MODIFICATION AND PERFORMANCE EVALUATION OF GREEN CHICKPEA POD STRIPPING CUM SHELLING MACHINE

THESIS

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Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur

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By

GAJENDRA PAWAR

Department of Post Harvest Process and Food Engineering

College of Agricultural Engineering

Jawaharlal Nehru Krishi Vishwa Vidyalaya

Jabalpur (M.P.)

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CERTIFICATE - I

*This is to certify that the thesis entitled "**Modification and Performance Evaluation of Green Chickpea Pod Stripping cum Shelling Machine** " submitted in partial fulfilment of the requirement for the degree of **Master of Technology** in Agricultural Engineering in **POST HARVEST PROCESS AND FOOD ENGINEERING** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **MR. GAJENDRA PAWAR** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.*

No part of the thesis has been submitted for any other degree or diploma (Certificate awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigation has been acknowledged by him.

Place : **(Dr. A. K. Gupta)**

Date : Chairman Advisory Committee

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

Chairman :	Dr. A. K. Gupta	…………………………………
Member :	Dr. V. K. Tiwari	…………………………………
Member :	Dr. S. K. Garg	…………………………………
Member :	Prof. Sheela Pandey	…………………………………

CERTIFICATE – II

This is to certify that the thesis entitled "***Modification and Performance Evaluation of Green Chickpea Pod Stripping cum Shelling Machine***" submitted by ***MR. GAJENDRA PAWAR*** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfillment of the requirements for the degree of ***Master of Technology*** in Agricultural Engineering in the Department of ***POST HARVEST PROCESS AND FOOD ENGINEERING*** has been, after evaluation, approved by the External Examiner and by the Student's Advisory Committee after an oral examination on the same.

Place : Jabalpur   **(Dr. A. K. Gupta)**

Date :   Chairman Advisory Committee

MEMBERS OF THE ADVISORY COMMITTEE

Chairman	Dr. A. K. Gupta	………………….......
Head of Deptt.	Dr. T. K. Bhattacharya	…………………......
Director of Instruction	Dr. P. K. Mishra	…………………......

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Place: Jabalpur

Date: ***(GAJENDRA PAWAR)***

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List of Symbols and Abbreviations

%	:	Percent
°	:	Degree
'	:	Minute
"	:	Second
AICRP	:	All India Coordinated Research Project
BIS	:	Bureau of Indian Standards
^{o}C	:	Degree Celsius
C.A.E	:	College of Agricultural Engineering
cm^3	:	Cubic centimetre
e.g.	:	Example
et al.	:	And others
Fig	:	Figure
g	:	Gram
GI	:	Galvanized Iron
IRRI	:	International Rice Research Institute
hr	:	Hour
i.e.	:	That is
JNKVV	:	Jawaharlal Nehru Krishi Vishwa Vidyalaya
kg	:	Kilogram
kg/min	:	Kilogram per minute
kg/m^3	:	Kilogram per cubic meter
Ltd	:	Limited
mm	:	Millimeter
min	:	Minute
m/hr	:	Meter per hour
m/s	:	Meter per second
M C	:	Moisture content
N	:	Newton
SD	:	Standard deviation
wt.	:	Weight
w.b.	:	Wet basis

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is an annual grain legume or "pulse crop" used extensively for human consumption. Its primary use in the United States and in European Countries is for salad bars, while in the Middle East and India it is more frequently cooked and blended with rice dishes. Chickpea is the third leading grain legume in the world and first in the South Asia. 92 percent of the area and 89 percent of the chickpea production is concentrated in the semi-arid tropical countries.

Chickpea is widely appreciated as health food. It is a protein rich supplement to cereal-based diets, especially to the poors in developing countries, where people are vegetarians or cannot afford animal protein. The pulse protein is rich in lysine and has low sulfur containing amino acids. It offers the most practical means of eradicating proteins malnutrition among vegetarian children and nursing mothers. Chickpea has a very important role in human diet in our country. Chickpea is a good source of zinc, folate and protein. It is also very high in dietary fiber and hence a healthy source of carbohydrates for persons with insulin sensitivity or diabetes. Chickpea is low in fat and most of this is polyunsaturated. In season, regular intake of about 40 g green chickpea has been shown to reduce low density lipo protein cholesterol quickly (Mandhyan, 2001).

Chickpea predominates among other pulse crops in terms of both area and production. In India, 2009-10 marked significant increase in area under chickpea (8.56 million ha) which is highest in last 10 years. Similarly, the chickpea production (7.35 million tonnes) also surpassed last 50 years record with highest productivity (858 kg/ha) ever recorded in the history of India. The area under chickpea has increased from 6.45 million ha in 1992-93 to 8.56 million ha in 2009-10. (Chickpea Research Highlights, 2009-2010).

India is the largest producer of chickpea in the world and contributed about 65% of total world production. In India, Madhya Pradesh alone contributed 44.20% of total production followed by Maharashtra (14.90%), Andhra Pradesh (11.32%), Karnataka (7.68%), Rajasthan (7.15%) and Uttar Pradesh (6.81%). In case of area, Madhya Pradesh stood first with 37.77% followed by Maharashtra (15.80%), Andhra Pradesh (7.92%), Karnataka (11.90%), Rajasthan (10.83%) and Uttar Pradesh (7.57%). Area, production and average yield of major chickpea producing states during 2009-2010 are shown in Table 1.1.

Table 1.1 Area, Production and Productivity of chickpea in different states of India during 2009-2010

S. No.	State	Area under cultivation (Mha)	Production (MT)	Yield (kg/ha)
1	Madhya Pradesh	3.09	3.30	1071
2	Maharashtra	1.29	1.11	863
3	Andhra Pradesh	0.65	0.85	1308
4	Karnataka	0.97	0.57	591
5	Rajasthan	0.88	0.53	604
6	Uttar Pradesh	0.62	0.51	824
7	Chhattisgarh	0.25	0.22	880
8	Gujarat	0.13	0.13	947
9	Haryana	0.08	0.06	738
10	Bihar	0.06	0.06	1014

Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation (2009-2010).

There are two main types of chickpea, i.e.; Kabuli, grown in the temperate regions and the Desi type, grown in the semi-arid tropics. Chickpea is an annual cool-season plant that ranges in height from one to three feet. Chickpea is a self-pollinated crop with flowers that are borne singly at the tip of auxiliary branches and that vary in colour from white to purple to faded blue. Most of the seed pods develop on the top portion of the plant, usually a minimum of fifteen to seventeen cm above the soil surface. Seed pods are short and inflated, with commercial types typically having one seed per pod.

