text{-}03\,M_c C_c + 3.839E\text{-}02\,u\,C_c + 1.025E\text{-}02\,M_c^2$$

$$R^2 = 0.920 \qquad \cdots(6.2)$$

$$E_s = 140.682 - 2.963\,u - 0.652\,M_C - 0.733\,C_c + 3.476E\text{-}02\,u\,M_c - 6.729E\text{-}03\,M_c C_c + 6.033E\text{-}02\,u\,C_c + 1.189E\text{-}02\,M_c^2$$

$$R^2 = 0.968 \qquad \cdots(6.3)$$

$$E_c = 100.662 - 0.295\,u + 1.523E\text{-}02\,u^2 + 5.033E\text{-}05\,C_c^2$$

$$R^2 = 0.923 \qquad \cdots(6.4)$$

$$L_t = -14.875 - 0.851\,M_c + 1.109\,C_c + 3.675E\text{-}03\,u\,C_c + 1.886E\text{-}02\,M_c^2 - 1.33E\text{-}02\,C_c^2$$

$$R^2 = 0.915 \qquad \cdots(6.5)$$

$$L_b = 0.160 - 1.414E\text{-}02\,M_c + 1.861E\text{-}04\,u\,M_c + 2.396E\text{-}04\,M_c^2$$

$$R^2 = 0.722 \qquad \cdots(6.6)$$

$$L_{gd} = -0.283 + 0.155\,M_C + 6.081E\text{-}03\,u\,M_c - 5.173E\text{-}03\,u\,C_c + 1.074E\text{-}02\,u^2$$

$$R^2 = 0..992 \qquad \cdots(6.7)$$

where E_d = dehusking efficiency, per cent,
E_s = shelling efficiency, per cent,
E_c = Cleaning efficiency, per cent,
L_t = thrower loss, per cent,
L_b = Blower loss, per cent,
L_{gd} = grain damage, per cent,
M_c = moisture content, per cent,
u = cylinder peripheral speed, m/s, and
C_c = concave clearances, mm

The ANOVA for multiple regression analysis is given in Appendix-C (C-3.1 to C-3.6). The analysis shows that all the coefficients included in each equation are highly significant on their respective dependent parameters. The high values of coefficient of determination indicate that the observed data could be accurately predicted by the proposed models.

6.3 Optimization of Operational Parameters

Using the multiple regression equations (eqns. (6.2) to (6.7)), the cylinder peripheral speed, moisture content and concave clearance were optimized based on total grain loss within 3.5-4 per cent. A matlab program based on search technique was used for the optimization of independent parameters (Appendix-D). The program was run by varying the peripheral speed from 10.4-12.9 m/s, moisture content from 15.4-25.6 per cent and concave clearance from 40-48 mm.The selected interval range for peripheral speed was 0.5 m/s, moisture content 1 per cent, and concave clearance 1 mm. The parameters were optimized based on the following criteria.

1. Restricting the total loss (collectable loss + non collectable loss) within 3.5 per cent
2. Restricting the non collectable loss (shelling loss + thrower loss + blower loss) within 30 per cent.

The results are presented in Tables 6.3 and 6.4. It is noticed that if the total loss is restricted to less than 3.5 per cent, the non collectable loss which is the loss other than the grain damage loss is found to be 35-40 per cent. How ever if this loss is restricted to less than 30 per cent then the total loss exceeds 3.5 per cent. The results indicating the optimum combination of operational parameters for these two criteria are summarized in Table 6.5.

Table 6.3 Combination of Optimum Independent Parameters for Restricting the Total Loss within 3.5 per cent

Concave clearance mm	Cylinder peripheral speed m/s	Moisture content %	Total loss %	collectable loss %	Non collectable loss %
40	10.4	15	3.319	60.269	39.731
40	10.4	16	3.457	64.173	35.827
40	10.9	15	3.465	59.367	40.633

Table 6.4 Combination of Optimum Independent Parameters for Restricting the Non Collectable Loss within 30 per cent

Concave clearance mm	Cylinder peripheral speed m/s	Moisture content %	Total loss %	collectable loss %	Non collectable loss %
40	10.4	18	3.78	70.30	29.70
40	10.4	19	3.96	72.59	27.41
40	10.9	18	3.88	70.13	29.87
40	11.4	18	3.99	70.00	30.00

Table 6.5 Combination of Operational Parameters for Optimum Performance of Maize Dehusker-cum-Sheller

S. No.	Desired criteria	Optimum combination of operational parameters
1	Total loss within 3.5 per cent	u = 10.4-10.9 m/s M_c = 15-16 per cent (wb) C_c = 40 mm
2	Non collectable loss within 30 per cent	u = 10.4-11.4 m/s M_c = 18-19 per cent (wb) C_c = 40 mm

The results presented above suggest that for optimum performance, the developed thresher may be operated using maize cobs at a moisture content of 15-19 per cent while maintaining the cylinder peripheral speed in the range of 10.4-11.4 m/s and concave clearance at 40 mm.

Based on the results presented in this chapter the following conclusions can be drawn.

1. The performance of the developed thresher was significantly affected by the moisture content of the crop as well as machine associated parameters, namely cylinder peripheral speed and concave clearance.

2. The dehusking, shelling and cleaning efficiencies were found to range from 98.5-100 per cent, 96.7-99.9 per cent and 99.3-99.5 per cent respectively within the range of test variables.

3. The total grain loss was observed to be 3.25-6 per cent. This includes 1.7-5 per cent as collectable loss and 1-3.4 per cent as non collectable loss. This shows that the contribution of grain damage was more than 50 per cent in many cases.

4. Based on multiple regression analysis, the empirical equations have been developed to predict the performance of the thresher in terms of input parameters such as moisture content, peripheral speed and concave clearance.

5. The operational parameters were optimized utilizing the developed empirical equations while restricting the total losses within 4 per cent. The results indicate that the developed thresher may be operated using maize cobs at a moisture content of 15-19 per cent while maintaining the cylinder peripheral speed in the range of 10.4-11.4 m/s and concave clearance at 40 mm.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Maize (*Zea mays L.*) is a coarse cereal and is the staple food in many developed countries. The area under maize in India is 7.42 million hectares with productivity of 1983 kg/ha. Tillage machinery *viz* rotavator, harrows, cultivator and hand operated maize shellers for shelling of maize cobs are available for various farm operations which are being partially adopted in the country by the maize growers. But the level of maize mechanization is less than 50 per cent. Considering the small size of land holdings in the country the high capacity maize shellers, which could be used on custom hiring services, are today the most needed equipment to accelerate the pace of mechanization in maize growing areas.

Adoption of maize cultivation on a large scale has led to the development of several designs of multi-crop threshers. These threshers require prior dehusking of the cob, which in itself is a distinct unit operation. Attempts have been made to develop machines for carrying out dehusking and threshing in a single operation to reduce processing time and cost of operation. However, a satisfactory design has not yet been released in the country. It is, therefore, necessary to optimize the design of different assemblies such as dehusking-cum-shelling, cleaning and separating, and power transmission units to achieve a satisfactory design of maize dehusker-cum-sheller. Development of such a thresher is expected to go a long way in popularizing the cultivation of maize on a larger area. With this requirement in mind, the present study was taken up with the following objectives:

1. To study the properties of maize kernel and maize cobs, which have bearing on mechanical dehusking and shelling.

2. To design and fabricate a prototype maize dehusker-cum-sheller based on functional and strength requirements.

3. To study the effect of some of the operational parameters such as crop moisture content, cylinder peripheral speed and concave clearance on dehusking and shelling of maize cobs.

4. To develop empirical models for evaluating the performance of the maize dehusker-cum-sheller.

5. To determine the suitable values of the operational parameters of the developed machine for optimum dehusking and shelling performance.

7.1 Physical and Mechanical Properties of Maize

The physical properties of common varieties of maize (kernel and cob) grown in the State of Andhra Pradesh, namely DHM 103, Harsha, Madhuri, BH 2187, Kargil 9000 and DHM 109 were studied. The main properties included in the study were moisture content, bulk density, length, width, thickness, sphericity and terminal velocity for kernel ; and size of cob, grain-to-non grain ratio and bulk density for the cob.

The lengths of the maize kernel of the six varieties were found to vary from 8.67 to 12.12 mm, while the width and thickness were in the range of 7.07 – 9.37 mm and 3.91 – 5.57 mm respectively. Based on these three dimensions, the size of the grain was found in the range of 6.94 – 7.93 mm. The sphericity of the maize grain for the six selected varieties varied between 0.80 and 0.63 and the terminal velocity of the grain between 13.1 and 14.15 m/s. These properties were determined in the moisture range of 8.7 to 12.4 per cent. For the maize cob, the bulk density ranged from 0.421-0.441 g/cm^3 and grain-to-non grain ratio from 2.64-4.34. These properties were used in the present study in designing feeding hopper, concave and sieve systems.

The force required for the separation of husk and single kernel from the maize cob of two varieties, namely DHM-103 and Harsha, was determined using a pendulum type experimental set up. The force was measured using single ended beam type load cell of 300 N capacity which was integrated with the DT 800 Data logger and PC. The experiments were conducted by setting the pendulum arm at 30°, 60° and 90° from the vertical plane. The purpose of selecting the three positions was just to assess at what position detachment of husk and grain takes place so that the force required could be measured conveniently. The experimental set up had provision for holding the maize cob in desired orientation to help detachment of grain and husk by specially made tool. The tool was mounted in the tool holder and vertical adjustment was possible to fix the tool in proper position convenient for removal of grain and husk. The force required to detach husk varied in the range of 5.83 to 23.26 N while the force required to detach a single kernel from the maize cob varied from 3.89 to 17.33 N. These data were taken into consideration while designing cylinder pegs in the present study.

7.2 Design and Fabrication of a Maize Dehusker-cum-Sheller

An axial flow type maize dehusker-cum-sheller machine powered by a 25-35 hp tractor was designed and fabricated based on functional and strength requirements. The design flow rate was 4000 kg/h. The machine includes a cylinder and concave assembly, a thrower-cum-blower, a separating and cleaning unit and power transmission system to various components. The design cylinder peripheral speed was 13.32 m/s. The type of threshing element used was peg-tooth. The pegs were staggered to enable the material to flow axially to the other end of the cylinder, where a thrower-cum-blower was used to remove the husk portion. A semi circular concave unit was used below the threshing cylinder for effective shelling. The concave clearance could be adjusted by moving the unit up or down with the help of four adjustable screws. A louver was provided on the inside cover of the cylinder to help in axial movement of the material. The dehusking and shelling of the maize cobs was accomplished between the rotating cylinder and the stationary concave screen. The material passing through the concave was cleaned from chaff particles by employing a centrifugal blower and finally the grains were separated from the foreign course particles by using a set of oscillating sieves and collected in a grain outlet.

7.3 Effect of Operational Parameters on Performance of Developed Machine

The performance studies were conducted on the developed machine to investigate the effect of its operational parameters on the basis of dehusking efficiency, shelling efficiency, cleaning efficiency, and various losses such as thrower loss, blower loss and visible grain damage. The tests were conducted at five levels of moisture content (15.4, 18.0, 20.5, 23.0, and 25.6 per cent), five levels of cylinder peripheral speed (10.41, 11.20, 11.92, 12.40 and 12.91 m/s) and three levels of concave clearance (40, 44 and 48 mm). The moisture content of the crop was varied by sun drying of the harvested crop and conducting experiments on different dates. Cylinder speed was varied by using different sizes of pulleys on driver and driven shafts. Concave clearance was varied by moving the concave assembly up or down with the help of adjustable screws. The results were statistically analyzed to find the significance level of different parameters and were discussed with the help of various curves drawn between moisture content and dependent parameters at varying cylinder speeds and concave clearances. The data were also analyzed to determine the total grain losses in terms of collectable (grain damage) and non collectable (grain losses other than grain damage) grain losses.

7.4 Development of Empirical Models

A multiple regression analysis, utilizing the data obtained in the present study, was carried out to develop empirical equations of the type shown below to predict the performance of the maize dehusker-cum-sheller in terms of various input parameters, such as moisture content, cylinder peripheral speed and concave clearance. For each performance parameter, only these coefficients were included in the analysis which had high level of significance.

$$y = a + b\,u + c\,M_c + d\,C_c + e\,u\,M_c + f\,M_c\,C_c + g\;u\,C_c + h\,M_c^2 + i\,u^2 + j\,C_c^2$$

where y = thresher performance parameters (dehusking efficiency, shelling efficiency, cleaning efficiency, thrower loss, blower loss and grain damage), and
a,...,j = empirical coefficients.

7.5 Optimization of Operational Parameters

Using the developed empirical equations the cylinder peripheral speed, moisture content and concave clearance were optimized based on the following criteria.

1. Restricting the total loss (collectable loss + non collectable loss) within 3.5 per cent

2. Restricting the non collectable loss (shelling loss + thrower loss + blower loss) within 30 per cent.

A Matlab program based on search technique was used for the optimization of independent parameters.

The studies conducted in the present investigation lead to the following major conclusions.

Conclusions

1. The physical properties of maize grain as well as maize cob for six different varieties grown in the state of Andhra Pradesh were determined. These include moisture content, bulk density, length, width, thickness, sphericity and terminal velocity for maize kernel; and size of cob, grain-to-non grain ratio and bulk density for the cob. These data can be used for designing concave and sieve systems of maize shellers.

2. The force required to detach husk from the maize cob ranged from 5.83 to 23.26 N and a single kernel from the maize cob from 7.57 to 22.4 N. These results were obtained in the husk moisture range of 10.5 to 21.11 per cent and grain moisture range of 9.8 to 18.0 per cent. These data may be utilized for designing cylinder pegs in maize threshers

3. An axial flow type maize dehusker-cum-sheller powered by a 25-35 hp tractor was designed and fabricated based on functional and strength requirements. Depending upon feed rate, crop moisture and setting of machine operational parameters the machine has been found to give grain output capacity of 1500 - 2000 kg/h with the total grain loss not exceeding 4 per cent.

4. The performance of the developed thresher was significantly affected by the moisture content of the crop (15.4-25.6 per cent) as well as machine associated parameters, namely cylinder peripheral speed (10.41-12.91 m/s) and concave clearance (40-48mm).

5. The dehusking, shelling and cleaning efficiencies were found to range from 98.5-100 per cent, 96.7-99.9 per cent and 99.3-99.5 per cent respectively within the range of test variables.

6. The total grain loss was observed to be 3.25 - 6 per cent. This includes 1.7-5 per cent as collectable loss (grain damage) and 1-3.4 per cent as non collectable loss (other than grain damage). This shows that the contribution of grain damage in total loss was more than 50 per cent in many cases.

7. The grain damage was found to increase almost linearly while all other losses decreased non-linearly with increase in moisture content from 15.4-25.6 per cent within the test range of cylinder peripheral speed and concave clearance. This shows that the crop is required to be threshed at an optimum moisture content to restrict the losses within acceptable limits.

8. Based on multiple regression analysis, the empirical equations were developed to predict the performance of the developed thresher on the basis of dehusking efficiency, shelling efficiency, cleaning efficiency, and various losses such as thrower loss, blower loss and visible grain damage. The high values of R^2 indicate that the data could be well predicted by the developed equations.

9. The operational parameters of the machine such as cylinder peripheral speed, crop moisture content and concave clearance were optimized utilizing the developed empirical equations while restricting the total loss within 4 per cent. Results indicated that for optimum performance the developed thresher may be operated using maize cobs at a moisture content of 15-19 per cent while maintaining the cylinder peripheral speed in the range of 10.4-11.4 m/s and concave clearance at 40 mm. It is, however, suggested that the extensive field trials may be conducted on the developed machine before the design is released for commercial production.

The final outcome of the present study includes the following

(i) Collection of a data base on physical and mechanical properties of maize kernel and maize cob.

(ii) A systematic design approach for optimum design of maize dehusker-cum-sheller.

(iii) Development of an efficient machine for dehusking and shelling of maize crop.

(iv) Prediction equations for evaluating the dehusking, shelling and cleaning performance of the developed machine.

The developed machine is expected to help the farmers to thresh their crop well in time and take up the next crop without delaying the sowing period. Such a machine will increase their profit margin due to reduced operating cost because of removal of husk and threshing being done in a single operation. A high capacity machine will also help them to earn extra revenue by using it on custom hiring service. Such a machine will, therefore, go a long way in boosting the pace of mechanization in maize growing regions of the country.

It is hoped that the research findings presented in the thesis would be useful to the scientists and engineers working in the area of dehusking and shelling of maize crops.

SUGGESTIONS FOR FUTURE WORK

1. The developed machine should be extensively tested in the farmers' field using different crop varieties and moisture contents (15-20 per cent) while maintaining the peripheral speed and concave clearance as suggested in the present study. The machine should be released for commercial production and adoption by the farmers only after successful field trials.

2. The feeding unit of the machine as well as its collection points may be designed keeping in view the ergonomic and safety requirements.

3. The machine may be tried to thresh other cereal crops such as wheat, sorghum, paddy, gram, soybean, sunflower and pigeon pea by making suitable adjustments in cylinder peripheral speed and concave clearance besides other modifications as desired to suit the crop requirements.

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APPENDIX-A

LOAD CELL SPECIFICATIONS

Table A-1 Specifications of Single Ended Beam Type Load Cell

Capacity	30 Kg
Sensitivity	2.0 ± 1 % m V/V
Non – linearity	± 0.02 % of applied load
Hysteresis	± 0.02 % of applied load
Repeatability	± 0.02 % of applied load
Creep (20 min)	± 0.02 % of applied load
Temp. effect span	0.015 % of applied load / 10°C
Temp. effect zero	0.02 % of applied load / 10°C
Temp. Compensated range	- 10 to + 50°C
Output resistance	350 ± 3 Ω
Input resistance	385 ± 15 Ω
Insulation resistance	> 5000 MΩ
Service load	100 % of rated capacity
Safe load	150 % of rated capacity
Ultimate load	200 % of rated capacity
Recommended excitation	5-15 Volts AC/DC
Maximum excitation	15 Volts
Construction	Aluminum Alloy
Environmental protection	IP 65

APPENDIX-B

TEST OBSERVATIONS

Table B-1 Effect of Cylinder Speed, Moisture Content and Concave Clearance on Performance of Maize Dehusker-cum-Sheller

Peripheral speed u	moisture content M_c	Concave clearance C_c	Dehusking efficiency E_d	Shelling efficiency E_s	Cleaning efficiency E_c	Thrower loss L_t	Blower loss L_b	Visible grain damage L_{gd}
(m/s)	(%)	(mm)	(%)	(%)	(%)	(%)	(%)	(%)
1	2	3	4	5	6	7	8	9
10.41	15.4	40	99.99	99.72	99.35	0.83	0.03	2.11
10.41	18	40	99.9	99.42	99.34	0.51	0.01	2.52
10.41	20.5	40	99.82	99.13	99.33	0.2	0.01	3.19
10.41	23	40	99.88	99.25	99.32	0.19	0.01	3.79
10.41	25.6	40	99.91	99.36	99.32	0.19	0	4.34
11.2	15.4	40	99.98	99.75	99.37	1.08	0.03	2.14
11.2	18	40	99.91	99.53	99.36	0.66	0.02	2.75
11.2	20.5	40	99.82	99.28	99.35	0.26	0.01	3.34
11.2	23	40	99.88	99.35	99.35	0.3	0.01	3.84
11.2	25.6	40	99.95	99.41	99.34	0.33	0	4.41
11.92	15.4	40	99.98	99.79	99.41	1.33	0.03	2.18
11.92	18	40	99.92	99.61	99.4	0.81	0.01	2.86
11.92	20.5	40	99.83	99.43	99.4	0.3	0.01	3.51
11.92	23	40	99.9	99.54	99.39	0.38	0.01	4
11.92	25.6	40	100	99.66	99.38	0.48	0.01	4.52
12.4	15.4	40	99.99	99.85	99.45	1.48	0.03	2.35
12.4	18	40	99.92	99.68	99.44	0.93	0.02	2.93
12.4	20.5	40	99.85	99.5	99.44	0.33	0.01	3.54
12.4	23	40	99.91	99.6	99.43	0.47	0.01	4.2
12.4	25.6	40	100	99.72	99.41	0.59	0.01	4.81

Contd...

1	2	3	4	5	6	7	8	9
12.91	15.4	40	100	99.91	99.5	1.62	0.04	2.46
12.91	18	40	99.93	99.72	99.49	0.98	0.02	3.03
12.91	20.5	40	99.87	99.57	99.47	0.36	0.02	3.57
12.91	23	40	99.91	99.67	99.46	0.52	0.01	4.17
12.91	25.6	40	100	99.8	99.45	0.7	0.01	5.04
10.41	15.4	44	98.96	98.91	99.35	1.06	0.03	2.04
10.41	18	44	98.95	98.53	99.35	0.67	0.02	2.44
10.41	20.5	44	98.94	98.15	99.34	0.29	0.01	2.82
10.41	23	44	99.41	97.89	99.32	0.29	0.01	3.5
10.41	25.6	44	99.87	97.89	99.31	0.29	0	4.18
11.2	15.4	44	99.17	99.13	99.39	1.26	0.03	2.08
11.2	18	44	99.1	98.83	99.37	0.86	0.02	2.57
11.2	20.5	44	99.02	98.53	99.36	0.33	0.01	3.01
11.2	23	44	99.46	98.31	99.35	0.36	0.02	3.63
11.2	25.6	44	99.92	98.31	99.35	0.4	0	4.21
11.92	15.4	44	99.4	99.35	99.42	1.44	0.03	2.13
11.92	18	44	99.27	99.14	99.41	0.92	0.02	2.74
11.92	20.5	44	99.12	98.91	99.4	0.38	0.01	3.25
11.92	23	44	99.53	98.79	99.39	0.46	0.01	3.74
11.92	25.6	44	99.97	98.79	99.38	0.53	0.01	4.26
12.4	15.4	44	99.55	99.38	99.46	1.68	0.04	2.11
12.4	18	44	99.43	99.2	99.45	1.02	0.02	2.83
12.4	20.5	44	99.31	99	99.44	0.39	0.02	3.28
12.4	23	44	99.68	99.1	99.42	0.61	0.02	3.8
12.4	25.6	44	99.98	99.1	99.41	0.81	0.02	4.4

Contd...

1	2	3	4	5	6	7	8	9
12.91	15.4	44	99.72	99.5	99.52	1.94	0.04	2.09
12.91	18	44	99.67	99.38	99.51	1.08	0.02	2.68
12.91	20.5	44	99.6	99.2	99.51	0.4	0.02	3.32
12.91	23	44	99.61	99.3	99.49	0.75	0.01	3.91
12.91	25.6	44	99.98	99.3	99.48	1.07	0.02	4.57
10.41	15.4	48	98.75	98.46	99.37	0.78	0.03	1.71
10.41	18	48	98.62	97.77	99.36	0.45	0.02	2.19
10.41	20.5	48	98.49	97.08	99.36	0.13	0.01	2.67
10.41	23	48	98.58	96.9	99.35	0.13	0.02	3.37
10.41	25.6	48	98.67	96.71	99.34	0.13	0	4.05
11.2	15.4	48	98.8	98.68	99.42	0.95	0.03	1.76
11.2	18	48	98.76	98.26	99.42	0.58	0.03	2.26
11.2	20.5	48	98.7	97.51	99.41	0.2	0.01	2.74
11.2	23	48	98.96	97.59	99.4	0.21	0.02	3.42
11.2	25.6	48	99.2	97.68	99.38	0.22	0	4.13
11.92	15.4	48	98.85	98.89	99.45	1.11	0.03	1.83
11.92	18	48	98.88	98.41	99.44	0.69	0.03	2.35
11.92	20.5	48	98.91	97.93	99.42	0.27	0.01	2.83
11.92	23	48	99.35	98.32	99.41	0.29	0.02	3.48
11.92	25.6	48	99.77	98.69	99.41	0.33	0.02	4.19
12.4	15.4	48	99.11	99.08	99.48	1.14	0.04	1.83
12.4	18	48	99.09	98.73	99.48	0.68	0.02	2.42
12.4	20.5	48	99.06	98.36	99.47	0.23	0.02	3.05
12.4	23	48	99.4	98.56	99.46	0.31	0.02	3.55
12.4	25.6	48	99.73	98.75	99.45	0.4	0.02	4.15
12.91	15.4	48	99.47	99.28	99.53	1.17	0.04	1.84
12.91	18	48	99.33	99.05	99.52	0.71	0.03	2.6
12.91	20.5	48	99.18	98.79	99.51	0.19	0.03	3.23
12.91	23	48	99.45	98.8	99.5	0.33	0.02	3.7
12.91	25.6	48	99.7	98.82	99.49	0.48	0.02	4.13

Table B-2.1 Experimental Data on Dehusking Efficiency
Replication-1

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c			44 mm Concave clearance, C_c			48 mm Concave clearance, C_c		
		W_{cf}	W_{hc}	E_d	W_{cf}	W_{hc}	E_d	W_{cf}	W_{hc}	E_d
m/s	%	kg	kg	%	kg	kg	%	kg	kg	%
10.41	15.4	5.60	0.0006	99.99	5.69	0.0626	98.90	5.75	0.0632	98.90
10.41	18	5.73	0.0023	99.96	5.76	0.0628	98.91	5.80	0.0824	98.58
10.41	20.5	6.00	0.0060	99.90	6.01	0.0649	98.92	6.07	0.0928	98.47
10.41	23	6.00	0.0096	99.84	6.04	0.0381	99.37	6.13	0.0859	98.60
10.41	25.6	6.13	0.0129	99.79	6.27	0.0069	99.89	6.33	0.0849	98.66
11.2	15.4	5.67	0.0023	99.96	5.73	0.0487	99.15	5.80	0.0719	98.76
11.2	18	5.87	0.0012	99.98	5.93	0.0504	99.15	5.97	0.0753	98.74
11.2	20.5	6.07	0.0158	99.74	6.13	0.0626	98.98	6.16	0.0788	98.72
11.2	23	6.13	0.0110	99.82	6.20	0.0360	99.42	6.23	0.0654	98.95
11.2	25.6	6.20	0.0012	99.98	6.27	0.0075	99.88	6.29	0.0510	99.19
11.92	15.4	5.73	0.0017	99.97	5.73	0.0333	99.42	5.80	0.0655	98.87
11.92	18	5.93	0.0071	99.88	6.00	0.0408	99.32	6.07	0.0655	98.92
11.92	20.5	6.13	0.0117	99.81	6.20	0.0533	99.14	6.23	0.0666	98.93
11.92	23	6.20	0.0093	99.85	6.27	0.0326	99.48	6.29	0.0390	99.38
11.92	25.6	6.23	0.0000	100.00	6.33	0.0032	99.95	6.37	0.0166	99.74
12.4	15.4	5.76	0.0006	99.99	5.83	0.0245	99.58	5.87	0.0546	99.07
12.4	18	5.96	0.0042	99.93	5.97	0.0317	99.47	6.00	0.0570	99.05
12.4	20.5	6.16	0.0105	99.83	6.20	0.0459	99.26	6.23	0.0554	99.11
12.4	23	6.21	0.0043	99.93	6.27	0.0219	99.65	6.31	0.0366	99.42
12.4	25.6	6.27	0.0000	100.00	6.33	0.0019	99.97	6.37	0.0147	99.77
12.91	15.4	5.80	0.0000	100.00	5.87	0.0176	99.70	5.89	0.0330	99.44
12.91	18	6.00	0.0030	99.95	6.07	0.0194	99.68	6.09	0.0427	99.30
12.91	20.5	6.20	0.0093	99.85	6.23	0.0218	99.65	6.27	0.0501	99.20
12.91	23	6.24	0.0062	99.9.	6.29	0.0271	99.57	6.33	0.0323	99.49
12.91	25.6	6.29	0.0000	100.00	6.33	0.0006	99.99	6.37	0.0204	99.68

W_{cf} = Total wt. of cob fed at hopper; W_{hc} = Wt. of husked cob at thrower outlet; E_d = Dehusking efficiency

Replication-2

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c			44 mm Concave clearance C_c			48 mm Concave clearance C_c		
		W_{cf}	W_{hc}	E_d	W_{cf}	W_{hc}	E_d	W_{cf}	W_{hc}	E_d
m/s	%	kg	kg	%	kg	kg	%	kg	kg	%
10.41	15.4	5.63	0.0000	100.00	5.69	0.0558	99.02	5.76	0.0749	98.70
10.41	18	5.76	0.0006	99.99	5.77	0.0583	98.99	5.77	0.0774	98.66
10.41	20.5	6.05	0.0133	99.78	6.00	0.0624	98.96	6.07	0.0904	98.51
10.41	23	6.08	0.0049	99.92	6.07	0.0334	99.45	6.15	0.0885	98.56
10.41	25.6	6.16	0.0043	99.93	6.29	0.0094	99.85	6.33	0.0836	98.68
11.2	15.4	5.71	0.0006	99.99	5.75	0.0465	99.19	5.81	0.0732	98.74
11.2	18	5.89	0.0094	99.84	5.91	0.0561	99.05	5.88	0.0717	98.78
11.2	20.5	6.04	0.0060	99.90	6.16	0.0579	99.06	6.21	0.0820	98.68
11.2	23	6.17	0.0037	99.94	6.17	0.0309	99.50	6.25	0.0644	98.97
11.2	25.6	6.23	0.0050	99.92	6.28	0.0025	99.96	6.28	0.0496	99.21
11.92	15.4	5.76	0.0006	99.99	5.76	0.0357	99.38	5.75	0.0672	98.83
11.92	18	5.97	0.0054	99.91	6.03	0.0470	99.22	6.07	0.0704	98.84
11.92	20.5	6.21	0.0093	99.85	6.16	0.0554	99.10	6.24	0.0686	98.90
11.92	23	6.24	0.0031	99.95	6.28	0.0264	99.58	6.28	0.0427	99.32
11.92	25.6	6.27	0.0000	100.00	6.35	0.0006	99.99	6.37	0.0127	99.8
12.4	15.4	5.80	0.0000	100.00	5.80	0.0278	99.52	5.88	0.0506	99.14
12.4	18	5.97	0.0054	99.91	5.93	0.0362	99.39	6.03	0.0524	99.13
12.4	20.5	6.23	0.0081	99.87	6.25	0.0406	99.35	6.25	0.0619	99.01
12.4	23	6.25	0.0069	99.89	6.32	0.0183	99.71	6.33	0.0393	99.38
12.4	25.6	6.29	0.0000	100.00	6.39	0.0000	100.00	6.37	0.0198	99.69
12.91	15.4	5.81	0.0000	100.00	5.88	0.0153	99.74	5.89	0.0295	99.5
12.91	18	6.00	0.0054	99.91	6.08	0.0207	99.66	6.08	0.0389	99.36
12.91	20.5	6.20	0.0068	99.89	6.19	0.0278	99.55	6.28	0.0528	99.16
12.91	23	6.27	0.0050	99.92	6.28	0.0220	99.65	6.33	0.0374	99.41
12.91	25.6	6.40	0.0000	100.00	6.33	0.0019	99.97	6.39	0.0179	99.72

W_{cf} = Total wt. of cob fed at hopper; W_{bc} = Wt. of husked cob at thrower outlet; E_d = Dehusking efficiency

Replication-3

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c			44 mm Concave clearance C_c			48 mm Concave clearance C_c		
		W_{cf}	W_{hc}	E_d	W_{cf}	W_{hc}	E_d	W_{cf}	W_{hc}	E_d
m/s	%	kg	kg	%	kg	kg	%	kg	kg	%
10.41	15.4	5.47	0.0016	99.97	5.61	0.0567	98.99	5.69	0.0729	98.72
10.41	18	5.80	0.0093	99.84	5.75	0.0586	98.98	5.80	0.0789	98.64
10.41	20.5	6.01	0.0084	99.86	6.01	0.0613	98.98	6.01	0.0932	98.45
10.41	23	6.04	0.0036	99.94	6.07	0.0364	99.40	6.15	0.0848	98.62
10.41	25.6	6.15	0.0025	99.96	6.28	0.0057	99.91	6.33	0.0855	98.65
11.2	15.4	5.65	0.0006	99.99	5.75	0.0460	99.20	5.80	0.0684	98.82
11.2	18	5.88	0.0029	99.95	5.89	0.0471	99.20	5.97	0.0717	98.80
11.2	20.5	6.03	0.0133	99.78	6.15	0.0590	99.04	6.15	0.0805	98.69
11.2	23	6.15	0.0092	99.85	6.20	0.0322	99.48	6.23	0.0629	98.99
11.2	25.6	6.20	0.0012	99.98	6.28	0.0038	99.94	6.28	0.0515	99.18
11.92	15.4	5.75	0.0017	99.97	5.75	0.0322	99.44	5.80	0.0690	98.81
11.92	18	5.89	0.0041	99.93	6.03	0.0428	99.29	6.03	0.0669	98.89
11.92	20.5	6.15	0.0123	99.80	6.20	0.0521	99.16	6.23	0.0660	98.94
11.92	23	6.20	0.0050	99.92	6.28	0.0276	99.56	6.33	0.0462	99.27
11.92	25.6	6.24	0.0000	100.00	6.33	0.0013	99.98	6.37	0.0159	99.75
12.4	15.4	5.76	0.0017	99.97	5.76	0.0288	99.50	5.83	0.0513	99.12
12.4	18	5.91	0.0065	99.89	5.97	0.0311	99.48	6.01	0.0529	99.12
12.4	20.5	6.15	0.0117	99.81	6.17	0.0432	99.30	6.23	0.0560	99.10
12.4	23	6.16	0.0080	99.87	6.28	0.0239	99.62	6.33	0.0405	99.36
12.4	25.6	6.27	0.0000	100.00	6.33	0.0006	99.99	6.37	0.0159	99.75
12.91	15.4	5.80	0.0000	100.00	5.88	0.0141	99.76	5.89	0.0301	99.49
12.91	18	6.01	0.0024	99.96	6.07	0.0188	99.69	6.09	0.0396	99.35
12.91	20.5	6.20	0.0043	99.93	6.23	0.0237	99.62	6.27	0.0476	99.24
12.91	23	6.24	0.0037	99.94	6.33	0.0234	99.63	6.33	0.0329	99.48
12.91	25.6	6.29	0.0000	100.00	6.37	0.0025	99.96	6.37	0.0166	99.74