The dry seeds of chickpea are harvested when the pods are fully ripe and have turned yellow, but before the pods start to shatter. Green chickpea pods are harvested for different purposes; eaten as fresh green vegetables, parched, fried, roasted, and boiled; as snack food, sweet and condiments; prepared with pepper, salt and lemon it is served as a side dish. Near cities where they can be readily marketed they are harvested for sale as a vegetable. Fully developed, bright green seed is preferred so pods should be harvested just before they start loosing their green colour. Green kernels used as a vegetable are commonly shelled from the pods by hand, but they may be mechanically shelled for large scale processing i.e., for canning and freezing. Chickpea, picked while it is still green is an excellent vegetable, but is currently an important market commodity in only a few areas of India. There is considerable potential for the increased consumption of vegetable chickpea in India and export of this produce may fetch foreign exchange as its export potential exists in countries like USA, U.K., Canada, Saudi Arab, UAE, Sri Lanka, Malaysia etc., because new high quality vegetable cultivars are becoming increasingly available and consumers are learning new ways of eating the crop.

Keeping in view the facts mentioned above, a machine has been developed at AICRP on Post Harvest Technology, College of Agricultural Engineering, JNKVV, Jabalpur which performs following functions.

1. Detach the green chickpea pods from the plants.
2. Shell the pods.
3. Separate the green kernels from the pods.

But the existing machine had the various problems as discussed below:

I. Stripping operation was difficult due to extra height of the machine.
II. During stripping operation plant was entrapped in stripping loops and might be hazardous to operator so it was not perfect from ergonomic point of view.

III. The existing machine had 3 shelling rollers and it was difficult to maintain the roller clearance and rollers speed ratio.

IV. The existing machine was too heavy to transport from one place to another.

Hence, present work was under taken in College of Agricultural Engineering for modification and performance evaluation of the modified machine with following specific objectives:

1. To study the physical properties of green chickpea pods.
2. To modify the stripping and shelling unit.
3. To evaluate the performance of the modified machine at different operating parameters.
4. To calculate the cost economics of the machine.

REVIEW OF LITERATURE

Chickpea is a major pulse crop of India but not much emphasis has been given on its processing in green form like other packed green products. Therefore, literature available on the mechanical aspects of its processing is inadequate. Because of non availability of information related to pod stripping and shelling, the attempts so far made by research workers to develop chickpea stripper and sheller have been random. So, in reviewing the literature, emphasis has been given on mechanical threshing and shelling of crops.

2.1 Threshing of Chickpea

Chickpea crop becomes ready for harvest when leaves turn reddish brown and start shedding. At this stage, pod moisture content ranges from 12 to 20 percent wet basis depending upon variety. Plants are either uprooted or cut at the ground level. Threshing operation is facilitated when these plant sundried to a moisture level ranging between 8 to 10 percent wet basis. Uprooted dried plants are threshed manually following any traditional method, while the cut and dried plants are threshed in mechanical thresher. Green chickpea used as vegetable are harvested manually and pods are stripped by hand. At this stage leaves of plants and pods are just started to change their colour from green to light yellow and moisture level of pods ranging between 65 to 72 percent wet basis.

Effective threshing in mechanical thresher will mostly depend on crop variety and its condition, material used for construction of concave and threshing element, concave clearance, feed rate and tip speed of threshing element. Brief review related to these threshing parameters, parameters related to force energy requirement in threshing of podded and cereal crops have been summarized and are presented in succeeding paragraphs.

2.1.1 Threshers for Pod Crops

Sharma and Devnani (1980) developed a variable speed thresher to establish the effect of clearance and speed on threshing parameters viz. feed rate, threshing efficiency, energy consumption and grain damage for soybean and cowpea crops at the moisture contents of 6.1 and 6.5% respectively. The thresher was provided with 30.5 cm long rasp bars mounted on 20 cm diameter drum while the concave clearance varied from 4 to 12 mm using cam arrangement. During the trial, tip speed was varied from 4.8 to 8.26 m/s.

The performance of thresher was evaluated for two cowpea varieties at six levels of drum speed between 300 to 550 rpm and two level of moisture content for speeds were 14.5 and 13.9% (w.b.) and their corresponding chaff moisture contents were 18.3 and 16.2% (w.b.). It was concluded that the threshing efficiency varied linearly with rpm and inversely with moisture content.

Huynh *et al.* (1982) reported that in rasp bar type threshing cylinders, kernels were detached from stem by a combination of stripping rubbing and impact. These actions involved the application of tensile, compressive, bending and twisting forces and their combination on a head of grain. In peg tooth cylinder threshing was achieved by impact or impulsive acceleration when pegs strike the grain. The impact action was based on difference in the coefficient of restitution of kernel and stalk.

Tandon *et al.* (1988) conducted trials on peg tooth type and rasp bar type threshing cylinders for black gram in order to determine the effect of grain moisture content and drum speed on threshing efficiency, visible and invisible grain damage. In rasp bar thresher, threshing efficiency was observed at 95% with 10 mm concave clearance and 10.3% (w.b.) moisture content.

Anwar and Gupta (1990) evaluated the performance of an axial flow grain legume thresher to thresh gram crop. Threshing mechanism consisted of a peg tooth cylinder rotating inside a two section cylindrical concave. The upper concave had inclined lugs which moved the threshing material axially. Concave clearance was adjusted using 0.5 mm thick shims. The material was fed into the opening between the cylinder and lower concave. Power was transmitted through a series of V-belts to the five major components like cylinder, delivery auger, centrifugal blower, rotary screen and auxiliary cleaner. The pegs on the rotating cylinder hit the material separating the grain from pod and straw, and at the same time accelerated them around the initial impact but further threshing was performed while the material moved axially until the straws were discharged by the straw-paddles at the opposite end.

Sinha and Dhaliwal (2007) studied machine-crop parameters for chickpea seed crop threshing. Moisture content, concave clearance and cylinder speed were taken as independent parameters and visible injury, internal injury, germination percentage and threshing efficiency were studied as dependent parameters. Cylinder speed was found the most critical factor affecting visible and internal injury. Moisture content adversely affected the internal injury levels in threshed seed. Combination of cylinder speed: 8.94 m/s, concave clearance: 14 mm and moisture content: 10% (w.b.) resulted seed of optimum quality with minimal visible and internal injury coupled with optimum threshing efficiency.