W_{cf} = Total wt. of cob fed at hopper; W_{hc} = Wt. of husked cob at thrower outlet; E_d = Dehusking efficiency

Replication-4

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c			44 mm Concave clearance C_c			48 mm Concave clearance C_c		
		W_{cf}	W_{hc}	E_d	W_{cf}	W_{hc}	E_d	W_{cf}	W_{hc}	E_d
m/s	%	kg	kg	%	kg	kg	%	kg	kg	%
10.41	15.4	5.60	0.0000	100.00	5.72	0.0040	99.93	5.80	0.0708	98.78
10.41	18	5.73	0.0109	99.81	5.80	0.0626	98.92	5.80	0.0812	98.60
10.41	20.5	6.00	0.0156	99.74	6.01	0.0661	98.90	6.08	0.0888	98.54
10.41	23	6.00	0.0108	99.82	6.12	0.0355	99.42	6.13	0.0895	98.54
10.41	25.6	6.13	0.0086	99.86	6.27	0.0107	99.83	6.33	0.0830	98.69
11.2	15.4	5.67	0.0023	99.96	5.80	0.0499	99.14	5.85	0.0714	98.78
11.2	18	5.87	0.0082	99.86	5.93	0.0534	99.10	5.97	0.0753	98.74
11.2	20.5	6.07	0.0085	99.86	6.15	0.0615	99.00	6.16	0.0795	98.71
11.2	23	6.13	0.0055	99.91	6.20	0.0347	99.44	6.23	0.0666	98.93
11.2	25.6	6.20	0.0050	99.92	6.29	0.0063	99.90	6.28	0.0490	99.22
11.92	15.4	5.73	0.0006	99.99	5.84	0.0374	99.36	5.89	0.0654	98.89
11.92	18	5.93	0.0024	99.96	6.01	0.0451	99.25	6.07	0.0686	98.87
11.92	20.5	6.13	0.0092	99.85	6.20	0.0570	99.08	6.23	0.0697	98.88
11.92	23	6.20	0.0074	99.88	6.28	0.0314	99.50	6.29	0.0434	99.31
11.92	25.6	6.23	0.0000	100.00	6.37	0.0025	99.96	6.31	0.0132	99.79
12.4	15.4	5.76	0.0000	100.00	5.83	0.0233	99.60	5.91	0.0532	99.1
12.4	18	5.96	0.0030	99.95	5.97	0.0370	99.38	6.00	0.0564	99.06
12.4	20.5	6.16	0.0068	99.89	6.24	0.0424	99.32	6.23	0.0610	99.02
12.4	23	6.21	0.0031	99.95	6.28	0.0163	99.74	6.31	0.0353	99.44
12.4	25.6	6.27	0.0000	100.00	6.37	0.0025	99.96	6.35	0.0184	99.71
12.91	15.4	5.80	0.0000	100.00	5.87	0.0188	99.68	5.93	0.0326	99.45
12.91	18	6.00	0.0060	99.90	6.07	0.0212	99.65	6.09	0.0420	99.31
12.91	20.5	6.20	0.0062	99.90	6.23	0.0262	99.58	6.27	0.0551	99.12
12.91	23	6.24	0.0075	99.88	6.29	0.0258	99.59	6.33	0.0367	99.42
12.91	25.6	6.29	0.0000	100.00	6.33	0.0000	100.00	6.43	0.0219	99.66

W_{cf} = Total wt. of cob fed at hopper; W_{hc} = Wt. of husked cob at thrower outlet; E_d = Dehusking efficiency

Table B-2.2 Experimental Data on Shelling Efficiency
Replication-1

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c				44 mm Concave clearance C_c				48 mm Concave clearance C_c			
		W_{cf}	W_i	W_u	E_s	W_{cf}	W_i	W_u	E_s	W_{cf}	W_i	W_u	E_s
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.60	4.2	0.0021	99.95	5.69	4.27	0.0491	98.85	5.75	4.31	0.0690	98.4
10.41	18	5.73	4.3	0.0120	99.72	5.76	4.32	0.0678	98.43	5.80	4.35	0.1001	97.7
10.41	20.5	6.00	4.5	0.0337	99.25	6.01	4.51	0.0383	99.15	6.07	4.55	0.1360	97.01
10.41	23	6.00	4.5	0.0293	99.35	6.04	4.53	0.0997	97.80	6.13	4.6	0.1449	96.85
10.41	25.6	6.13	4.6	0.0267	99.42	6.27	4.7	0.1058	97.75	6.33	4.75	0.1591	96.65
11.2	15.4	5.67	4.25	0.0064	99.85	5.73	4.3	0.0310	99.28	5.80	4.35	0.0600	98.62
11.2	18	5.87	4.4	0.0167	99.62	5.93	4.45	0.0543	98.78	5.97	4.48	0.0824	98.16
11.2	20.5	6.07	4.55	0.0296	99.35	6.13	4.6	0.0653	98.58	6.16	4.62	0.1173	97.46
11.2	23	6.13	4.6	0.0285	99.38	6.20	4.65	0.0804	98.27	6.23	4.67	0.1158	97.52
11.2	25.6	6.20	4.65	0.0130	99.72	6.27	4.7	0.0837	98.22	6.29	4.72	0.1104	97.66
11.92	15.4	5.73	4.3	0.0077	99.82	5.73	4.3	0.0215	99.50	5.80	4.35	0.0513	98.82
11.92	18	5.93	4.45	0.0116	99.74	6.00	4.5	0.0396	99.12	6.07	4.55	0.1178	97.41
11.92	20.5	6.13	4.6	0.0129	99.72	6.20	4.65	0.0553	98.81	6.23	4.67	0.1060	97.73
11.92	23	6.20	4.65	0.0167	99.64	6.27	4.7	0.0592	98.74	6.29	4.72	0.0821	98.26
11.92	25.6	6.23	4.67	0.0065	99.86	6.33	4.75	0.0589	98.76	6.37	4.78	0.0660	98.62
12.4	15.4	5.76	4.32	0.0043	99.9	5.83	4.37	0.0192	99.56	5.87	4.4	0.0431	99.02
12.4	18	5.96	4.47	0.0054	99.88	5.97	4.48	0.0291	99.35	6.00	4.5	0.0796	98.23
12.4	20.5	6.16	4.62	0.0176	99.62	6.20	4.65	0.0395	99.15	6.23	4.67	0.0794	98.3
12.4	23	6.21	4.66	0.0121	99.74	6.27	4.7	0.0352	99.25	6.31	4.73	0.0695	98.53
12.4	25.6	6.27	4.7	0.0023	99.95	6.33	4.75	0.0451	99.05	6.37	4.78	0.0741	98.45
12.91	15.4	5.80	4.35	0.0048	99.89	5.87	4.4	0.0268	99.39	5.89	4.42	0.0331	99.25
12.91	18	6.00	4.5	0.0090	99.8	6.07	4.55	0.0309	99.32	6.09	4.57	0.0526	98.85
12.91	20.5	6.20	4.65	0.0140	99.7	6.23	4.67	0.0383	99.18	6.27	4.7	0.0583	98.76
12.91	23	6.24	4.68	0.0047	99.9	6.29	4.72	0.0850	98.20	6.33	4.75	0.0641	98.65
12.91	25.6	6.29	4.72	0.0104	99.78	6.33	4.75	0.0822	98.27	6.37	4.78	0.0583	98.78

W_{cf}= Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_u = Wt. of unshelled grain; E_s = Shelling efficiency

Replication-2

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c				44 mm Concave clearance C_c				48 mm Concave clearance C_c			
		W_{cf}	W_l	W_u	E_s	W_{cf}	W_l	W_u	E_s	W_{cf}	W_l	W_u	E_s
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.63	4.22	0.0034	99.92	5.69	4.27	0.0444	98.96	5.76	4.32	0.0639	98.52
10.41	18	5.76	4.32	0.0380	99.12	5.77	4.33	0.0593	98.63	5.77	4.33	0.0935	97.84
10.41	20.5	6.05	4.54	0.0449	99.01	6.00	4.5	0.1215	97.30	6.07	4.55	0.1297	97.15
10.41	23	6.08	4.56	0.0319	99.3	6.07	4.55	0.0928	97.96	6.15	4.61	0.1406	96.95
10.41	25.6	6.16	4.62	0.0323	99.3	6.29	4.72	0.0939	98.01	6.33	4.75	0.1534	96.77
11.2	15.4	5.71	4.28	0.0150	99.65	5.75	4.31	0.0440	98.98	5.81	4.36	0.0549	98.74
11.2	18	5.89	4.42	0.0248	99.44	5.91	4.43	0.0496	98.88	5.88	4.41	0.0723	98.36
11.2	20.5	6.04	4.53	0.0317	99.3	6.16	4.62	0.0702	98.48	6.21	4.66	0.1137	97.56
11.2	23	6.17	4.63	0.0324	99.3	6.17	4.63	0.0764	98.35	6.25	4.69	0.1097	97.66
11.2	25.6	6.23	4.67	0.0411	99.12	6.28	4.71	0.0754	98.40	6.28	4.71	0.1083	97.7
11.92	15.4	5.76	4.32	0.0104	99.76	5.76	4.32	0.0346	99.20	5.75	4.31	0.0448	98.96
11.92	18	5.97	4.48	0.0305	99.32	6.03	4.52	0.0045	99.90	6.07	4.55	0.0268	99.41
11.92	20.5	6.21	4.66	0.0410	99.12	6.16	4.62	0.0457	99.01	6.24	4.68	0.0875	98.13
11.92	23	6.24	4.68	0.0262	99.44	6.28	4.71	0.0546	98.84	6.28	4.71	0.0763	98.38
11.92	25.6	6.27	4.7	0.0301	99.36	6.35	4.76	0.0562	98.82	6.37	4.78	0.0593	98.76
12.4	15.4	5.80	4.35	0.0087	99.8	5.80	4.35	0.0322	99.26	5.88	4.41	0.0379	99.14
12.4	18	5.97	4.48	0.0045	99.9	5.93	4.45	0.0436	99.02	6.03	4.52	0.0348	99.23
12.4	20.5	6.23	4.67	0.0290	99.38	6.25	4.69	0.0084	99.82	6.25	4.69	0.0741	98.42
12.4	23	6.25	4.69	0.0328	99.3	6.32	4.74	0.0512	98.92	6.33	4.75	0.0670	98.59
12.4	25.6	6.29	4.72	0.0038	99.92	6.39	4.79	0.0393	99.18	6.37	4.78	0.0454	99.05
12.91	15.4	5.81	4.36	0.0031	99.93	5.88	4.41	0.0172	99.61	5.89	4.42	0.0305	99.31
12.91	18	6.00	4.5	0.0157	99.65	6.08	4.56	0.0283	99.38	6.08	4.56	0.0342	99.25
12.91	20.5	6.20	4.65	0.0246	99.47	6.19	4.64	0.0348	99.25	6.28	4.71	0.0556	98.82
12.91	23	6.27	4.7	0.0075	99.84	6.28	4.71	0.0754	98.40	6.33	4.75	0.0499	98.95
12.91	25.6	6.40	4.8	0.0115	99.76	6.33	4.75	0.0793	98.33	6.39	4.79	0.0575	98.8

W_{cf} = Total wt. of cob fed at hopper; W_l = Wt of total sample feed at hopper; W_u = Wt. of unshelled grain; E_s = Shelling efficiency

Replication-3

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c				44 mm Concave clearance C_c				48 mm Concave clearance C_c			
		W_{cf}	W_i	W_u	E_s	W_{cf}	W_i	W_u	E_s	W_{cf}	W_i	W_u	E_s
m/s	%	kg	kg	kg	%		kg	kg	%		kg	kg	%
10.41	15.4	5.47	4.1	0.0156	99.62	5.61	4.21	0.0417	99.01	5.69	4.27	0.0670	98.43
10.41	18	5.80	4.35	0.0270	99.38	5.75	4.31	0.0612	98.58	5.80	4.35	0.1405	96.77
10.41	20.5	6.01	4.51	0.0406	99.1	6.01	4.51	0.0767	98.30	6.01	4.51	0.1362	96.98
10.41	23	6.04	4.53	0.0385	99.15	6.07	4.55	0.0824	98.19	6.15	4.61	0.1498	96.75
10.41	25.6	6.15	4.61	0.0221	99.52	6.28	4.71	0.0885	98.12	6.33	4.75	0.1525	96.79
11.2	15.4	5.65	4.24	0.0042	99.9	5.75	4.31	0.0353	99.18	5.80	4.35	0.0618	98.58
11.2	18	5.88	4.41	0.0221	99.5	5.89	4.42	0.0530	98.80	5.97	4.48	0.0806	98.2
11.2	20.5	6.03	4.52	0.0384	99.15	6.15	4.61	0.0724	98.43	6.15	4.61	0.1153	97.5
11.2	23	6.15	4.61	0.0221	99.52	6.20	4.65	0.0814	98.25	6.23	4.67	0.1168	97.5
11.2	25.6	6.20	4.65	0.0288	99.38	6.28	4.71	0.0801	98.30	6.28	4.71	0.1112	97.64
11.92	15.4	5.75	4.31	0.0129	99.7	5.75	4.31	0.0293	99.32	5.80	4.35	0.0500	98.85
11.92	18	5.89	4.42	0.0080	99.82	6.03	4.52	0.0334	99.26	6.03	4.52	0.0809	98.21
11.92	20.5	6.15	4.61	0.0286	99.38	6.20	4.65	0.0484	98.96	6.23	4.67	0.0981	97.9
11.92	23	6.20	4.65	0.0223	99.52	6.28	4.71	0.0584	98.76	6.33	4.75	0.0808	98.3
11.92	25.6	6.24	4.68	0.0075	99.84	6.33	4.75	0.0608	98.72	6.37	4.78	0.0645	98.65
12.4	15.4	5.76	4.32	0.0091	99.79	5.76	4.32	0.0268	99.38	5.83	4.37	0.0358	99.18
12.4	18	5.91	4.43	0.0186	99.58	5.97	4.48	0.0336	99.25	6.01	4.51	0.0559	98.76
12.4	20.5	6.15	4.61	0.0254	99.45	6.17	4.63	0.0440	99.05	6.23	4.67	0.0785	98.32
12.4	23	6.16	4.62	0.0092	99.8	6.28	4.71	0.0400	99.15	6.33	4.75	0.0713	98.5
12.4	25.6	6.27	4.7	0.0179	99.62	6.33	4.75	0.0551	98.84	6.37	4.78	0.0645	98.65
12.91	15.4	5.80	4.35	0.0043	99.9	5.88	4.41	0.0176	99.60	5.89	4.42	0.0354	99.2
12.91	18	6.01	4.51	0.0068	99.85	6.07	4.55	0.0337	99.26	6.09	4.57	0.0448	99.02
12.91	20.5	6.20	4.65	0.0223	99.52	6.23	4.67	0.0458	99.02	6.27	4.7	0.0663	98.59
12.91	23	6.24	4.68	0.0300	99.36	6.33	4.75	0.0808	98.30	6.33	4.75	0.0608	98.72
12.91	25.6	6.29	4.72	0.0104	99.78	6.37	4.78	0.0846	98.23	6.37	4.78	0.0545	98.86

W_{cf}= Total wt. of cob fed at hopper; W_i= Wt of total sample feed at hopper; W_u = Wt. of unshelled grain; E_s = Shelling efficieney