2.1.2 Threshers for Grain Crops

In IRRI (1970) a multicrop thresher was developed, operated by p.t.o. having three sections viz; threshing, separating and straw throwing. The threshing section consisted of a spike tooth cylinder and a concave arrangement with a housing fitted with internal spiral fins. During threshing most of the grain alongwith straw moved axially along the threshing cylinder and was delivered into a rotary separator. The test results indicated that 42 spikes in the cylinder and 12 on the concave gave good performance on the cylinder. The spikes were evenly spaced in a spiral arrangement, on the concave, and mounted in two rows near the feed opening of the concave.

Harrington (1970) designed a multicrop thresher with spike tooth cylinder and a fixed concave on the line of Japanese paddy thresher and American paddy threshers. At 2.5 cm concave clearance the losses in paddy and wheat were reported to be 3%. The thresher was not suitable for straw making as it normally reduced wheat straw to 25-50% of original length depending upon cylinder speed and crop moisture content. Cylinder tip speed in a range of 1200-1400 rpm resulted into 0.1% visible damage.

Singh and Kumar (1976) studied the effect of swinging hammer, spike tooth and rasp-bar cylinder on the threshing effectiveness and the damage of wheat. The cylinder speed was found to be important variable in unthreshed grain and damage model. Increase in the cylinder speed and decreased in the concave clearance, decreased the unthreshed grain but increased threshed grain and the power requirement. It was also observed that swinging hammer type cylinder consumed more power than rasp-bar and spike tooth cylinder.

Verma *et al.* (1978) investigated the incidents of accidents in wheat threshers. The accidents were highest in drum type threshers followed by syndicators and beater type threshers. Number of accidents on spike tooth thresher was minimum. An improved design of feeding chute was suggested for safe feeding of the crop in thresher.

Majumdar (1981) tested four threshers named spike tooth-I, spike tooth-II, hammer mill and axial flow for wheat, gram, maize, soybean, sorghum, and paddy crops. The results showed that with wheat, the output capacity was 205, 130, 170 kg/hr. The cleaning efficiencies were 98.1, 98.8, 36.9 and 38.1% and grain losses were 1.29, 4.71, 3.16 and 0.58% respectively.

As per BIS specification (IS: 3327-1965) pedal operated, paddy thresher consisted mainly of a well balanced cylinder with series of threshing teeth fixed on wooden slats. It was worked by pedal and gear drive mechanism. Paddy bundles of suitable sizes were applied to the teeth. Grains were separated by combing as well as by hammering action of threshing teeth.

Performance parameter for stripping cylinder:

Goss *et al.* (1958) studied the performance of stripping cylinder. It was concluded that primary performance of threshing unit depends on the percent of seeds detached from non grain parts of the plant and the percent of seeds that is damaged.

2.2 Shelling of Chickpea

Shelling is a process of removal of chickpea kernels from pods in such a way so that kernels can be taken out of them safely to be used for food purpose, without changing the shape or damaging the outer seed coat. The relevant literature available is reported accordingly:

Mayor (1959a, 1959b) developed a mechanical technique for slitting the seed coat of the peas prior to dehydrations. As a result of the slitting operation, the rate of drying was increased. The re-hydration ratio was increased and the quality of the re-hydrated product was improved.

Talburt and Smith (1975) had designed abrasion peelers for potatoes, batch type as well as continuous type. Abrasive grits used to grind the skin from potato. It was found that these machines works best with relatively smooth potatoes because it was difficult for abrasive surface, to enter into deep set eyes, reach into crevices. Small diameter abrasive roll was best for contour shelling. Peeler should tumble the mass and rotate the individual potatoes so that all surfaces were exposed to action. It was also found that two little load will cause potatoes to bounce and skip over the abrasive surfaces, resulting in incomplete shelling. The abrasive action and exposure time effected shelling.

Sharma and Mandhyan (1986) developed a manually operated Green Pea Shelling Machine at AICRP on Post Harvest Technology Scheme, Jabalpur centre. Investigations were carried out on the effect of roller inclinations, roller abrasive surface on shelling efficiency. The four roller inclination viz. 0°, 13°39‘, 15°15‘ and 16°48‘ with three roller surfaces viz. punched tin sheet, cycle tyre treads and gunny bag having coefficient of friction values as 0.839, 0.649 and 0.810 respectively. Highest recovery of undamaged kernel (92.7%) was obtained by shelling peas with punched tin sheet roller at roller inclination 16°48‘, followed by 89.8% at inclination of 15°15‘. The third highest recovery of 88.4% was obtained at roller inclination of 16°48‘ with gunny bag abrasive surface. In the entire three abrasive surfaces it was observed that the recoveries were highest at roller inclination of 16°48‘, followed by 15°15‘ and 13°39‘. However, recovery was found slightly better at 0° inclination compared to an inclination of 13°39‘. It was also observed that the abrasive surface made of punched tin sheet and tyre treads give 100% shelling efficiency at all roller inclinations. However, in roller having woven jute cutting, the shelling efficiency reduced to 97% at 13°39‘ and 88% at 0° inclinations. It was also found that shelling take 85% less time in shelling of 100 kg of fresh green pea pods as compared to manual shelling. The capacity of developed green pea peeler was 25 kg/hr. The peeler was suitable to peel green pea pods (80.2% moisture content at w.b.) at roller-concave clearance of 12 mm and roller speed of 45 rpm.

Singh and Sharma (1987) developed Power Operated Green Pea Shelling Machine at AICRP on Post Harvest Technology Scheme, Jabalpur centre. Investigations were carried out to optimize various design parameters and crop parameters for developed machine. For investigation, Arkel variety of pea was selected. The roller clearance was fixed at 12 mm, speed of roller to be 50 rpm, roller inclination angle to be 16°8‘ and studied the effect of moisture contents (w.b.) of pea pods on efficiency and capacity of machine. Pea pods at moisture content (w.b.) in range of 76-82% were used and found that whole kernel recovery of green pea pods was highest (95.5-96%) and in moisture range of 73-74%, capacity of machine was found 50 kg/hr.

Mbuvi and Litchfield (1994) investigated two green pea shellers and a green pea combine harvester for their effectiveness in shelling and harvesting green soybeans. The two shellers were a rubber roller-type (Taylor) and a rotary drum-beater type (Sinclair-Scott). The effect of blanching green soybean pods before shelling on shelling efficiency, seed damage, and quality of the shelled product was also studied. Shelling efficiency using the Taylor sheller was 95% and seed damage was 3%. Use of the Sinclanir-Scott sheller resulted in 77% shelling efficiency and 7% seed damage. There were significant differences in shelling efficiency, seed damage, FTC texture reading, and Hunter colour factor of green soybeans between blanched and unblanched samples; however, these qualities did not differ significantly between blanching times of 1 to 5 min. The stripping of pods off the plants by the combine harvester was sufficiently acceptable, seed recovery or seed removal from the pods was 87% while seed damage of the shelled product was 11%, and about 5% estimated field losses during harvest.

Sanjeeva and Maruthi (2008) developed a prototype machine for dehulling of pretreated pulse grain. The dehulling unit consists of an abrasive roller and a stationery concentric perforated mesh drum over it. The separation of hull and splitting of chickpea grain was effected by abrasive action and shear forces caused on the grain when the roller rotates in the drum. The machine was tested using conventional and improved grain pretreatment methods. A dehulling index of 0.93 and dhal recovery of 78% was obtained with improved pretreatment method.

Audu *et al.* (2004) developed a locust bean dehuller to reduce the time and labour required in the traditional manual dehulling of African locust bean (*Parkia biglobosa*) seeds, which are processed into a food condiment and flavouring agent. The dehuller principally consisted of two concentric cylinders, a power transmission shaft and a prime mover. The space between the two cylinders constituted the dehulling chamber. After design and construction, the dehuller was evaluated based on three parameters, viz. moisture content of beans, length of the dehulling head and the speed of rotation of the inner cylinder. Tests showed that efficiency of the machine increased linearly with increases in all the three parameters. The throughput of the dehuller decreased with increases in moisture content and length of dehulling head, but increased with increase in dehulling speed. The maximum values of dehulling efficiency and throughput obtained were 70.3% and 0.51 kg/min respectively.

Ezaki (1973) observed that in case of husking by rubber roll (paddy) deformation caused by shear and compression of the two rotating rubber surfaces was sufficient to split and separate the husk from the grains. The paddy was passed through the clearance between two rubber rolls, rotating in opposite directions at different speed. The clearance between them was smaller than mean thickness of paddy. One part of husk was subjected to shearing force where as the other part in contact with slower roll was under compression and thus subjected to breaking force.

Wimberly (1983) observed that in rubber roll paddy dehusker, the faster operating, unadjusted rubber roll wore out faster than adjusted roll. The rolls were interchangeable, and their location should be changed from time to time to ensure even wear. Uneven wear on a roll changed the peripheral speed and reduced hulling capacity. For optimum performance, the grain should be evenly distributed over the full width of rolls. Otherwise the roll surface wears out unevenly, reducing efficiency and capacity. Unevenly worn out rolls can be corrected by turning them on a lathe.

Heating adversely affected the durability of rubber rollers. To prolong their life, the rollers are change when they are too hot, they must be allowed to cool. Most of the rubber roll huskers incorporated an air cooling system whereby air was drawn through the housing to reduce roll temperature.

Mitchell *et al*. (1969) developed a commercial machine for shelling peas after numerous tests of methods for removing peas from pods. A standardized feed gap between the conveyor and the rollers separated shelled peas from unshelled pods. Pods which fail to be gripped by the roller pass to a second slightly modified shelling section. Extensive tests showed that a greater yield of peas was obtained from the sheller operated on hand picked peas, than from conventional stationary or mobile viners operated on vines. Yield for the combination of a mechanical pea pod picker which would be necessary for commercial operations and the pea sheller was not determined. Peas from the sheller were virtually undamaged in contrast to vined peas and were consequently superior in flavour.

REVIEW OF LITERATURE

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Huynh *et. al.* (1982) reported that in rasp bar type threshing cylinders, kernels were detached from stem by a combination of stripping rubbing and impact. These actions involved the application of tensile, compressive, bending and twisting forces and their combination on a head of grain. In peg tooth cylinder threshing was achieved by impact or impulsive acceleration when pegs strike the grain. The impact action was based on difference in the coefficient of restitution of kernel and stalk.

Tandon *et. al.* (1988) conducted trials on peg tooth type and rasp bar type threshing cylinders for black gram in order to determine the effect of grain moisture content and drum speed on threshing efficiency, visible and invisible grain damage. In rasp bar thresher, threshing efficiency was observed at 95% with 10 mm concave clearance and 10.3% (w.b.) moisture content.

Anwar and Gupta (1990) evaluated the performance of an axial flow grain legume thresher to thresh gram crop. Threshing mechanism consisted of a peg tooth cylinder rotating inside a two section cylindrical concave. The upper concave had inclined lugs which moved the threshing material axially. Concave clearance was adjusted using 0.5 mm thick shims. The material was fed into the opening between the cylinder and lower concave. Power was transmitted through a series of V-belts to the five major components like cylinder, delivery auger, centrifugal blower, rotary screen and auxiliary cleaner. The pegs on the rotating cylinder hit the material separating the grain from pod and straw, and at the same time accelerated them around the initial impact but further threshing was performed while the material moved axially until the straws were discharged by the straw-paddles at the opposite end.

Sinha and Dhaliwal (2007) studied machine-crop parameters for chickpea seed crop threshing. Moisture content, concave clearance and cylinder speed were taken as independent parameters and visible injury, internal injury, germination percentage and threshing efficiency were studied as dependent parameters. Cylinder speed was found the most critical factor affecting visible and internal injury. Moisture content adversely affected the internal injury levels in threshed seed. Combination of cylinder speed: 8.94 m/s, concave clearance: 14 mm and moisture content: 10% (w.b.) resulted seed of optimum quality with minimal visible and internal injury coupled with optimum threshing efficiency.

2.1.2 Threshers for Grain Crops

In IRRI (1970) a multicrop thresher was developed, operated by p.t.o. having three sections viz; threshing, separating and straw throwing. The threshing section consisted of a spike tooth cylinder and a concave arrangement with a housing fitted with internal spiral fins. During threshing most of the grain alongwith straw moved axially along the threshing cylinder and was delivered into a rotary separator. The test results indicated that 42 spikes in the cylinder and 12 on the concave gave good performance on the cylinder. The spikes were evenly spaced in a spiral arrangement, on the concave, and mounted in two rows near the feed opening of the concave.

Harrington (1970) designed a multicrop thresher with spike tooth cylinder and a fixed concave on the line of Japanese paddy thresher and

American paddy threshers. At 2.5 cm concave clearance the losses in paddy and wheat were reported to be 3%. The thresher was not suitable for straw making as it normally reduced wheat straw to 25-50% of original length depending upon cylinder speed and crop moisture content. Cylinder tip speed in a range of 1200-1400 rpm resulted into 0.1% visible damage.

Singh and Kumar (1976) studied the effect of swinging hammer, spike tooth and rasp-bar cylinder on the threshing effectiveness and the damage of wheat. The cylinder speed was found to be important variable in unthreshed grain and damage model. Increase in the cylinder speed and decreased in the concave clearance, decreased the unthreshed grain but increased threshed grain and the power requirement. It was also observed that swinging hammer type cylinder consumed more power than rasp-bar and spike tooth cylinder.