Replication-4

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c				44 mm Concave clearance C_c				48 mm Concave clearance C_c			
		W_{cf}	W_i	W_u	E_s	W_{cf}	W_i	W_u	E_s	W_{cf}	W_i	W_u	E_s
m/s	%	kg	kg	kg	%		kg	kg	%		kg	kg	%
10.41	15.4	5.60	4.2	0.0256	99.39	5.72	4.29	0.0511	98.81	5.80	4.35	0.0657	98.49
10.41	18	5.73	4.3	0.0232	99.46	5.80	4.35	0.0661	98.48	5.80	4.35	0.0535	98.77
10.41	20.5	6.00	4.5	0.0378	99.16	6.01	4.51	0.0902	98.00	6.08	4.56	0.1286	97.18
10.41	23	6.00	4.5	0.0360	99.2	6.12	4.59	0.1060	97.69	6.13	4.6	0.1357	97.05
10.41	25.6	6.13	4.6	0.0368	99.2	6.27	4.7	0.1053	97.76	6.33	4.75	0.1601	96.63
11.2	15.4	5.67	4.25	0.0170	99.6	5.80	4.35	0.0400	99.08	5.85	4.39	0.0536	98.78
11.2	18	5.87	4.4	0.0194	99.56	5.93	4.45	0.0507	98.86	5.97	4.48	0.0753	98.32
11.2	20.5	6.07	4.55	0.0309	99.32	6.15	4.61	0.0632	98.63	6.16	4.62	0.1146	97.52
11.2	23	6.13	4.6	0.0368	99.2	6.20	4.65	0.0758	98.37	6.23	4.67	0.1083	97.68
11.2	25.6	6.20	4.65	0.0270	99.42	6.29	4.72	0.0793	98.32	6.28	4.71	0.1074	97.72
11.92	15.4	5.73	4.3	0.0052	99.88	5.84	4.38	0.0272	99.38	5.89	4.42	0.0473	98.93
11.92	18	5.93	4.45	0.0196	99.56	6.01	4.51	0.0325	99.28	6.07	4.55	0.0632	98.61
11.92	20.5	6.13	4.6	0.0248	99.46	6.20	4.65	0.0535	98.85	6.23	4.67	0.0953	97.96
11.92	23	6.20	4.65	0.0205	99.56	6.28	4.71	0.0556	98.82	6.29	4.72	0.0784	98.34
11.92	25.6	6.23	4.67	0.0196	99.58	6.37	4.78	0.0545	98.86	6.31	4.73	0.0601	98.73
12.4	15.4	5.76	4.32	0.0039	99.91	5.83	4.37	0.0297	99.32	5.91	4.43	0.0452	98.98
12.4	18	5.96	4.47	0.0286	99.36	5.97	4.48	0.0367	99.18	6.00	4.5	0.0585	98.7
12.4	20.5	6.16	4.62	0.0208	99.55	6.24	4.68	0.0477	98.98	6.23	4.67	0.0752	98.39
12.4	23	6.21	4.66	0.0205	99.56	6.28	4.71	0.0433	99.08	6.31	4.73	0.0653	98.62
12.4	25.6	6.27	4.7	0.0287	99.39	6.37	4.78	0.0320	99.33	6.35	4.76	0.0547	98.85
12.91	15.4	5.80	4.35	0.0035	99.92	5.87	4.4	0.0264	99.40	5.93	4.45	0.0285	99.36
12.91	18	6.00	4.5	0.0189	99.58	6.07	4.55	0.0200	99.56	6.09	4.57	0.0420	99.08
12.91	20.5	6.20	4.65	0.0191	99.59	6.23	4.67	0.0304	99.35	6.27	4.7	0.0381	99.19
12.91	23	6.24	4.68	0.0197	99.58	6.29	4.72	0.0802	98.30	6.33	4.75	0.0532	98.88
12.91	25.6	6.29	4.72	0.0057	99.88	6.33	4.75	0.0774	98.37	6.43	4.82	0.0559	98.84

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_u = Wt. of unshelled grain; E_s = Shelling efficiency

Table B-2.3 Experimental Data on Cleaning Efficiency Replication-1

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c			44 mm Concave clearance C_c			48 mm Concave clearance C_c		
		W_m	W_c	E_c	W_m	W_c	E_c	W_m	W_c	E_c
m/s	%	g	g	%	g	g	%	g	g	%
10.41	15.4	100	99.31	99.31	100	99.32	99.32	100	99.4	99.4
10.41	18	100	99.3	99.3	100	99.32	99.32	100	99.35	99.35
10.41	20.5	100	99.31	99.31	100	99.33	99.33	100	99.34	99.34
10.41	23	100	99.29	99.29	100	99.31	99.31	100	99.33	99.33
10.41	25.6	100	99.29	99.29	100	99.3	99.3	100	99.35	99.35
11.2	15.4	100	99.38	99.38	100	99.36	99.36	100	99.41	99.41
11.2	18	100	99.39	99.39	100	99.36	99.36	100	99.41	99.41
11.2	20.5	100	99.34	99.34	100	99.35	99.35	100	99.4	99.4
11.2	23	100	99.34	99.34	100	99.36	99.36	100	99.45	99.45
11.2	25.6	100	99.33	99.33	100	99.33	99.33	100	99.35	99.35
11.92	15.4	100	99.37	99.37	100	99.43	99.43	100	99.43	99.43
11.92	18	100	99.37	99.37	100	99.44	99.44	100	99.46	99.46
11.92	20.5	100	99.36	99.36	100	99.37	99.37	100	99.43	99.43
11.92	23	100	99.37	99.37	100	99.38	99.38	100	99.4	99.4
11.92	25.6	100	99.36	99.36	100	99.4	99.4	100	99.36	99.36
12.4	15.4	100	99.44	99.44	100	99.44	99.44	100	99.49	99.49
12.4	18	100	99.47	99.47	100	99.46	99.46	100	99.49	99.49
12.4	20.5	100	99.47	99.47	100	99.41	99.41	100	99.45	99.45
12.4	23	100	99.41	99.41	100	99.4	99.4	100	99.5	99.5
12.4	25.6	100	99.46	99.46	100	99.39	99.39	100	99.42	99.42
12.91	15.4	100	99.45	99.45	100	99.53	99.53	100	99.55	99.55
12.91	18	100	99.51	99.51	100	99.5	99.5	100	99.5	99.5
12.91	20.5	100	99.46	99.46	100	99.5	99.5	100	99.49	99.49
12.91	23	100	99.48	99.48	100	99.47	99.47	100	99.52	99.52
12.91	25.6	100	99.44	99.44	100	99.46	99.46	100	99.53	99.53

W_m = Total wt. of sample material; W_c = Wt. of whole grain; E_c = Cleaning efficiency

Replication-2

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c			44 mm Concave clearance C_c			48 mm Concave clearance C_c		
		W_m	W_c	E_c	W_m	W_c	E_c	W_m	W_c	E_c
m/s	%	kg	kg	%	kg	kg	%	kg	kg	%
10.41	15.4	100	99.39	99.39	100	99.38	99.38	100	99.34	99.34
10.41	18	100	99.38	99.38	100	99.38	99.38	100	99.37	99.37
10.41	20.5	100	99.35	99.35	100	99.35	99.35	100	99.38	99.38
10.41	23	100	99.35	99.35	100	99.33	99.33	100	99.37	99.37
10.41	25.6	100	99.35	99.35	100	99.32	99.32	100	99.33	99.33
11.2	15.4	100	99.36	99.36	100	99.42	99.42	100	99.43	99.43
11.2	18	100	99.33	99.33	100	99.38	99.38	100	99.43	99.43
11.2	20.5	100	99.36	99.36	100	99.37	99.37	100	99.42	99.42
11.2	23	100	99.36	99.36	100	99.34	99.34	100	99.35	99.35
11.2	25.6	100	99.35	99.35	100	99.37	99.37	100	99.41	99.41
11.92	15.4	100	99.45	99.45	100	99.41	99.41	100	99.47	99.47
11.92	18	100	99.43	99.43	100	99.37	99.37	100	99.43	99.43
11.92	20.5	100	99.44	99.44	100	99.43	99.43	100	99.41	99.41
11.92	23	100	99.41	99.41	100	99.4	99.4	100	99.42	99.42
11.92	25.6	100	99.4	99.4	100	99.36	99.36	100	99.44	99.44
12.4	15.4	100	99.46	99.46	100	99.48	99.48	100	99.47	99.47
12.4	18	100	99.41	99.41	100	99.44	99.44	100	99.47	99.47
12.4	20.5	100	99.41	99.41	100	99.47	99.47	100	99.49	99.49
12.4	23	100	99.45	99.45	100	99.44	99.44	100	99.42	99.42
12.4	25.6	100	99.36	99.36	100	99.43	99.43	100	99.48	99.48
12.91	15.4	100	99.55	99.55	100	99.51	99.51	100	99.51	99.51
12.91	18	100	99.47	99.47	100	99.52	99.52	100	99.54	99.54
12.91	20.5	100	99.48	99.48	100	99.52	99.52	100	99.53	99.53
12.91	23	100	99.44	99.44	100	99.51	99.51	100	99.48	99.48
12.91	25.6	100	99.46	99.46	100	99.5	99.5	100	99.44	99.44

W_m = Total wt. of sample material; W_c = Wt. of whole grain; E_c = Cleaning efficiency

Replication-3

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c			44 mm Concave clearance C_c			48 mm Concave clearance C_c		
		W_m	W_c	E_c	W_m	W_c	E_c	W_m	W_c	E_c
m/s	%	kg	kg	%	kg	kg	%	kg	kg	%
10.41	15.4	100	99.36	99.36	100	99.34	99.34	100	99.38	99.38
10.41	18	100	99.36	99.36	100	99.34	99.34	100	99.38	99.38
10.41	20.5	100	99.34	99.34	100	99.38	99.38	100	99.37	99.37
10.41	23	100	99.33	99.33	100	99.3	99.3	100	99.38	99.38
10.41	25.6	100	99.33	99.33	100	99.28	99.28	100	99.36	99.36
11.2	15.4	100	99.4	99.4	100	99.38	99.38	100	99.43	99.43
11.2	18	100	99.32	99.32	100	99.38	99.38	100	99.43	99.43
11.2	20.5	100	99.39	99.39	100	99.35	99.35	100	99.43	99.43
11.2	23	100	99.39	99.39	100	99.36	99.36	100	99.38	99.38
11.2	25.6	100	99.32	99.32	100	99.33	99.33	100	99.4	99.4
11.92	15.4	100	99.43	99.43	100	99.44	99.44	100	99.46	99.46
11.92	18	100	99.41	99.41	100	99.39	99.39	100	99.42	99.42
11.92	20.5	100	99.42	99.42	100	99.42	99.42	100	99.44	99.44
11.92	23	100	99.35	99.35	100	99.37	99.37	100	99.43	99.43
11.92	25.6	100	99.39	99.39	100	99.39	99.39	100	99.43	99.43
12.4	15.4	100	99.47	99.47	100	99.42	99.42	100	99.46	99.46
12.4	18	100	99.46	99.46	100	99.48	99.48	100	99.46	99.46
12.4	20.5	100	99.46	99.46	100	99.45	99.45	100	99.46	99.46
12.4	23	100	99.42	99.42	100	99.43	99.43	100	99.47	99.47
12.4	25.6	100	99.43	99.43	100	99.4	99.4	100	99.41	99.41
12.91	15.4	100	99.52	99.52	100	99.54	99.54	100	99.54	99.54
12.91	18	100	99.5	99.5	100	99.53	99.53	100	99.51	99.51
12.91	20.5	100	99.42	99.42	100	99.53	99.53	100	99.52	99.52
12.91	23	100	99.5	99.5	100	99.5	99.5	100	99.53	99.53
12.91	25.6	100	99.42	99.42	100	99.49	99.49	100	99.5	99.5

W_m = Total wt. of sample material; W_c = Wt. of whole grain; E_c = Cleaning efficiency

Replication-4

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c			44 mm Concave clearance C_c			48 mm Concave clearance C_c		
		W_m	W_c	E_c	W_m	W_c	E_c	W_m	W_c	E_c
m/s	%	kg	kg	%	kg	kg	%	kg	kg	%
10.41	15.4	100	99.34	99.34	100	99.36	99.36	100	99.36	99.36
10.41	18	100	99.32	99.32	100	99.36	99.36	100	99.34	99.34
10.41	20.5	100	99.32	99.32	100	99.3	99.3	100	99.35	99.35
10.41	23	100	99.31	99.31	100	99.34	99.34	100	99.32	99.32
10.41	25.6	100	99.31	99.31	100	99.34	99.34	100	99.32	99.32
11.2	15.4	100	99.34	99.34	100	99.4	99.4	100	99.41	99.41
11.2	18	100	99.4	99.4	100	99.36	99.36	100	99.41	99.41
11.2	20.5	100	99.31	99.31	100	99.37	99.37	100	99.39	99.39
11.2	23	100	99.31	99.31	100	99.34	99.34	100	99.42	99.42
11.2	25.6	100	99.36	99.36	100	99.37	99.37	100	99.36	99.36
11.92	15.4	100	99.39	99.39	100	99.4	99.4	100	99.44	99.44
11.92	18	100	99.39	99.39	100	99.43	99.43	100	99.46	99.46
11.92	20.5	100	99.38	99.38	100	99.38	99.38	100	99.4	99.4
11.92	23	100	99.43	99.43	100	99.41	99.41	100	99.39	99.39
11.92	25.6	100	99.37	99.37	100	99.37	99.37	100	99.39	99.39
12.4	15.4	100	99.43	99.43	100	99.5	99.5	100	99.5	99.5
12.4	18	100	99.42	99.42	100	99.42	99.42	100	99.5	99.5
12.4	20.5	100	99.42	99.42	100	99.43	99.43	100	99.48	99.48
12.4	23	100	99.44	99.44	100	99.41	99.41	100	99.45	99.45
12.4	25.6	100	99.39	99.39	100	99.42	99.42	100	99.49	99.49
12.91	15.4	100	99.48	99.48	100	99.5	99.5	100	99.52	99.52
12.91	18	100	99.48	99.48	100	99.49	99.49	100	99.53	99.53
12.91	20.5	100	99.52	99.52	100	99.49	99.49	100	99.5	99.5
12.91	23	100	99.42	99.42	100	99.48	99.48	100	99.47	99.47
12.91	25.6	100	99.48	99.48	100	99.47	99.47	100	99.48	99.48

W_m = Total wt. of sample material; W_c = Wt. of whole grain; E_c = Cleaning efficiency

Table B-2.4 Experimental data on thrower loss
Replication-1

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c				44 mm Concave clearance C_c				48 mm Concave clearance C_c			
		W_{cf}	W_i	W_{gt}	L_t	W_{cf}	W_i	W_{gt}	L_t	W_{cf}	W_i	W_{gt}	L_t
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.60	4.2	0.0336	0.80	5.69	4.27	0.0440	1.03	5.75	4.31	0.0332	0.77
10.41	18	5.73	4.3	0.0211	0.49	5.76	4.32	0.0294	0.68	5.80	4.35	0.0191	0.44
10.41	20.5	6.00	4.5	0.0081	0.18	6.01	4.51	0.0122	0.27	6.07	4.55	0.0055	0.12
10.41	23	6.00	4.5	0.0072	0.16	6.04	4.53	0.0127	0.28	6.13	4.6	0.0074	0.16
10.41	25.6	6.13	4.6	0.0069	0.15	6.27	4.7	0.0127	0.27	6.33	4.75	0.0081	0.17
11.2	15.4	5.67	4.25	0.0446	1.05	5.73	4.3	0.0529	1.23	5.80	4.35	0.0409	0.94
11.2	18	5.87	4.4	0.0273	0.62	5.93	4.45	0.0369	0.83	5.97	4.48	0.0237	0.53
11.2	20.5	6.07	4.55	0.0100	0.22	6.13	4.6	0.0143	0.31	6.16	4.62	0.0088	0.19
11.2	23	6.13	4.6	0.0133	0.29	6.20	4.65	0.0181	0.39	6.23	4.67	0.0112	0.24
11.2	25.6	6.20	4.65	0.0149	0.32	6.27	4.7	0.0179	0.38	6.29	4.72	0.0118	0.25
11.92	15.4	5.73	4.3	0.0589	1.37	5.73	4.3	0.0624	1.45	5.80	4.35	0.0496	1.14
11.92	18	5.93	4.45	0.0374	0.84	6.00	4.5	0.0396	0.88	6.07	4.55	0.0305	0.67
11.92	20.5	6.13	4.6	0.0120	0.26	6.20	4.65	0.0172	0.37	6.23	4.67	0.0117	0.25
11.92	23	6.20	4.65	0.0167	0.36	6.27	4.7	0.0226	0.48	6.29	4.72	0.0118	0.25
11.92	25.6	6.23	4.67	0.0205	0.44	6.33	4.75	0.0238	0.50	6.37	4.78	0.0148	0.31
12.4	15.4	5.76	4.32	0.0631	1.46	5.83	4.37	0.0739	1.69	5.87	4.4	0.0488	1.11
12.4	18	5.96	4.47	0.0411	0.92	5.97	4.48	0.0439	0.98	6.00	4.5	0.0315	0.70
12.4	20.5	6.16	4.62	0.0139	0.30	6.20	4.65	0.0167	0.36	6.23	4.67	0.0093	0.20
12.4	23	6.21	4.66	0.0205	0.44	6.27	4.7	0.0282	0.60	6.31	4.73	0.0161	0.34
12.4	25.6	6.27	4.7	0.0291	0.62	6.33	4.75	0.0371	0.78	6.37	4.78	0.0172	0.36
12.91	15.4	5.80	4.35	0.0713	1.64	5.87	4.4	0.0845	1.92	5.89	4.42	0.0491	1.11
12.91	18	6.00	4.5	0.0446	0.99	6.07	4.55	0.0501	1.10	6.09	4.57	0.0315	0.69
12.91	20.5	6.20	4.65	0.0195	0.42	6.23	4.67	0.0196	0.42	6.27	4.7	0.0080	0.17
12.91	23	6.24	4.68	0.0215	0.46	6.29	4.72	0.0335	0.71	6.33	4.75	0.0143	0.30
12.91	25.6	6.29	4.72	0.0349	0.74	6.33	4.75	0.0494	1.04	6.37	4.78	0.0210	0.44

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gt} = Wt. of grain collected at thrower outlet; L_t = Thrower loss