Verma *et. al.* (1978) investigated the incidents of accidents in wheat threshers. The accidents were highest in drum type threshers followed by syndicators and beater type threshers. Number of accidents on spike tooth thresher was minimum. An improved design of feeding chute was suggested for safe feeding of the crop in thresher.

Majumdar (1981) tested four threshers named spike tooth-I, spike tooth-II, hammer mill and axial flow for wheat, gram, maize, soybean, sorghum, and paddy crops. The results showed that with wheat, the output capacity was 205, 130, 170 kg/hr. The cleaning efficiencies were 98.1, 98.8, 36.9 and 38.1% and grain losses were 1.29, 4.71, 3.16 and 0.58% respectively.

As per BIS specification (IS: 3327-1965) pedal operated, paddy thresher consisted mainly of a well balanced cylinder with series of threshing teeth fixed on wooden slats. It was worked by pedal and gear drive mechanism. Paddy bundles of suitable sizes were applied to the teeth. Grains were separated by combing as well as by hammering action of threshing teeth.

Performance parameter for stripping cylinder:

Goss *et. al.* (1958) studied the performance of stripping cylinder. It was concluded that primary performance of threshing unit depends on the percent of seeds detached from non grain parts of the plant and the percent of seeds that is damaged.

2.2 Shelling of Chickpea

Shelling is a process of removal of chickpea kernels from pods in such a way so that kernels can be taken out of them safely to be used for food purpose, without changing the shape or damaging the outer seed coat. The relevant literature available is reported accordingly:

Mayor *et. al.* (1959a, 1959b) developed a mechanical technique for slitting the seed coat of the peas prior to dehydrations. As a result of the slitting operation, the rate of drying was increased. The re-hydration ratio was increased and the quality of the re-hydrated product was improved.

Talburt and Smith (1975) had designed abrasion peelers for potatoes of, batch type as well as continuous type. Abrasive grits used to grind the skin from potato. It was found that these machines works best with relatively smooth potatoes because it was difficult for abrasive surface, to enter into deep set eyes, reach into crevices. Small diameter abrasive roll was best for contour shelling. Peeler should tumble the mass and rotate the individual potatoes so that all surfaces were exposed to action. It was also found that two little load will cause potatoes to bounce and skip over the abrasive surfaces, resulting in incomplete shelling. The abrasive action and exposure time effected shelling.

Sharma and Mandhyan (1986) developed a manually operated Green Pea Shelling Machine at AICRP on Post Harvest Technology Scheme, Jabalpur centre. Investigations were carried out on the effect of roller inclinations, roller abrasive surface on shelling efficiency. The four roller inclination viz. 0°, 13°39‘, 15°15‘ and 16°48‘ with three roller surfaces viz. punched tin sheet, cycle tyre treads and gunny bag having coefficient of friction values as 0.839, 0.649 and 0.810 respectively. Highest recovery of undamaged kernel (92.7%) was obtained by shelling peas with punched tin sheet roller at roller inclination 16°48‘, followed by

89.8% at inclination of 15°15‘. The third highest recovery of 88.4% was obtained at roller inclination of 16°48‘ with gunny bag abrasive surface. In the entire three abrasive surfaces it was observed that the recoveries were highest at roller inclination of 16°48‘, followed by 15°15‘ and 13°39‘. However, recovery was found slightly better at 0° inclination compared to an inclination of 13°39‘. It was also observed that the abrasive surface made of punched tin sheet and tyre treads give 100% shelling efficiency at all roller inclinations. However, in roller having woven jute cutting, the shelling efficiency reduced to 97% at 13°39‘ and 88% at 0° inclinations. It was also found that shelling take 85% less time in shelling of 100 kg of fresh green pea pods as compared to manual shelling. The capacity of developed green pea peeler was 25 kg/hr. The peeler was suitable to peel green pea pods (80.2% moisture content at w.b.) at roller-concave clearance of 12 mm and roller speed of 45 rpm.

Singh and Sharma (1987) developed Power Operated Green Pea Shelling Machine at AICRP on Post Harvest Technology Scheme, Jabalpur centre. Investigations were carried out to optimize various design parameters and crop parameters for developed machine. For investigation, Arkel variety of pea was selected. The roller clearance was fixed at 12 mm, speed of roller to be 50 rpm, roller inclination angle to be 16°8‘ and studied the effect of moisture contents (w.b.) of pea pods on efficiency and capacity of machine. Pea pods at moisture content (w.b.) in range of 76-82% were used and found that whole kernel recovery of green pea pods was highest (95.5-96%) and in moisture range of 73-74%, capacity of machine was found 50 kg/hr.

Mbuvi and Litchfield (1994) investigated two green pea shellers and a green pea combine harvester for their effectiveness in shelling and harvesting green soybeans. The two shellers were a rubber roller-type (Taylor) and a rotary drum-beater type (Sinclair-Scott). The effect of blanching green soybean pods before shelling on shelling efficiency, seed damage, and quality of the shelled product was also studied. Shelling efficiency using the Taylor sheller was 95% and seed damage was 3%. Use of the Sinclanir-Scott sheller resulted in 77% shelling efficiency and 7% seed damage. There were significant differences in shelling efficiency, seed damage, FTC texture reading, and Hunter colour factor of green soybeans between blanched and unblanched samples; however, these qualities did not differ significantly between blanching times of 1 to 5 min. The stripping of pods off the plants by the combine harvester was sufficiently acceptable, seed recovery or seed removal from the pods was 87% while seed damage of the shelled product was 11%, and about 5% estimated field losses during harvest.

Sanjeeva and Maruthi (2008) developed a prototype machine for dehulling of pretreated pulse grain. The dehulling unit consists of an abrasive roller and a stationery concentric perforated mesh drum over it. The separation of hull and splitting of chickpea grain was effected by abrasive action and shear forces caused on the grain when the roller rotates in the drum. The machine was tested using conventional and improved grain pretreatment methods. A dehulling index of 0.93 and dhal recovery of 78% was obtained with improved pretreatment method.