Replication-2

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c				44 mm Concave clearance C_c				48 mm Concave clearance C_c			
		W_{cf}	W_i	W_{gt}	L_t	W_{cf}	W_i	W_{gt}	L_t	W_{cf}	W_i	W_{gt}	L_t
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.63	4.22	0.0363	0.86	5.69	4.27	0.0465	1.09	5.76	4.32	0.0341	0.79
10.41	18	5.76	4.32	0.0229	0.53	5.77	4.33	0.0286	0.66	5.77	4.33	0.0199	0.46
10.41	20.5	6.05	4.54	0.0100	0.22	6.00	4.5	0.0140	0.31	6.07	4.55	0.0064	0.14
10.41	23	6.08	4.56	0.0100	0.22	6.07	4.55	0.0137	0.30	6.15	4.61	0.0046	0.10
10.41	25.6	6.16	4.62	0.0106	0.23	6.29	4.72	0.0146	0.31	6.33	4.75	0.0043	0.09
11.2	15.4	5.71	4.28	0.0475	1.11	5.75	4.31	0.0556	1.29	5.81	4.36	0.0419	0.96
11.2	18	5.89	4.42	0.0309	0.70	5.91	4.43	0.0394	0.89	5.88	4.41	0.0278	0.63
11.2	20.5	6.04	4.53	0.0136	0.30	6.16	4.62	0.0162	0.35	6.21	4.66	0.0098	0.21
11.2	23	6.17	4.63	0.0144	0.31	6.17	4.63	0.0153	0.33	6.25	4.69	0.0084	0.18
11.2	25.6	6.23	4.67	0.0159	0.34	6.28	4.71	0.0198	0.42	6.28	4.71	0.0089	0.19
11.92	15.4	5.76	4.32	0.0557	1.29	5.76	4.32	0.0618	1.43	5.75	4.31	0.0465	1.08
11.92	18	5.97	4.48	0.0349	0.78	6.03	4.52	0.0434	0.96	6.07	4.55	0.0323	0.71
11.92	20.5	6.21	4.66	0.0158	0.34	6.16	4.62	0.0180	0.39	6.24	4.68	0.0136	0.29
11.92	23	6.24	4.68	0.0187	0.40	6.28	4.71	0.0207	0.44	6.28	4.71	0.0160	0.34
11.92	25.6	6.27	4.7	0.0244	0.52	6.35	4.76	0.0267	0.56	6.37	4.78	0.0167	0.35
12.4	15.4	5.80	4.35	0.0661	1.52	5.80	4.35	0.0726	1.67	5.88	4.41	0.0516	1.17
12.4	18	5.97	4.48	0.0421	0.94	5.93	4.45	0.0472	1.06	6.03	4.52	0.0298	0.66
12.4	20.5	6.23	4.67	0.0168	0.36	6.25	4.69	0.0197	0.42	6.25	4.69	0.0122	0.26
12.4	23	6.25	4.69	0.0235	0.50	6.32	4.74	0.0294	0.62	6.33	4.75	0.0133	0.28
12.4	25.6	6.29	4.72	0.0264	0.56	6.39	4.79	0.0398	0.83	6.37	4.78	0.0210	0.44
12.91	15.4	5.81	4.36	0.0698	1.60	5.88	4.41	0.0864	1.96	5.89	4.42	0.0544	1.23
12.91	18	6.00	4.5	0.0437	0.97	6.08	4.56	0.0483	1.06	6.08	4.56	0.0333	0.73
12.91	20.5	6.20	4.65	0.0140	0.30	6.19	4.64	0.0176	0.38	6.28	4.71	0.0099	0.21
12.91	23	6.27	4.7	0.0273	0.58	6.28	4.71	0.0372	0.79	6.33	4.75	0.0171	0.36
12.91	25.6	6.40	4.8	0.0317	0.66	6.33	4.75	0.0523	1.10	6.39	4.79	0.0249	0.52

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gt} = Wt. of grain collected at thrower outlet; L_t = Thrower loss

Replication-3

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c				44 mm Concave clearance C_c				48 mm Concave clearance C_c			
		W_{cf}	W_i	W_{gt}	L_t	W_{cf}	W_i	W_{gt}	L_t	W_{cf}	W_i	W_{gt}	L_t
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.47	4.1	0.0332	0.81	5.61	4.21	0.0429	1.02	5.69	4.27	0.0325	0.76
10.41	18	5.80	4.35	0.0218	0.50	5.75	4.31	0.0276	0.64	5.80	4.35	0.0187	0.43
10.41	20.5	6.01	4.51	0.0108	0.24	6.01	4.51	0.0117	0.26	6.01	4.51	0.0068	0.15
10.41	23	6.04	4.53	0.0077	0.17	6.07	4.55	0.0123	0.27	6.15	4.61	0.0055	0.12
10.41	25.6	6.15	4.61	0.0083	0.18	6.28	4.71	0.0141	0.30	6.33	4.75	0.0067	0.14
11.2	15.4	5.65	4.24	0.0432	1.02	5.75	4.31	0.0517	1.20	5.80	4.35	0.0400	0.92
11.2	18	5.88	4.41	0.0300	0.68	5.89	4.42	0.0362	0.82	5.97	4.48	0.0251	0.56
11.2	20.5	6.03	4.52	0.0108	0.24	6.15	4.61	0.0157	0.34	6.15	4.61	0.0083	0.18
11.2	23	6.15	4.61	0.0148	0.32	6.20	4.65	0.0158	0.34	6.23	4.67	0.0089	0.19
11.2	25.6	6.20	4.65	0.0172	0.37	6.28	4.71	0.0184	0.39	6.28	4.71	0.0099	0.21
11.92	15.4	5.75	4.31	0.0569	1.32	5.75	4.31	0.0603	1.40	5.80	4.35	0.0479	1.10
11.92	18	5.89	4.42	0.0362	0.82	6.03	4.52	0.0411	0.91	6.03	4.52	0.0307	0.68
11.92	20.5	6.15	4.61	0.0129	0.28	6.20	4.65	0.0158	0.34	6.23	4.67	0.0121	0.26
11.92	23	6.20	4.65	0.0149	0.32	6.28	4.71	0.0198	0.42	6.33	4.75	0.0128	0.27
11.92	25.6	6.24	4.68	0.0229	0.49	6.33	4.75	0.0242	0.51	6.37	4.78	0.0143	0.30
12.4	15.4	5.76	4.32	0.0644	1.49	5.76	4.32	0.0734	1.70	5.83	4.37	0.0489	1.12
12.4	18	5.91	4.43	0.0399	0.90	5.97	4.48	0.0448	1.00	6.01	4.51	0.0293	0.65
12.4	20.5	6.15	4.61	0.0134	0.29	6.17	4.63	0.0176	0.38	6.23	4.67	0.0098	0.21
12.4	23	6.16	4.62	0.0222	0.48	6.28	4.71	0.0273	0.58	6.33	4.75	0.0143	0.30
12.4	25.6	6.27	4.7	0.0259	0.55	6.33	4.75	0.0380	0.80	6.37	4.78	0.0182	0.38
12.91	15.4	5.80	4.35	0.0692	1.59	5.88	4.41	0.0838	1.90	5.89	4.42	0.0508	1.15
12.91	18	6.01	4.51	0.0424	0.94	6.07	4.55	0.0473	1.04	6.09	4.57	0.0320	0.70
12.91	20.5	6.20	4.65	0.0181	0.39	6.23	4.67	0.0205	0.44	6.27	4.7	0.0071	0.15
12.91	23	6.24	4.68	0.0234	0.50	6.33	4.75	0.0347	0.73	6.33	4.75	0.0147	0.31
12.91	25.6	6.29	4.72	0.0340	0.72	6.37	4.78	0.0502	1.05	6.37	4.78	0.0225	0.47

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gt} = Wt. of grain collected at thrower outlet; L_t = Thrower loss

Replication-4

Peripheral speed u	moisture content M_c	40 mm Concave clearance C_c				44 mm Concave clearance C_c				48 mm Concave clearance C_c			
		W_{cf}	W_i	W_{gt}	L_t	W_{cf}	W_i	W_{gt}	L_t	W_{cf}	W_i	W_{gt}	L_t
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.60	4.2	0.0357	0.85	5.72	4.29	0.0472	1.10	5.80	4.35	0.0348	0.80
10.41	18	5.73	4.3	0.0224	0.52	5.80	4.35	0.0305	0.70	5.80	4.35	0.0204	0.47
10.41	20.5	6.00	4.5	0.0072	0.16	6.01	4.51	0.0144	0.32	6.08	4.56	0.0050	0.11
10.41	23	6.00	4.5	0.0095	0.21	6.12	4.59	0.0142	0.31	6.13	4.6	0.0064	0.14
10.41	25.6	6.13	4.6	0.0092	0.20	6.27	4.7	0.0132	0.28	6.33	4.75	0.0057	0.12
11.2	15.4	5.67	4.25	0.0485	1.14	5.80	4.35	0.0574	1.32	5.85	4.39	0.0430	0.98
11.2	18	5.87	4.4	0.0282	0.64	5.93	4.45	0.0401	0.90	5.97	4.48	0.0269	0.60
11.2	20.5	6.07	4.55	0.0127	0.28	6.15	4.61	0.0148	0.32	6.16	4.62	0.0102	0.22
11.2	23	6.13	4.6	0.0129	0.28	6.20	4.65	0.0177	0.38	6.23	4.67	0.0107	0.23
11.2	25.6	6.20	4.65	0.0135	0.29	6.29	4.72	0.0194	0.41	6.28	4.71	0.0108	0.23
11.92	15.4	5.73	4.3	0.0576	1.34	5.84	4.38	0.0648	1.48	5.89	4.42	0.0495	1.12
11.92	18	5.93	4.45	0.0356	0.80	6.01	4.51	0.0419	0.93	6.07	4.55	0.0319	0.70
11.92	20.5	6.13	4.6	0.0147	0.32	6.20	4.65	0.0195	0.42	6.23	4.67	0.0131	0.28
11.92	23	6.20	4.65	0.0205	0.44	6.28	4.71	0.0236	0.50	6.29	4.72	0.0146	0.31
11.92	25.6	6.23	4.67	0.0219	0.47	6.37	4.78	0.0263	0.55	6.31	4.73	0.0170	0.36
12.4	15.4	5.76	4.32	0.0635	1.47	5.83	4.37	0.0725	1.66	5.91	4.43	0.0514	1.16
12.4	18	5.96	4.47	0.0429	0.96	5.97	4.48	0.0466	1.04	6.00	4.5	0.0320	0.71
12.4	20.5	6.16	4.62	0.0171	0.37	6.24	4.68	0.0187	0.40	6.23	4.67	0.0117	0.25
12.4	23	6.21	4.66	0.0214	0.46	6.28	4.71	0.0301	0.64	6.31	4.73	0.0151	0.32
12.4	25.6	6.27	4.7	0.0301	0.64	6.37	4.78	0.0392	0.82	6.35	4.76	0.0200	0.42
12.91	15.4	5.80	4.35	0.0718	1.65	5.87	4.4	0.0871	1.98	5.93	4.45	0.0530	1.19
12.91	18	6.00	4.5	0.0459	1.02	6.07	4.55	0.0510	1.12	6.09	4.57	0.0329	0.72
12.91	20.5	6.20	4.65	0.0153	0.33	6.23	4.67	0.0168	0.36	6.27	4.7	0.0108	0.23
12.91	23	6.24	4.68	0.0253	0.54	6.29	4.72	0.0363	0.77	6.33	4.75	0.0166	0.35
12.91	25.6	6.29	4.72	0.0321	0.68	6.33	4.75	0.0518	1.09	6.43	4.82	0.0236	0.49

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gt} = Wt. of grain collected at thrower outlet; L_t = Thrower loss

Table B-2.5 Experimental data on blower loss
Replication-1

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c				44 mm Concave clearance, C_c				48 mm Concave clearance, C_c			
		W_{cf}	W_i	W_{gb}	L_b	W_{cf}	W_i	W_{gb}	L_b	W_{cf}	W_i	W_{gb}	L_b
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.60	4.2	0.00210	0.05	5.69	4.27	0.00214	0.05	5.75	4.31	0.00216	0.05
10.41	18	5.73	4.3	0.00034	0.008	5.76	4.32	0.00173	0.040	5.80	4.35	0.00174	0.040
10.41	20.5	6.00	4.5	0.00050	0.011	6.01	4.51	0.00050	0.011	6.07	4.55	0.00050	0.011
10.41	23	6.00	4.5	0.00045	0.010	6.04	4.53	0.00045	0.010	6.13	4.6	0.00138	0.030
10.41	25.6	6.13	4.6	0.00000	0.000	6.27	4.7	0.00000	0.000	6.33	4.75	0.00000	0.000
11.2	15.4	5.67	4.25	0.00170	0.040	5.73	4.3	0.00172	0.040	5.80	4.35	0.00174	0.040
11.2	18	5.87	4.4	0.00176	0.040	5.93	4.45	0.00178	0.040	5.97	4.48	0.00045	0.010
11.2	20.5	6.07	4.55	0.00036	0.008	6.13	4.6	0.00037	0.008	6.16	4.62	0.00037	0.008
11.2	23	6.13	4.6	0.00046	0.010	6.20	4.65	0.00140	0.030	6.23	4.67	0.00140	0.030
11.2	25.6	6.20	4.65	0.00000	0.000	6.27	4.7	0.00000	0.000	6.29	4.72	0.00000	0.000
11.92	15.4	5.73	4.3	0.00043	0.010	5.73	4.3	0.00043	0.010	5.80	4.35	0.00044	0.010
11.92	18	5.93	4.45	0.00036	0.008	6.00	4.5	0.00135	0.030	6.07	4.55	0.00182	0.040
11.92	20.5	6.13	4.6	0.00051	0.011	6.20	4.65	0.00051	0.011	6.23	4.67	0.00047	0.010
11.92	23	6.20	4.65	0.00047	0.010	6.27	4.7	0.00047	0.010	6.29	4.72	0.00142	0.030
11.92	25.6	6.23	4.67	0.00037	0.008	6.33	4.75	0.00038	0.008	6.37	4.78	0.00048	0.010
12.4	15.4	5.76	4.32	0.00173	0.040	5.83	4.37	0.00219	0.050	5.87	4.4	0.00220	0.050
12.4	18	5.96	4.47	0.00134	0.030	5.97	4.48	0.00134	0.030	6.00	4.5	0.00135	0.030
12.4	20.5	6.16	4.62	0.00046	0.010	6.20	4.65	0.00140	0.030	6.23	4.67	0.00140	0.030
12.4	23	6.21	4.66	0.00037	0.008	6.27	4.7	0.00094	0.020	6.31	4.73	0.00095	0.020
12.4	25.6	6.27	4.7	0.00052	0.011	6.33	4.75	0.00048	0.010	6.37	4.78	0.00048	0.010
12.91	15.4	5.80	4.35	0.00218	0.050	5.87	4.4	0.00220	0.050	5.89	4.42	0.00221	0.050
12.91	18	6.00	4.5	0.00135	0.030	6.07	4.55	0.00137	0.030	6.09	4.57	0.00046	0.010
12.91	20.5	6.20	4.65	0.00093	0.020	6.23	4.67	0.00093	0.020	6.27	4.7	0.00188	0.040
12.91	23	6.24	4.68	0.00037	0.008	6.29	4.72	0.00038	0.008	6.33	4.75	0.00143	0.030
12.91	25.6	6.29	4.72	0.00052	0.011	6.33	4.75	0.00048	0.010	6.37	4.78	0.00048	0.010

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gb} = Wt. of grain collected at blower outlet; L_b = Blower loss

Replication-2

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c				44 mm Concave clearance, C_c				48 mm Concave clearance, C_c			
		W_{cf}	W_i	W_{gb}	L_b	W_{cf}	W_i	W_{gb}	L_b	W_{cf}	W_i	W_{gb}	L_b
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.63	4.22	0.00042	0.01	5.69	4.27	0.00043	0.01	5.76	4.32	0.00043	0.01
10.41	18	5.76	4.32	0.00052	0.012	5.77	4.33	0.00000	0.000	5.77	4.33	0.00000	0.000
10.41	20.5	6.05	4.54	0.00041	0.009	6.00	4.5	0.00041	0.009	6.07	4.55	0.00041	0.009
10.41	23	6.08	4.56	0.00046	0.010	6.07	4.55	0.00046	0.010	6.15	4.61	0.00046	0.010
10.41	25.6	6.16	4.62	0.00000	0.000	6.29	4.72	0.00000	0.000	6.33	4.75	0.00000	0.000
11.2	15.4	5.71	4.28	0.00086	0.020	5.75	4.31	0.00086	0.020	5.81	4.36	0.00087	0.020
11.2	18	5.89	4.42	0.00000	0.000	5.91	4.43	0.00000	0.000	5.88	4.41	0.00088	0.020
11.2	20.5	6.04	4.53	0.00054	0.012	6.16	4.62	0.00055	0.012	6.21	4.66	0.00056	0.012
11.2	23	6.17	4.63	0.00046	0.010	6.17	4.63	0.00046	0.010	6.25	4.69	0.00047	0.010
11.2	25.6	6.23	4.67	0.00000	0.000	6.28	4.71	0.00000	0.000	6.28	4.71	0.00000	0.000
11.92	15.4	5.76	4.32	0.00086	0.020	5.76	4.32	0.00086	0.020	5.75	4.31	0.00086	0.020
11.92	18	5.97	4.48	0.00054	0.012	6.03	4.52	0.00045	0.010	6.07	4.55	0.00091	0.020
11.92	20.5	6.21	4.66	0.00042	0.009	6.16	4.62	0.00042	0.009	6.24	4.68	0.00047	0.010
11.92	23	6.24	4.68	0.00047	0.010	6.28	4.71	0.00047	0.010	6.28	4.71	0.00047	0.010
11.92	25.6	6.27	4.7	0.00056	0.012	6.35	4.76	0.00057	0.012	6.37	4.78	0.00096	0.020
12.4	15.4	5.80	4.35	0.00087	0.020	5.80	4.35	0.00131	0.030	5.88	4.41	0.00132	0.030
12.4	18	5.97	4.48	0.00045	0.010	5.93	4.45	0.00045	0.010	6.03	4.52	0.00045	0.010
12.4	20.5	6.23	4.67	0.00047	0.010	6.25	4.69	0.00047	0.010	6.25	4.69	0.00047	0.010
12.4	23	6.25	4.69	0.00056	0.012	6.32	4.74	0.00095	0.020	6.33	4.75	0.00095	0.020
12.4	25.6	6.29	4.72	0.00042	0.009	6.39	4.79	0.00096	0.020	6.37	4.78	0.00096	0.020
12.91	15.4	5.81	4.36	0.00131	0.030	5.88	4.41	0.00132	0.030	5.89	4.42	0.00133	0.030
12.91	18	6.00	4.5	0.00045	0.010	6.08	4.56	0.00046	0.010	6.08	4.56	0.00091	0.020
12.91	20.5	6.20	4.65	0.00093	0.020	6.19	4.64	0.00093	0.020	6.28	4.71	0.00094	0.020
12.91	23	6.27	4.7	0.00056	0.012	6.28	4.71	0.00057	0.012	6.33	4.75	0.00048	0.010
12.91	25.6	6.40	4.8	0.00043	0.009	6.33	4.75	0.00095	0.020	6.39	4.79	0.00096	0.020

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gb} = Wt. of grain collected at blower outlet; L_b = Blower loss

Replication-3

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c				44 mm Concave clearance, C_c				48 mm Concave clearance, C_c			
		W_{cf}	W_i	W_{gb}	L_b	W_{cf}	W_i	W_{gb}	L_b	W_{cf}	W_i	W_{gb}	L_b
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.47	4.1	0.00082	0.02	5.61	4.21	0.00084	0.02	5.69	4.27	0.00085	0.02
10.41	18	5.80	4.35	0.00039	0.009	5.75	4.31	0.00043	0.010	5.80	4.35	0.00044	0.010
10.41	20.5	6.01	4.51	0.00036	0.008	6.01	4.51	0.00036	0.008	6.01	4.51	0.00036	0.008
10.41	23	6.04	4.53	0.00045	0.010	6.07	4.55	0.00046	0.010	6.15	4.61	0.00000	0.000
10.41	25.6	6.15	4.61	0.00000	0.000	6.28	4.71	0.00000	0.000	6.33	4.75	0.00000	0.000
11.2	15.4	5.65	4.24	0.00042	0.010	5.75	4.31	0.00043	0.010	5.80	4.35	0.00044	0.010
11.2	18	5.88	4.41	0.00044	0.010	5.89	4.42	0.00044	0.010	5.97	4.48	0.00179	0.040
11.2	20.5	6.03	4.52	0.00041	0.009	6.15	4.61	0.00041	0.009	6.15	4.61	0.00041	0.009
11.2	23	6.15	4.61	0.00046	0.010	6.20	4.65	0.00093	0.020	6.23	4.67	0.00093	0.020
11.2	25.6	6.20	4.65	0.00000	0.000	6.28	4.71	0.00000	0.000	6.28	4.71	0.00000	0.000
11.92	15.4	5.75	4.31	0.00172	0.040	5.75	4.31	0.00172	0.040	5.80	4.35	0.00174	0.040
11.92	18	5.89	4.42	0.00040	0.009	6.03	4.52	0.00000	0.000	6.03	4.52	0.00045	0.010
11.92	20.5	6.15	4.61	0.00037	0.008	6.20	4.65	0.00037	0.008	6.23	4.67	0.00047	0.010
11.92	23	6.20	4.65	0.00047	0.010	6.28	4.71	0.00047	0.010	6.33	4.75	0.00095	0.020
11.92	25.6	6.24	4.68	0.00042	0.009	6.33	4.75	0.00043	0.009	6.37	4.78	0.00143	0.030
12.4	15.4	5.76	4.32	0.00043	0.010	5.76	4.32	0.00259	0.060	5.83	4.37	0.00262	0.060
12.4	18	5.91	4.43	0.00089	0.020	5.97	4.48	0.00000	0.000	6.01	4.51	0.00000	0.000
12.4	20.5	6.15	4.61	0.00046	0.010	6.17	4.63	0.00093	0.020	6.23	4.67	0.00093	0.020
12.4	23	6.16	4.62	0.00042	0.009	6.28	4.71	0.00141	0.030	6.33	4.75	0.00143	0.030
12.4	25.6	6.27	4.7	0.00038	0.008	6.33	4.75	0.00143	0.030	6.37	4.78	0.00143	0.030
12.91	15.4	5.80	4.35	0.00261	0.060	5.88	4.41	0.00265	0.060	5.89	4.42	0.00265	0.060
12.91	18	6.01	4.51	0.00090	0.020	6.07	4.55	0.00091	0.020	6.09	4.57	0.00183	0.040
12.91	20.5	6.20	4.65	0.00140	0.030	6.23	4.67	0.00140	0.030	6.27	4.7	0.00047	0.010
12.91	23	6.24	4.68	0.00042	0.009	6.33	4.75	0.00043	0.009	6.33	4.75	0.00095	0.020
12.91	25.6	6.29	4.72	0.00038	0.008	6.37	4.78	0.00143	0.030	6.37	4.78	0.00143	0.030

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gb} = Wt. of grain collected at blower outlet; L_b = Blower loss

Replication-4

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c				44 mm Concave clearance, C_c				48 mm Concave clearance, C_c			
		W_{cf}	W_i	W_{gb}	L_b	W_{cf}	W_i	W_{gb}	L_b	W_{cf}	W_i	W_{gb}	L_b
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.60	4.2	0.00168	0.04	5.72	4.29	0.00172	0.04	5.80	4.35	0.00174	0.04
10.41	18	5.73	4.3	0.00047	0.011	5.80	4.35	0.00131	0.030	5.80	4.35	0.00131	0.030
10.41	20.5	6.00	4.5	0.00054	0.012	6.01	4.51	0.00054	0.012	6.08	4.56	0.00055	0.012
10.41	23	6.00	4.5	0.00045	0.010	6.12	4.59	0.00046	0.010	6.13	4.6	0.00184	0.040
10.41	25.6	6.13	4.6	0.00000	0.000	6.27	4.7	0.00000	0.000	6.33	4.75	0.00000	0.000
11.2	15.4	5.67	4.25	0.00213	0.050	5.80	4.35	0.00218	0.050	5.85	4.39	0.00220	0.050
11.2	18	5.87	4.4	0.00132	0.030	5.93	4.45	0.00134	0.030	5.97	4.48	0.00224	0.050
11.2	20.5	6.07	4.55	0.00050	0.011	6.15	4.61	0.00051	0.011	6.16	4.62	0.00051	0.011
11.2	23	6.13	4.6	0.00046	0.010	6.20	4.65	0.00093	0.020	6.23	4.67	0.00093	0.020
11.2	25.6	6.20	4.65	0.00000	0.000	6.29	4.72	0.00000	0.000	6.28	4.71	0.00000	0.000
11.92	15.4	5.73	4.3	0.00215	0.050	5.84	4.38	0.00219	0.050	5.89	4.42	0.00221	0.050
11.92	18	5.93	4.45	0.00049	0.011	6.01	4.51	0.00180	0.040	6.07	4.55	0.00228	0.050
11.92	20.5	6.13	4.6	0.00055	0.012	6.20	4.65	0.00056	0.012	6.23	4.67	0.00047	0.010
11.92	23	6.20	4.65	0.00047	0.010	6.28	4.71	0.00047	0.010	6.29	4.72	0.00094	0.020
11.92	25.6	6.23	4.67	0.00051	0.011	6.37	4.78	0.00053	0.011	6.31	4.73	0.00095	0.020
12.4	15.4	5.76	4.32	0.00216	0.050	5.83	4.37	0.00087	0.020	5.91	4.43	0.00089	0.020
12.4	18	5.96	4.47	0.00179	0.040	5.97	4.48	0.00179	0.040	6.00	4.5	0.00180	0.040
12.4	20.5	6.16	4.62	0.00046	0.010	6.24	4.68	0.00094	0.020	6.23	4.67	0.00093	0.020
12.4	23	6.21	4.66	0.00051	0.011	6.28	4.71	0.00047	0.010	6.31	4.73	0.00047	0.010
12.4	25.6	6.27	4.7	0.00056	0.012	6.37	4.78	0.00096	0.020	6.35	4.76	0.00095	0.020
12.91	15.4	5.80	4.35	0.00087	0.020	5.87	4.4	0.00088	0.020	5.93	4.45	0.00089	0.020
12.91	18	6.00	4.5	0.00090	0.020	6.07	4.55	0.00091	0.020	6.09	4.57	0.00229	0.050
12.91	20.5	6.20	4.65	0.00047	0.010	6.23	4.67	0.00047	0.010	6.27	4.7	0.00235	0.050
12.91	23	6.24	4.68	0.00051	0.011	6.29	4.72	0.00052	0.011	6.33	4.75	0.00095	0.020
12.91	25.6	6.29	4.72	0.00057	0.012	6.33	4.75	0.00095	0.020	6.43	4.82	0.00096	0.020

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gb} = Wt. of grain collected at blower outlet; L_b = Blower loss

Table B-2.6 Experimental Data on Visible Grain Damage
Replication-1

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c				44 mm Concave clearance, C_c				48 mm Concave clearance, C_c			
		W_{cf}	W_i	W_{dg}	L_{gd}	W_{cf}	W_i	W_{dg}	L_{gd}	W_{cf}	W_i	W_{dg}	L_{gd}
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.60	4.2	0.0869	2.07	5.69	4.27	0.0880	2.06	5.75	4.31	0.0720	1.67
10.41	18	5.73	4.3	0.1071	2.49	5.76	4.32	0.1063	2.46	5.80	4.35	0.0922	2.12
10.41	20.5	6.00	4.5	0.1422	3.16	6.01	4.51	0.1263	2.8	6.07	4.55	0.1183	2.60
10.41	23	6.00	4.5	0.1674	3.72	6.04	4.53	0.1581	3.49	6.13	4.6	0.1527	3.32
10.41	25.6	6.13	4.6	0.2001	4.35	6.27	4.7	0.1960	4.17	6.33	4.75	0.1933	4.07
11.2	15.4	5.67	4.25	0.0901	2.12	5.73	4.3	0.0886	2.06	5.80	4.35	0.0740	1.7
11.2	18	5.87	4.4	0.1219	2.77	5.93	4.45	0.1113	2.5	5.97	4.48	0.0986	2.2
11.2	20.5	6.07	4.55	0.1538	3.38	6.13	4.6	0.1366	2.97	6.16	4.62	0.1247	2.7
11.2	23	6.13	4.6	0.1757	3.82	6.20	4.65	0.1660	3.57	6.23	4.67	0.1578	3.38
11.2	25.6	6.20	4.65	0.2055	4.42	6.27	4.7	0.1998	4.25	6.29	4.72	0.1935	4.1
11.92	15.4	5.73	4.3	0.0942	2.19	5.73	4.3	0.0920	2.14	5.80	4.35	0.0783	1.8
11.92	18	5.93	4.45	0.1291	2.9	6.00	4.5	0.1215	2.7	6.07	4.55	0.1047	2.3
11.92	20.5	6.13	4.6	0.1610	3.5	6.20	4.65	0.1497	3.22	6.23	4.67	0.1308	2.8
11.92	23	6.20	4.65	0.1855	3.99	6.27	4.7	0.1748	3.72	6.29	4.72	0.1624	3.44
11.92	25.6	6.23	4.67	0.2102	4.5	6.33	4.75	0.2014	4.24	6.37	4.78	0.1993	4.17
12.4	15.4	5.76	4.32	0.1011	2.34	5.83	4.37	0.0918	2.1	5.87	4.4	0.0792	1.8
12.4	18	5.96	4.47	0.1301	2.91	5.97	4.48	0.1277	2.85	6.00	4.5	0.1080	2.4
12.4	20.5	6.16	4.62	0.1631	3.53	6.20	4.65	0.1516	3.26	6.23	4.67	0.1406	3.01
12.4	23	6.21	4.66	0.1962	4.21	6.27	4.7	0.1795	3.82	6.31	4.73	0.1651	3.49
12.4	25.6	6.27	4.7	0.2270	4.83	6.33	4.75	0.2043	4.3	6.37	4.78	0.1969	4.12
12.91	15.4	5.80	4.35	0.1057	2.43	5.87	4.4	0.0911	2.07	5.89	4.42	0.0796	1.8
12.91	18	6.00	4.5	0.1359	3.02	6.07	4.55	0.1210	2.66	6.09	4.57	0.1197	2.62
12.91	20.5	6.20	4.65	0.1665	3.58	6.23	4.67	0.1541	3.3	6.27	4.7	0.1504	3.2
12.91	23	6.24	4.68	0.1947	4.16	6.29	4.72	0.1836	3.89	6.33	4.75	0.1767	3.72
12.91	25.6	6.29	4.72	0.2384	5.05	6.33	4.75	0.2161	4.55	6.37	4.78	0.1965	4.11

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gd} = Wt of broken grain; L_{gd} = Grain damage

Replication-2

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c				44 mm Concave clearance, C_c				48 mm Concave clearance, C_c			
		W_{cf}	W_i	W_{gd}	L_{gd}	W_{cf}	W_i	W_{gd}	L_{gd}	W_{cf}	W_i	W_{gd}	L_{gd}
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.63	4.22	0.0869	2.06	5.69	4.27	0.0863	2.02	5.76	4.32	0.0756	1.75
10.41	18	5.76	4.32	0.1128	2.61	5.77	4.33	0.1052	2.43	5.77	4.33	0.0979	2.26
10.41	20.5	6.05	4.54	0.1462	3.22	6.00	4.5	0.1274	2.83	6.07	4.55	0.1247	2.74
10.41	23	6.08	4.56	0.1751	3.84	6.07	4.55	0.1602	3.52	6.15	4.61	0.1577	3.42
10.41	25.6	6.16	4.62	0.2014	4.36	6.29	4.72	0.1978	4.19	6.33	4.75	0.1929	4.06
11.2	15.4	5.71	4.28	0.0924	2.16	5.75	4.31	0.0905	2.1	5.81	4.36	0.0794	1.82
11.2	18	5.89	4.42	0.1229	2.78	5.91	4.43	0.1170	2.64	5.88	4.41	0.1023	2.32
11.2	20.5	6.04	4.53	0.1545	3.41	6.16	4.62	0.1409	3.05	6.21	4.66	0.1295	2.78
11.2	23	6.17	4.63	0.1773	3.83	6.17	4.63	0.1708	3.69	6.25	4.69	0.1623	3.46
11.2	25.6	6.23	4.67	0.2055	4.4	6.28	4.71	0.1964	4.17	6.28	4.71	0.1959	4.16
11.92	15.4	5.76	4.32	0.0933	2.16	5.76	4.32	0.0916	2.12	5.75	4.31	0.0802	1.86
11.92	18	5.97	4.48	0.1268	2.83	6.03	4.52	0.1257	2.78	6.07	4.55	0.1092	2.4
11.92	20.5	6.21	4.66	0.1626	3.49	6.16	4.62	0.1497	3.24	6.24	4.68	0.1338	2.86
11.92	23	6.24	4.68	0.1891	4.04	6.28	4.71	0.1771	3.76	6.28	4.71	0.1658	3.52
11.92	25.6	6.27	4.7	0.2143	4.56	6.35	4.76	0.2033	4.27	6.37	4.78	0.2012	4.21
12.4	15.4	5.80	4.35	0.1040	2.39	5.80	4.35	0.0922	2.12	5.88	4.41	0.0820	1.86
12.4	18	5.97	4.48	0.1322	2.95	5.93	4.45	0.1242	2.79	6.03	4.52	0.1103	2.44
12.4	20.5	6.23	4.67	0.1653	3.54	6.25	4.69	0.1520	3.24	6.25	4.69	0.1449	3.09
12.4	23	6.25	4.69	0.1965	4.19	6.32	4.74	0.1754	3.7	6.33	4.75	0.1715	3.61
12.4	25.6	6.29	4.72	0.2275	4.82	6.39	4.79	0.2156	4.5	6.37	4.78	0.1998	4.18
12.91	15.4	5.81	4.36	0.1086	2.49	5.88	4.41	0.0926	2.1	5.89	4.42	0.0831	1.88
12.91	18	6.00	4.5	0.1373	3.05	6.08	4.56	0.1231	2.7	6.08	4.56	0.1176	2.58
12.91	20.5	6.20	4.65	0.1655	3.56	6.19	4.64	0.1545	3.33	6.28	4.71	0.1535	3.26
12.91	23	6.27	4.7	0.1946	4.14	6.28	4.71	0.1851	3.93	6.33	4.75	0.1748	3.68
12.91	25.6	6.40	4.8	0.2400	5.00	6.33	4.75	0.2180	4.59	6.39	4.79	0.1988	4.15