Audu *et. al.* (2004) developed a locust bean dehuller to reduce the time and labour required in the traditional manual dehulling of African locust bean (*Parkia biglobosa*) seeds, which are processed into a food condiment and flavouring agent. The dehuller principally consisted of two concentric cylinders, a power transmission shaft and a prime mover. The space between the two cylinders constituted the dehulling chamber. After design and construction, the dehuller was evaluated based on three parameters, viz. moisture content of beans, length of the dehulling head and the speed of rotation of the inner cylinder. Tests showed that efficiency of the machine increased linearly with increases in all the three parameters. The throughput of the dehuller decreased with increases in moisture content and length of dehulling head, but increased with increase in dehulling speed. The maximum values of dehulling efficiency and throughput obtained were 70.3% and 0.51 kg/min respectively.

Ezaki (1973) observed that in case of husking by rubber roll (paddy) deformation caused by shear and compression of the two rotating rubber surfaces was sufficient to split and separate the husk from the grains. The paddy was passed through the clearance between two rubber rolls, rotating in opposite directions at different speed. The clearance between them was smaller than mean thickness of paddy. One part of husk was subjected to shearing force where as the other part in contact with slower roll was under compression and thus subjected to breaking force.

Wimberly (1983) observed that in rubber roll paddy dehusker, the faster operating, unadjusted rubber roll wore out faster than adjusted roll. The rolls were interchangeable, and their location should be changed from time to time to ensure even wear. Uneven wear on a roll changed the peripheral speed and reduced hulling capacity. For optimum performance, the grain should be evenly distributed over the full width of rolls. Otherwise the roll surface wears out unevenly, reducing efficiency and capacity. Unevenly worn out rolls can be corrected by turning them on a lathe.

Heating adversely affected the durability of rubber rollers. To prolong their life, the rollers are change when they are too hot, they must be allowed to cool. Most of the rubber roll huskers incorporated an air cooling system whereby air was drawn through the housing to reduce roll temperature.

Mitchell *et. al*. (1969) developed a commercial machine for shelling peas after numerous tests of methods for removing peas from pods. A standardized feed gap between the conveyor and the rollers separated shelled peas from unshelled pods. Pods which fail to be gripped by the roller pass to a second slightly modified shelling section. Extensive tests showed that a greater yield of peas was obtained from the sheller operated on hand picked peas, than from conventional stationary or mobile viners operated on vines. Yield for the combination of a mechanical pea pod picker which would be necessary for commercial operations and the pea sheller was not determined. Peas from the sheller were virtually undamaged in contrast to vined peas and were consequently superior in flavour.

MATERIAL AND METHODS

This chapter deals with the description of theoretical consideration, design consideration, modification, materials consumed, experimental plan, physical properties and equipments and instruments, to achieve the objective of the present investigation. The present research work on modification and performance evaluation of green chickpea pod stripping cum shelling machine was undertaken in the Department of Post Harvest Process & Food Engineering, College of Agricultural Engineering, JNKVV, Jabalpur.

3.1 Theoretical Consideration for Stripping Unit

The prime function of stripping unit is to detach the green chickpea pods from the plants with minimum damage to pods. Detachment of pods is primarily achieved by impact action, wherein combing and tearing actions are also associated between the stripping elements. The impact action in stripper is stimulated by rotating the cylinder having stripping element at its periphery and along the drum length. When such cylinders are rotated at high speed, most pods from the plant, which are moving relatively slow, are shattered by the repeated impacts. Increased crop thickness or high feed rate will, therefore, relatively reduce pod damage and separation from plant, and vice versa. Proper selection and adjustment in design for effective stripping will primarily depend on the moisture content and feed rate of the green chickpea plants.

3.1.1 Theoretical Capacity of Stripper

The theoretical capacity of stripper was calculated as recommended by Mandhyan *et. al.* (2001)

1. One fourth circumference of stripper comes in contact with plant at the time of stripping

2. Three fourth length of plant is in contact with stripper

Calculations:

Diameter of the stripper

= 330 mm

Therefore, circumference

= $\pi \times 330$

= 1036.73 mm

Considering time for which the plant is held before stripping unit

= 20 seconds

The part of plant which can be stripped off in one second

$$= \frac{(1/4 \times 1036.73)}{20}$$

= 12.96 mm

Considering, the rpm of the stripper to be 130.

The length of the plant that would be stripped of in one hour

= 12.96 × 2.17 ×3600 (130/60 = 2.17)

= 101243.52 mm/hr

= 101.24 m/hr

It was observed that, average length of the plant of variety JG322 = 0.408 m

Therefore, part of the plant in contact with stripper

= 3 / 4 × 0.408

= 0.306 m

Average weight of one plant =140 g

Thus, weight of plant that would be stripped off in one hour

$$= \frac{101.24 \times 0.140}{0.306}$$

= 46.32 kg/hr

Hence, theoretical capacity = 46.32 kg/hr

3.1.2 Analysis of Forces in Stripping Unit

Centrifugal Force:

A force acts in outward direction on a body rotating in a circle around a central point. This force is termed as centrifugal force.

Centrifugal force is equal and opposite to centripetal force i.e. it acts outwards.

$$F_c = \frac{mv^2}{R}$$

Where,

F_c = Centrifugal Force

m= W/g = mass of stripping roller

W = Weight of stripping roller = 12.0 kg

R = Radius of stripping roller = 0.165 m

g = Acceleration due to gravity

It was found that the detachment of pods from the plant started at 90 rpm of stripping roller.

The peripheral velocity at 90 rpm can be calculated as fallows

$$\text{Circumference} = \pi D$$

$$= \pi \times 0.33$$

$$= 1.037 \text{ m}$$

$$\text{Peripheral Velocity (v)} = \frac{90}{60} \times 1.037$$

$$= 1.56 \text{ m/s}$$

Therefore the equation becomes

$$F_c = \frac{1.223 \times (1.56)^2}{0.165}$$

$$= 18.04 \text{ N}$$

(m= W/g = 12.0 / 9.81=1.223)

Therefore, the minimum force developed for stripping the pods from the plant by the stripper roller will be 18.04 N.

3.2 Theoretical Consideration for Shelling Unit

The prime function of shelling unit is to detach the green chickpea kernels from husk or pod. Shelling is preferably achieved by subjecting the pods to abrasive force. Generally three to nine passes in shelling zone are required for shelling, and this depends on moisture content, variety and pod size of the green chickpea plant.

The basic principle behind the design and development of the shelling unit of green chickpea pod stripping cum shelling machine is the distribution of the energy on the surface of the pod during shelling of the pods between two surfaces.

In shelling operation two basic principles of size reduction should be considered:

1. Distribution of the energy on the surface.
2. Distribution of the energy to the internal structure.

Therefore selection of roller speed (rpm) and abrasive surface has following considerations:

1. The energy applied by roller is equal or more then the energy required to detach the kernel from the pod or husk.
2. The energy absorbed by the kernel should be less than its elastic limit to prevent breakage of kernel.