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gd} = Wt of broken grain; L_{gd} = Grain damage

Replication-3

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c				44 mm Concave clearance, C_c				48 mm Concave clearance, C_c			
		W_{cf}	W_i	W_{dg}	L_{gd}	W_{cf}	W_i	W_{dg}	L_{gd}	W_{cf}	W_i	W_{dg}	L_{gd}
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.47	4.1	0.0882	2.15	5.61	4.21	0.0863	2.05	5.69	4.27	0.0722	1.69
10.41	18	5.80	4.35	0.1114	2.56	5.75	4.31	0.1056	2.45	5.80	4.35	0.0931	2.14
10.41	20.5	6.01	4.51	0.1416	3.14	6.01	4.51	0.1281	2.84	6.01	4.51	0.1186	2.63
10.41	23	6.04	4.53	0.1699	3.75	6.07	4.55	0.1583	3.48	6.15	4.61	0.1540	3.34
10.41	25.6	6.15	4.61	0.1992	4.32	6.28	4.71	0.0966	2.05	6.33	4.75	0.1914	4.03
11.2	15.4	5.65	4.24	0.0890	2.1	5.75	4.31	0.0892	2.07	5.80	4.35	0.0753	1.73
11.2	18	5.88	4.41	0.1230	2.79	5.89	4.42	0.1118	2.53	5.97	4.48	0.0999	2.23
11.2	20.5	6.03	4.52	0.1546	3.42	6.15	4.61	0.1378	2.99	6.15	4.61	0.1254	2.72
11.2	23	6.15	4.61	0.1775	3.85	6.20	4.65	0.1669	3.59	6.23	4.67	0.1588	3.4
11.2	25.6	6.20	4.65	0.2041	4.39	6.28	4.71	0.2011	4.27	6.28	4.71	0.1917	4.07
11.92	15.4	5.75	4.31	0.0944	2.19	5.75	4.31	0.0905	2.1	5.80	4.35	0.0779	1.79
11.92	18	5.89	4.42	0.1255	2.84	6.03	4.52	0.1248	2.76	6.03	4.52	0.1049	2.32
11.92	20.5	6.15	4.61	0.1627	3.53	6.20	4.65	0.1525	3.28	6.23	4.67	0.1312	2.81
11.92	23	6.20	4.65	0.1865	4.01	6.28	4.71	0.1757	3.73	6.33	4.75	0.1644	3.46
11.92	25.6	6.24	4.68	0.2101	4.49	6.33	4.75	0.2019	4.25	6.37	4.78	0.1979	4.14
12.4	15.4	5.76	4.32	0.0998	2.31	5.76	4.32	0.0903	2.09	5.83	4.37	0.0791	1.81
12.4	18	5.91	4.43	0.1294	2.92	5.97	4.48	0.1259	2.81	6.01	4.51	0.1073	2.38
12.4	20.5	6.15	4.61	0.1637	3.55	6.17	4.63	0.1537	3.32	6.23	4.67	0.1410	3.02
12.4	23	6.16	4.62	0.1931	4.18	6.28	4.71	0.1780	3.78	6.33	4.75	0.1672	3.52
12.4	25.6	6.27	4.7	0.2256	4.8	6.33	4.75	0.2185	4.6	6.37	4.78	0.1965	4.11
12.91	15.4	5.80	4.35	0.1066	2.45	5.88	4.41	0.0931	2.11	5.89	4.42	0.0804	1.82
12.91	18	6.01	4.51	0.1371	3.04	6.07	4.55	0.1183	2.6	6.09	4.57	0.1206	2.64
12.91	20.5	6.20	4.65	0.1651	3.55	6.23	4.67	0.1560	3.34	6.27	4.7	0.1499	3.19
12.91	23	6.24	4.68	0.1961	4.19	6.33	4.75	0.1853	3.9	6.33	4.75	0.1781	3.75
12.91	25.6	6.29	4.72	0.2384	5.05	6.37	4.78	0.2180	4.56	6.37	4.78	0.1969	4.12

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gd} = Wt of broken grain; L_{gd} = Grain damage

Replication-4

Peripheral speed, u	moisture content, M_c	40 mm Concave clearance, C_c				44 mm Concave clearance, C_c				48 mm Concave clearance, C_c			
		W_{cf}	W_i	W_{dg}	L_{gd}	W_{cf}	W_i	W_{dg}	L_{gd}	W_{cf}	W_i	W_{dg}	L_{gd}
m/s	%	kg	kg	kg	%	kg	kg	kg	%	kg	kg	kg	%
10.41	15.4	5.60	4.2	0.0907	2.16	5.72	4.29	0.0871	2.03	5.80	4.35	0.0744	1.71
10.41	18	5.73	4.3	0.1041	2.42	5.80	4.35	0.1053	2.42	5.80	4.35	0.0953	2.19
10.41	20.5	6.00	4.5	0.1458	3.24	6.01	4.51	0.1267	2.81	6.08	4.56	0.1218	2.67
10.41	23	6.00	4.5	0.1733	3.85	6.12	4.59	0.1611	3.51	6.13	4.6	0.1550	3.37
10.41	25.6	6.13	4.6	0.1992	4.33	6.27	4.7	0.1955	4.16	6.33	4.75	0.1924	4.05
11.2	15.4	5.67	4.25	0.0927	2.18	5.80	4.35	0.0909	2.09	5.85	4.39	0.0773	1.76
11.2	18	5.87	4.4	0.1170	2.66	5.93	4.45	0.1161	2.61	5.97	4.48	0.1012	2.26
11.2	20.5	6.07	4.55	0.1542	3.39	6.15	4.61	0.1397	3.03	6.16	4.62	0.1266	2.74
11.2	23	6.13	4.6	0.1776	3.86	6.20	4.65	0.1707	3.67	6.23	4.67	0.1597	3.42
11.2	25.6	6.20	4.65	0.2060	4.43	6.29	4.72	0.1964	4.16	6.28	4.71	0.1945	4.13
11.92	15.4	5.73	4.3	0.0937	2.18	5.84	4.38	0.0946	2.16	5.89	4.42	0.0809	1.83
11.92	18	5.93	4.45	0.1277	2.87	6.01	4.51	0.1227	2.72	6.07	4.55	0.1069	2.35
11.92	20.5	6.13	4.6	0.1619	3.52	6.20	4.65	0.1516	3.26	6.23	4.67	0.1322	2.83
11.92	23	6.20	4.65	0.1841	3.96	6.28	4.71	0.1766	3.75	6.29	4.72	0.1643	3.48
11.92	25.6	6.23	4.67	0.2116	4.53	6.37	4.78	0.2046	4.28	6.31	4.73	0.1982	4.19
12.4	15.4	5.76	4.32	0.1020	2.36	5.83	4.37	0.0931	2.13	5.91	4.43	0.0811	1.83
12.4	18	5.96	4.47	0.1314	2.94	5.97	4.48	0.1286	2.87	6.00	4.5	0.1089	2.42
12.4	20.5	6.16	4.62	0.1635	3.54	6.24	4.68	0.1544	3.3	6.23	4.67	0.1424	3.05
12.4	23	6.21	4.66	0.1967	4.22	6.28	4.71	0.1837	3.9	6.31	4.73	0.1679	3.55
12.4	25.6	6.27	4.7	0.2251	4.79	6.37	4.78	0.2008	4.2	6.35	4.76	0.1975	4.15
12.91	15.4	5.80	4.35	0.1074	2.47	5.87	4.4	0.0915	2.08	5.93	4.45	0.0819	1.84
12.91	18	6.00	4.5	0.1355	3.01	6.07	4.55	0.1256	2.76	6.09	4.57	0.1188	2.6
12.91	20.5	6.20	4.65	0.1669	3.59	6.23	4.67	0.1546	3.31	6.27	4.7	0.1518	3.23
12.91	23	6.24	4.68	0.1961	4.19	6.29	4.72	0.1850	3.92	6.33	4.75	0.1758	3.7
12.91	25.6	6.29	4.72	0.2388	5.06	6.33	4.75	0.2176	4.58	6.43	4.82	0.1991	4.13

W_{cf} = Total wt. of cob fed at hopper; W_i = Wt of total sample feed at hopper; W_{gd} = Wt of broken grain; L_{gd} = Grain damage

APPENDIX-C

STATISTICAL ANALYSIS

C-1 Second Degree Polynomial Coefficients and their R^2 Values

Table C-1 Empirical Coefficients to Predict Dependent Parameters against Moisture Content for different Peripheral Speeds and Concave Clearances (Fig. 6.1 to Fig. 6.6)

- **Dehusking Efficiency (Fig. 6.1)**

$$E_d = aM_c^2 + bM_c + c$$

Cylinder speed m/s	Concave clearance mm	a	b	c	R^2
10.41	40	0.0041	-0.1767	101.73	0.8995
11.2	40	0.0047	-0.1955	101.89	0.8997
11.92	40	0.0052	-0.2135	102.04	0.8952
12.4	40	0.0049	-0.2007	101.92	0.9405
12.91	40	0.0046	-0.1886	101.82	0.9633
10.41	44	0.0155	-0.5443	103.69	0.9787
11.2	44	0.0172	-0.6323	104.84	0.9699
11.92	44	0.0185	-0.704	105.87	0.9549
12.4	44	0.0145	-0.5499	104.59	0.9351
12.91	44	0.0101	-0.3941	103.44	0.8495
10.41	48	0.0072	-0.3026	101.71	0.9221
11.2	48	0.0096	-0.3534	101.98	0.9568
11.92	48	0.013	-0.4403	102.57	0.9832
12.4	48	0.0117	-0.4167	102.77	0.9734
12.91	48	0.0131	-0.5129	104.28	0.9219

- **Shelling Efficiency (Fig. 6.2)**

$$E_s = aM_c^2 + bM_c + c$$

Cylinder speed m/s	Concave clearance mm	a	b	c	R^2
10.41	40	0.0134	-0.5843	105.55	0.9479
11.2	40	0.0096	-0.4266	104.06	0.9481
11.92	40	0.097	-0.4104	103.82	0.9309
12.4	40	0.0094	-0.3974	103.76	0.9312
12.91	40	0.0097	-0.4084	103.9	0.9565
10.41	44	0.0096	-0.4996	104.35	0.9899
11.2	44	0.0074	-0.3896	103.39	0.9888
11.92	44	0.0058	-0.2949	102.54	0.9893
12.4	44	0.0072	-0.3202	102.61	0.9001
12.91	44	0.0056	-0.2504	102.02	0.8443
10.41	48	0.0164	-0.8463	107.61	0.9922
11.2	48	0.0201	-0.9296	108.29	0.9304
11.92	48	0.028	-1.1668	110.24	0.9127
12.4	48	0.018	-0.7693	106.68	0.9264
12.91	48	0.0084	-0.3898	103.31	0.9728

- **Cleaning Efficiency (Fig. 6.3)**

$$E_c = aM_c^2 + bM_c + c$$

Cylinder speed m/s	Concave clearance mm	a	b	c	R^2
10.41	40	0.0002	-0.0121	99.486	0.9815
11.2	40	0.0001	-0.0072	99.454	0.9577
11.92	40	-0.0001	0.0017	99.409	0.9577
12.4	40	-0.0003	0.0098	99.374	0.9529
12.91	40	0.0001	-0.0095	99.623	0.9854
10.41	44	-0.0003	0.0091	99.29	0.9624
11.2	44	0.0004	-0.0219	99.623	0.9953
11.92	44	0	-0.0039	99.481	0.9999
12.4	44	-0.0001	-0.0007	99.497	0.9854
12.91	44	-0.0002	0.0049	99.495	0.9516
10.41	48	-0.0001	0.0017	99.369	0.9577
11.2	48	-0.0004	0.014	99.308	99.308
11.92	48	0.0003	-0.0177	99.648	0.9624
12.4	48	-0.0002	0.0058	99.443	0.9815
12.91	48	-7E-15	-0.0039	99.591	0.9999

- **Thrower Loss (Fig. 6.4)**

$$L_t = aM_c^2 + bM_c + c$$

Cylinder speed m/s	Concave clearance mm	a	b	c	R^2
10.41	40	0.0102	-0.4828	5.8464	0.984
11.2	40	0.0146	-0.6716	7.9725	0.9761
11.92	40	0.0199	-0.9011	10.499	0.9715
12.4	40	0.026	-1.0166	11.792	0.9567
12.91	40	0.0264	-1.1713	13.43	0.9639
10.41	44	0.0126	-0.5936	7.2163	0.9818
11.2	44	0.0157	-0.7298	8.8156	0.9615
11.92	44	0.0196	-0.8934	10.57	0.9683
12.4	44	0.028	-1.2323	14.039	0.9552
12.91	44	0.0369	-1.596	17.766	0.954
10.41	48	0.0107	-0.5014	5.9796	0.982
11.2	48	0.0125	-0.5855	7.0102	0.9782
11.92	48	0.0148	-0.6845	8.1541	0.9783
12.4	48	0.0178	-0.8008	9.2773	0.9698
12.91	48	0.0205	-0.9085	10.334	0.9505

- **Blower Loss (Fig. 6.5)**

$$L_b = aM_c^2 + bM_c + c$$

Cylinder speed m/s	Concave clearance mm	a	b	c	R^2
10.41	40	0.0002	-0.0113	0.1498	0.8157
11.2	40	0.0001	-0.0072	0.1145	0.9577
11.92	40	0.0004	-0.0195	0.2248	0.8626
12.4	40	0.0003	-0.0154	0.1894	0.9809
12.91	40	0.0003	-0.0163	0.211	0.9272
10.41	44	0.0001	-0.0072	0.1145	0.9577
11.2	44	0.000003	-0.0022	0.0632	0.6977
11.92	44	0.0003	-0.0154	0.1894	0.9809
12.4	44	0.0001	-0.0195	0.2348	0.8626
12.91	44	0.0005	-0.0245	0.286	0.8967
10.41	48	-0.000003	-0.0022	0.0632	0.6977
11.2	48	-0.0001	0.0019	0.0279	0.7337
11.92	48	0.0003	-0.0144	0.1779	0.5433
12.4	48	0.0004	-0.0195	0.2348	0.8626
12.91	48	0.0001	-0.0065	0.1136	0.9192

- **Grain Damage (Fig. 6.6)**

$$L_{gd} = aM_c^2 + bM_c + c$$

Cylinder speed m/s	Concave clearance mm	a	b	c	R^2
10.41	40	0.0023	0.1307	-0.4911	0.9957
11.2	40	-0.0018	0.2973	-2.0001	0.9997
11.92	40	-0.0052	0.4435	-3.4128	0.9995
12.4	40	0.0012	0.1946	-0.942	0.9995
12.91	40	0.0072	-0.0477	1.5068	0.9984
10.41	44	0.0094	-0.1737	2.5007	0.998
11.2	44	0.0039	0.0491	0.3995	0.9989
11.92	44	-0.0022	0.2967	-1.9123	0.9997
12.4	44	-0.0019	0.2954	-1.9602	0.9965
12.91	44	0.001	0.203	-1.2769	0.9998
10.41	48	0.0068	-0.0461	0.8185	0.9989
11.2	48	0.0068	-0.0446	0.8512	0.9993
11.92	48	0.006	-0.0154	0.6551	0.9995
12.4	48	-0.0012	0.2756	-2.1386	0.9993
12.91	48	-0.0089	0.5906	-5.1302	0.9998

C-2 Mean Values Showing Interaction Effects of Independent Parameters

Table C-2.1 Mean Values Showing Interaction Effect (Two Variables) of Cylinder Speed, Moisture Content and Concave Clearance on Dehusking Efficiency of Maize Dehusker-cum-Sheller.

Cylinder speed, u, m/s	Moisture content, M_c, %					Mean
	15.4	18.0	20.5	23.0	25.6	
10.41	99.33	99.16	99.08	99.29	99.48	99.27
11.20	99.31	99.27	99.18	99.43	99.96	99.43
11.92	99.41	99.36	99.29	99.58	99.91	99.51
12.40	99.55	99.48	99.41	99.66	99.90	99.60
12.91	99.73	99.64	99.56	99.66	99.89	99.70
Mean	99.46	99.38	99.30	99.53	99.83	

Cylinder speed, u, m/s	Concave Clearance, C_c, mm			Mean
	40	44	48	
10.41	99.90	99.28	98.63	99.27
11.20	99.91	99.34	98.88	99.38
11.92	99.93	99.46	99.15	99.51
12.40	99.93	99.59	99.28	99.60
12.91	99.95	99.72	99.43	99.70
Mean	99.92	99.48	99.07	

Moisture content, M_c, %	Concave clearance, C_c, mm			Mean
	40	44	48	
15.4	99.99	99.41	99.00	99.46
18.0	99.92	99.29	98.94	99.38
20.5	99.84	99.20	98.87	99.30
23.0	99.90	99.54	99.14	99.53
25.6	99.97	99.94	99.41	99.78
Mean	99.92	99.48	99.07	

LSD for	Significance level	
	0.01	0.05
u	0.0324	0.0247
M_c	0.0324	0.0247
C_c	0.0251	0.0191
u x M_c	0.0725	0.0552
u x C_c	0.0561	0.0427
M_c x C_c	0.0561	0.0427

Table C-2.2 Mean Values Showing Interaction Effect (Two Variables) of Cylinder Speed, Moisture Content and Concave Clearance on Shelling Efficiency of Maize Dehusker-cum-Sheller.

Cylinder speed, u, m/s	Moisture content, M_c, %					Mean
	15.4	18.0	20.5	23.0	25.6	
10.41	99.03	98.57	98.13	98.02	97.99	98.35
11.20	99.19	98.87	98.44	98.44	98.44	98.68
11.92	98.44	98.44	98.44	98.44	98.44	98.44
12.40	98.44	98.44	98.44	98.44	98.44	98.44
12.91	98.44	98.44	98.44	98.44	98.44	98.44
Mean	98.71	98.55	98.38	98.36	98.35	

Cylinder speed, u, m/s	Concave Clearance, C_c, mm			Mean
	40	44	48	
10.41	99.38	98.29	97.38	98.35
11.20	99.46	98.62	97.94	98.68
11.92	99.60	99.05	98.45	99.03
12.40	99.67	99.21	98.70	99.19
12.91	99.73	98.94	98.96	99.21
Mean	99.57	98.82	98.29	

Moisture content, M_c, %	Concave clearance, C_c, mm			Mean
	40	44	48	
15.4	99.80	99.25	98.88	99.31
18.0	99.59	99.07	98.44	99.03
20.5	99.38	98.82	97.94	98.71
23.0	99.48	98.48	98.03	98.67
25.6	99.59	98.48	98.13	98.73
Mean	99.57	98.82	98.29	

LSD for	Significance level	
	0.01	0.05
u	0.1056	0.0804
M_c	0.1056	0.0804
C_c	0.0816	0.0621
u x M_c	0.2361	0.1796
u x C_c	0.1829	0.1391
M_c x C_c	0.1829	0.1391

Table C-2.3 Mean Values Showing Interaction Effect (Two Variables) of Cylinder Speed, Moisture Content and Concave Clearance on Cleaning Efficiency of Maize Dehusker-cum-Sheller.

Cylinder speed, u, m/s	Moisture content, M_c, %					Mean
	15.4	18.0	20.5	23.0	25.6	
10.41	99.36	99.35	99.34	99.33	99.32	99.34
11.20	99.39	99.38	99.37	99.37	99.36	99.37
11.92	99.36	99.36	99.36	99.36	99.36	99.36
12.40	99.36	99.36	99.36	99.36	99.36	99.36
12.91	99.36	99.36	99.36	99.36	99.36	99.36
Mean	99.36	99.36	99.36	99.35	99.35	

Cylinder speed, u, m/s	Concave Clearance, C_c, mm			Mean
	40	44	48	
10.41	99.33	99.33	99.36	99.34
11.20	99.35	99.36	99.41	99.37
11.92	99.40	99.40	99.43	99.41
12.40	99.43	99.43	99.43	99.43
12.91	99.43	99.43	99.43	99.43
Mean	99.39	99.39	99.41	

Moisture content, M_c, %	Concave clearance, C_c, mm			Mean
	40	44	48	
15.4	99.42	99.43	99.45	99.43
18.0	99.41	99.42	99.44	99.42
20.5	99.40	99.41	99.43	99.41
23.0	99.39	99.39	99.42	99.40
25.6	99.38	99.39	99.41	99.39
Mean	99.40	99.41	99.43	

LSD for	Significance level	
	0.01	0.05
u	0.0120	0.0091
M_c	0.0120	0.0091
C_c	0.0095	0.0072
u x M_c	0.0273	0.0208
u x C_c	0.0211	0.0161
M_c x C_c	0.0470	0.0358

Table C-2.4 Mean Values Showing Interaction Effect (Two Variables) of Cylinder Speed, Moisture Content and Concave Clearance on Thrower loss of Maize Dehusker-cum-Sheller.

Cylinder speed, u, m/s	Moisture content, M_c, %					Mean
	15.4	18.0	20.5	23.0	25.6	
10.41	0.89	0.54	0.21	0.20	0.20	0.41
11.20	1.10	0.70	0.26	0.29	0.32	0.53
11.92	1.29	0.81	0.32	0.38	0.45	0.65
12.40	1.44	0.88	0.32	0.46	0.60	0.74
12.91	1.58	0.92	0.32	0.53	0.75	0.82
Mean	1.26	0.77	0.28	0.37	0.46	

Cylinder speed, u, m/s	Concave Clearance, C_c, mm			Mean
	40	44	48	
10.41	0.38	0.52	0.32	0.41
11.20	0.53	0.64	0.43	0.53
11.92	0.66	0.75	0.54	0.65
12.40	0.76	0.90	0.55	0.74
12.91	0.84	1.05	0.58	0.82
Mean	0.63	0.77	0.48	

Moisture content, M_c, %	Concave clearance, C_c, mm			Mean
	40	44	48	
15.4	1.27	1.48	1.03	1.26
18.0	0.78	0.91	0.62	0.77
20.5	0.29	0.36	0.20	0.28
23.0	0.37	0.49	0.26	0.37
25.6	0.46	0.62	0.31	0.46
Mean	0.63	0.77	0.48	

LSD for	Significance level	
	0.01	0.05
u	0.0135	0.0103
M_c	0.0135	0.0103
C_c	0.0106	0.0080
u x M_c	0.0306	0.0233
u x C_c	0.0237	0.0180
M_c x C_c	0.0237	0.0180

Table C-2.5 Mean Values Showing Interaction Effect (Two Variables) of Cylinder Speed, Moisture Content and Concave Clearance on Blower loss of Maize Dehusker-cum-Sheller.

Cylinder speed, u, m/s	Moisture content, M_c, %					Mean
	15.4	18.0	20.5	23.0	25.6	
10.41	0.03	0.02	0.01	0.01	0.00	0.01
11.20	0.03	0.02	0.01	0.02	0.00	0.02
11.92	0.03	0.02	0.01	0.01	0.01	0.02
12.40	0.04	0.02	0.02	0.02	0.02	0.02
12.91	0.04	0.02	0.02	0.01	0.02	0.02
Mean	0.03	0.02	0.01	0.01	0.01	

Cylinder speed, u, m/s	Concave Clearance, C_c, mm			Mean
	40	44	48	
10.41	0.01	0.01	0.02	0.01
11.20	0.01	0.02	0.02	0.02
11.92	0.01	0.02	0.02	0.02
12.40	0.02	0.02	0.02	0.02
12.91	0.02	0.02	0.03	0.02
Mean	0.02	0.02	0.02	

Moisture content, M_c, %	Concave clearance, C_c, mm			Mean
	40	44	48	
15.4	0.03	0.03	0.03	0.03
18.0	0.02	0.02	0.03	0.02
20.5	0.01	0.01	0.02	0.01
23.0	0.01	0.01	0.02	0.01
25.6	0.01	0.01	0.01	0.01
Mean	0.02	0.02	0.02	

LSD for	Significance level	
	0.01	0.05
u	0.0051	0.0039
M_c	0.0051	0.0039
C_c	0.0040	0.0030
u x M_c	0.0117	0.0089
u x C_c	0.0091	0.0069
M_c x C_c	0.0091	0.0069

Table C-2.6 Mean Values Showing Interaction Effect (Two Variables) of Cylinder Speed, Moisture Content and Concave Clearance on Grain Damage of Maize Dehusker-cum-Sheller.

Cylinder speed, u, m/s	Moisture content, M_c, %					Mean
	15.4	18.0	20.5	23.0	25.6	
10.41	1.95	2.38	2.89	3.55	4.01	2.96
11.20	1.99	2.52	3.05	3.63	4.25	3.09
11.92	2.04	2.65	3.20	3.74	4.32	3.19
12.40	2.10	2.72	3.29	3.85	4.45	3.28
12.91	2.13	2.77	3.37	3.93	4.58	3.36
Mean	2.04	2.61	3.16	3.74	4.32	

Cylinder speed, u, m/s	Concave Clearance, C_c, mm			Mean
	40	44	48	
10.41	3.19	2.89	2.79	2.96
11.20	3.31	3.10	2.85	3.09
11.92	3.41	3.22	2.93	3.19
12.40	3.57	3.28	2.99	3.28
12.91	3.65	3.31	3.10	3.36
Mean	3.43	3.16	2.93	

Moisture content, M_c, %	Concave clearance, C_c, mm			Mean
	40	44	48	
15.4	2.25	2.09	1.79	2.04
18.0	2.82	2.65	2.36	2.61
20.5	3.44	3.14	2.90	3.16
23.0	4.00	3.72	3.50	3.74
25.6	4.62	4.22	4.12	4.32
Mean	3.43	3.16	2.93	

LSD for	Significance level	
	0.01	0.05
u	0.0605	0.0460
M_c	0.0605	0.0460
C_c	0.0466	0.0355
u x M_c	0.1348	0.1026
u x C_c	0.1046	0.0796
M_c x C_c	0.1046	0.0796

C-3 ANOVA for Multiple Regression Analysis

C-3.1 Dehusking efficiency

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.959	.920	.913	.1343

a Predictors: (Constant), M_c^2, u x C_c, C_c, M_cx C_c, u, M_c

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.043	6	2.340	129.691	.000
	Residual	1.227	68	1.805E-02		
	Total	15.270	74			

a Predictors: (Constant), M_c^2, u x C_c, C_c, M_cx C_c, u, M_c
b Dependent Variable: E_d

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	130.327	3.101		42.025	.000
	u	-1.509	.237	-2.952	-6.356	.000
	M_c	-.626	.082	-4.988	-7.608	.000
	C_c	-.669	.069	-4.841	-9.686	.000
	u x C_c	3.839E-02	.005	4.654	7.132	.000
	M_c x C_c	5.412E-03	.001	2.064	4.093	.000
	M_c^2	1.025E-02	.001	3.354	7.228	.000

a Dependent Variable: E_d

C-3.2 Shelling efficiency

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.984	.968	.965	.1357

a Predictors: (Constant), u x M_c, C_c, u, M_c^2, M_c x C_c, u x C_c, M_c

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	37.704	7	5.386	292.501	.000
	Residual	1.234	67	1.841E-02		
	Total	38.938	74			

a Predictors: (Constant), u x M_c, C_c, u, M_c^2, M_c x C_c, u x C_c, M_c
b Dependent Variable: E_s

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
	(Constant)	140.682	3.352		41.971	.000
	u	-2.963	.260	-3.629	-11.379	.000
	M_c	-.652	.102	-3.250	-6.421	.000
	C_c	-.733	.070	-3.322	-10.505	.000
	u x C_c	6.033E-02	.005	4.581	11.097	.000
	M_c x C_c	-6.729E-03	.001	-1.607	-5.038	.000
	M_c^2	1.189E-02	.001	2.436	8.299	.000
	u x M_c	3.476E-02	.005	2.223	7.031	.000

a Dependent Variable: E_s

C.3.3 Cleaning efficiency

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.961	.923	.920	1.657E-02

a Predictors: (Constant), C_c^2, u^2, u

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.234	3	7.801E-02	284.204	.000
	Residual	1.949E-02	71	2.745E-04		
	Total	.254	74			

a Predictors: (Constant), C_c^2, u^2, u
b Dependent Variable: E_c

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	100.662	.399		252.571	.000
	u	-.295	.069	-4.474	-4.290	.000
	u^2	1.523E-02	.003	5.389	5.168	.000
	C_c^2	5.033E-05	.000	.249	7.564	.000

a Dependent Variable: E_c

C-3.4 Thrower loss

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.957	.915	.909	.1253

a Predictors: (Constant), C_c^2, M_c^2, u x C_c, M_c, C_c

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11.676	5	2.335	148.652	.000
	Residual	1.084	69	1.571E-02		
	Total	12.760	74			

a Predictors: (Constant), C_c^2, M_c^2, u x C_c, M_c, C_c
b Dependent Variable: L_t

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	-14.875	3.739		-3.978	.000
	M_c	-.851	.054	-7.414	-15.655	.000
	C_c	1.109	.169	8.778	6.561	.000
	u x C_c	3.675E-03	.000	.487	9.887	.000
	M_c^2	1.886E-02	.001	6.752	14.256	.000
	C_c^2	-1.330E-02	.002	-9.271	-6.931	.000

a Dependent Variable: L_t

C-3.5 Blower loss

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.850	.722	.710	5.602E-03

a Predictors: (Constant), M_c^2, u x M_c, M_c

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.780E-03	3	1.927E-03	61.406	.000
	Residual	2.228E-03	71	3.138E-05		
	Total	8.008E-03	74			

a Predictors: (Constant), M_c^2, u x M_c, M_c
b Dependent Variable: L_b

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	.160	.024		6.551	.000
	M_c	-1.414E-02	.002	-4.917	-5.736	.000
	u x M_c	1.861E-04	.000	.830	5.283	.000
	M_c^2	2.396E-04	.000	3.425	4.053	.000

a Dependent Variable: L_b

C-3.6 Grain damage

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.996	.992	.991	8.050E-02

a Predictors: (Constant), u^2, M_c, u x C_c, u x M_c

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	54.039	4	13.510	2084.782	.000
	Residual	.454	70	6.480E-03		
	Total	54.493	74			

a Predictors: (Constant), u^2, M_c, u x C_c, u x M_c
b Dependent Variable: L_{gd}

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
	(Constant)	-.283	.368		-.769	.444
	M_c	.155	.034	.654	4.556	.000
	u x M_c	6.081E-03	.003	.329	2.107	.039
	u x C_c	-5.173E-03	.000	-.332	-21.461	.000
	u^2	1.074E-02	.003	.259	4.109	.000

a Dependent Variable: L_{gd}

APPENDIX-D

OPTIMIZATION PROGRAMME

D.1 Matlab Program for Optimization of Independent Parameters

```
clear all;
close all;
clc
syms x
s=[];
A=[];
j=0;
B=[];
i=0;
for Cc = 40:1:48
   for u = 10.4:0.5:13.0
      for Mc = 15:1:26
         j=j+1;
         A(j,1)=Cc;
         A(j,2)=u;
         A(j,3)=Mc;

DE = 130.327 - 0.626*Mc - 1.509*u - 0.669*Cc  + 0.005412*Mc*Cc +
      0.03839*u*Cc + 0.01025*(Mc)^2;
A(j,4)=DE;

SE = 140.682  - 0.652*Mc - 2.963*u - 0.733*Cc + 0.03476*Mc*u –
      0.006729*Mc*Cc + 0.06033*u*Cc + 0.01189*(Mc)^2;
A(j,5)=SE;

CE = 100.662 - 0.295*u  + 0.01523*(u)^2 + 0.00005033*(Cc)^2;
A(j,6) = CE;

TL =  -14.875 - 0.851*Mc + 1.109*Cc  + 0.003675*u*Cc + 0.01886*(Mc)^2  -
```

```
        0.0133*(Cc)^2;
A(j,7)=TL;

BL = 0.160 - 0.01414*Mc  + 0.0001861*Mc*u + 0.0002396*(Mc)^2 ;
A(j,8)=BL;

GD = - 0.283 + 0.155*Mc + 0.006081* Mc*u - 0.005173*u*Cc +
0.01074*(u)^2 ;
A(j,9)=GD;

A(j,10)=100-SE;
A(j,11)=A(j,10)+A(j,8)+A(j,7);
A(j,12)=A(j,11)+A(j,9);
A(j,13)=A(j,9)*100/A(j,12);
A(j,14)=A(j,10)*100/A(j,12);
A(j,15)=A(j,7)*100/A(j,12);
A(j,16)=A(j,8)*100/A(j,12);

if A(j,12)<4
  i=i+1;
  B(i,12)=A(j,12);
  B(i,1)=A(j,1);
  B(i,2)=A(j,2);
  B(i,3)=A(j,3);
  B(i,4)=A(j,4);
  B(i,5)=A(j,5);
  B(i,6)=A(j,6);
  B(i,7)=A(j,7);
  B(i,8)=A(j,8);
  B(i,9)=A(j,9);
  B(i,10)=A(j,10);
  B(i,11)=A(j,11);
  B(i,13)=A(j,13);
  B(i,14)=A(j,14);
```

```
  B(i,15)=A(j,15);
  B(i,16)=A(j,16);
end;

    end
  end
end

print={'Cc,mm' , 'u,m/s','Mc,%','Ed,%','Es,%', 'Ec,%','Lt,%','Lb,%',
'Lgd,%','SL,%', 'TNCL,%', 'GTL,%', 'GDCTL,%', 'SLCTL,%','TLCTL,%',
'BLCTL,%', };
print
A
B
z = xlswrite('optimization.xls', print, 'Temperatures', 'A1')
z = xlswrite('optimization.xls',A, 'Temperatures', 'A2')
y = xlswrite('optimization.xls', print, 'final', 'A1')
z = xlswrite('optimization.xls',B, 'final', 'A2')
```