3.2.1 Analysis of Forces in Shelling Unit

In the shelling unit detachment of kernels from the pods was the resultant of

1. Compression and shear
2. Abrasion and friction

In the shelling unit the compression force exerted on the pods mainly due to the revolution of shelling roller and it may be equal to the centrifugal force.

Centrifugal Force

Centrifugal force for shelling roller up to the pods can be given by:

$$Fc = \frac{mv^2}{R}$$

From the trials, conducted on shelling unit it was observed at rpm of 170 pods start to shell

At rpm = 170

Dia. of shelling roller = 170 mm

Circumference = π D

= $\pi \times 0.17$

= 0.534 m

Distance covered in one second

$$= \frac{170}{60}$$

= 2.833 revolutions

Peripheral velocity for 2.833 revolutions

= 0.534 × 2.833

= 1.513 m/s

Hence,

v = 1.513 m/s

Therefore the equation becomes

$$Fc = \frac{0.815 \times (1.513)^2}{0.085}$$

= 21.94 N

(W = wt. of shelling roller= 8 kg; so m= W/g =8.00 / 9.81=0.815)

Frictional Force

Whenever a body slides over the surface, the frictional forces existing between the surfaces in relative motion are called forces of kinetic friction. The ratio between the force of friction, F, and normal force to the surface of contact, N, is given by the well-known relationship

$$\mu_k = F/N$$

$$\text{or } F = N \times \mu_k$$

In case of shelling the normal force may be equal to the centrifugal force due to revolution of shelling roller

$$N = 21.94 \text{ N}$$

The coefficient of friction between the abrasive surface of shelling roller and the pod surface was 0.64

So, the frictional force

$$F = 21.94 \times 0.64 = 14.04 \text{ N}$$

3.2.2 Length of Travel

On the basis of dimensions of the pod, the length of travel is calculated. The knowledge of length of travel is required to decide the gap between the rollers. Length of travel is an important factor affecting the desired shelling and breakage. It gives the idea about relation between clearance and breakage. (Phirke, 2005)

The complete path of travel of pod is calculated by the expression.

$$L = [0.5D\,(d-b) + 0.25(d^2-b^2)]^{0.5}$$

Where, D = roller diameter

b = clearance between the rollers

d = initial size of the pod

But the pods came in contact of shelling zone for five times.

Hence,

$$L = 5\,[0.5D\,(d-b) + 0.25(d^2-b^2)]^{0.5}$$

Considering the initial size of the pod to be shelled (d) = 14.28 mm

Length of travel or path for different clearance:

Length of travel or path for 12 mm clearance =

$$L = 5\,[0.5D\,(d-b) + 0.25(d^2-b^2)]^{0.5}$$

$$= 5\,[0.5 \times 170(14.28 - 12) + 0.25(14.28^2 - 12^2)]^{0.5}$$

$$= 5\,[193.80 + 14.97]^{0.5}$$

$$= 5 \times 14.44$$

$= 72.24$ mm

Length of travel or path for 11 mm clearance =

$$L = 5\ [0.5D\ (d-b) + 0.25(d^2 - b^2)]^{0.5}$$

$$= 5\ [0.5 \times 170(14.28 - 11) + 0.25(14.28^2 - 11^2)]^{0.5}$$

$$= 5\ [278.80 + 20.72]^{0.5}$$

$$= 5 \times 17.30$$

$= 86.53$ mm

Length of travel or path for 10 mm clearance =

$$L = 5\ [0.5D\ (d-b) + 0.25(d^2 - b^2)]^{0.5}$$

$$= 5\ [0.5 \times 170(14.28 - 10) + 0.25(14.28^2 - 10^2)]^{0.5}$$

$$= 5\ [363.80 + 25.97]^{0.5}$$

$$= 5 \times 19.74$$

$= 98.71$ mm

From the above calculations it is observed that as the clearance increases the length of travel is decreases.

3.3 Description and Defects of Existing Machine

The green chickpea pod stripping cum shelling machine consisted of a stripping unit, a shelling unit and a cleaning unit. The machine occupied a floor area of 0.645 × 0.760 m and its height was 1.865 m. Frame of the machine had hexagonal shape of 1.43 m height. At the top of the frame, stripping roller was mounted and driven by pulley belt mechanism. Length and diameter of stripping roller was 380 mm and 260 mm respectively. Pentagonal stripping loops were made of GI fencing wire of 4 mm diameter, were fixed on periphery of roller. Spacing between two loops was 22.5 mm. To strip the pods, a bunch of green chickpea plants was held in front of the stripping unit in such a way that leaves and pods were projected into the stripping loops but due to spacing and shape of loops, plants were badly trapped and hazardous from ergonomic point of view. The detached pods along with shredding fell into the shelling unit, which consisted of three rollers, upper two enclosed with rubber following with corrugated metal sheet and third with only corrugated rubber sheet.

All the three rollers were of same size i.e. 260 mm diameter and 360 mm length. The upper two rollers operated at different speed i.e. one was faster and other was slower in reverse direction. The third roller operated at medium speed having direction same as the faster roller. As the pods fell on the rollers they offered compression and shearing force, resulting in shelling of pods. But this mechanism had the problem of maintaining shelling roller speed and speed ratio of shelling rollers. The green kernels were separated from husk in the cleaning unit. The stripping and shelling efficiency of the machine were 93.66 and 89.44% respectively.

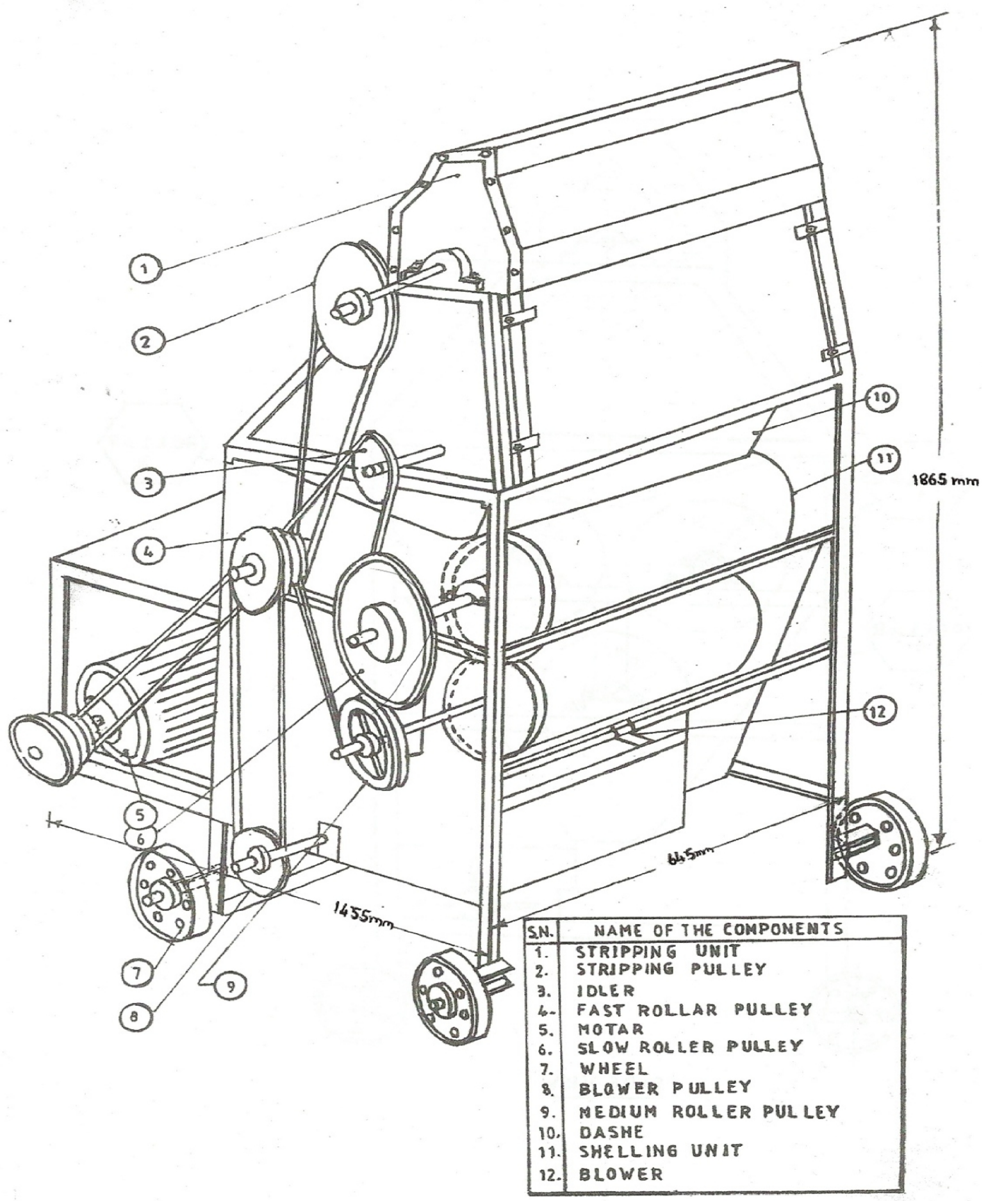


Fig 3.1 Isometric View of the Existing Green Chickpea Pod Stripping cum Shelling Machine

Plate 3.1 Existing Green Chickpea Pod Stripping cum Shelling Machine

3.4 Design Consideration

The green chickpea pod stripping cum shelling machine was designed and modified as a functional and experimental unit. The design of machine components were based on the principles of operations, tested and compared with the conventional method, to give a correct shape in form of prototype. The mechanical design details were also given with due attention so, as to give adequate functional rigidity for the design of machine.

3.4.1 Design and Modification Steps

Following steps were taken in designing and modify a green chickpea pod stripping cum shelling machine:

a) Make a list of components which are semi-finished or bought-out items and of parts to be fabricated. Collect information about the suppliers, specification details and cost of items.

b) Make rough sketch of the machine; locate all components, determining the size by using principles of machine design and strength of materials.

c) Estimate the cost of machine using available information about the cost of finished, semi finished, fabricated items, labour cost, overheads etc.

d) Predict the performance of machine using machine efficiency values of 70 percent and the recommended operational speeds. The economic justification could be based upon its long usage or related to the overcoming the timeliness constraints and effect on yield in conjunction with other essential inputs.

e) Fabricate the prototype, according to the design specifications.

f) Determine the performance of the prototype in laboratory and under actual conditions with respect to pod stripping and shelling.

g) Fabricate the final prototype. Make a few replicates for extensive evaluation at user’s level.

h) Finalize the design.

3.5 General Design and Modification Consideration

Before deciding to design and modify a green chickpea pod stripping cum shelling machine one should consider the market demand for the machine by conducting surveys of existing pod stripping and shelling practices, implements/machine used, farmers’ preferences, etc.

A new design will be initiated either to provide a machine for stripping and shelling of green chickpea pods, if not existed or to provide an improved design to overcome problems/defects of existing practice of machine. If the forecast for the demand of such a machine is favorable the engineering design process may be initiated and should involve a few selected manufacturers and farmers as cooperators.

The design and modification of machine consists of several steps and would require basic information about the following:

a) Crop and their characteristics.

b) Physical property of green chickpea pod.

c) Sources of power available.

d) Labour requirement for machine operation.

e) Level of manufacturing skill at small finished components.

f) Ease of operation, calibration and maintenance.

g) Safety and operation, calibration and maintenance.

h) Safety and operator's comfort.

i) Expected level of cost of machine and cost of machine operation.

j) Net benefit expected at farmer's level.

3.5.1 Functional Requirements

The machine was designed and modified to fulfil the following functional requirements:

(1) To detach the pods from the plants properly.

(2) To remove the husk of pods with minimum damage to the kernel.

The mechanical functional requirements of different individual units of machine are given below:

a) Stripping Roller

(1) It should be strong enough to withstand with different speed and feed rate.

(2) The shape and size of the stripping element should be such that it detaches the pods with ease.

(3) It should be easily repairable.

(4) It should be easily cleanable.

b) Pod Collection Unit and Discharge Chute

(1) It should hold sufficient quantity of chickpea pods.

(2) There should be provision in the pod collection unit and discharge chute for declogging due to the pods.

(3) It should be easily cleanable.

c) Shelling unit

I. Shelling Drum

(1) It should be strong enough that to avoid damages and cracks during shelling operation.

(2) It should be stable to perform the shelling operation effectively and smoothly.

(3) It should be made of non reactive material to keep the natural taste of chickpea kernel.

(4) It should be adjustable so that the clearance with shelling roller can be adjusted.

II. Shelling Roller

(1) It should be strong enough to withstand with different speed and feed.

(2) It should be made of non corrosive and non reactive material.

(3) The peripheral length of the shelling roller should be enough so that the husk of pod removes completely without damaging the kernel.

(4) It should be easily repairable.

(5) It should be easily cleanable.

3.6 Modification of Stripping Unit

3.6.1 Modification of Stripping Roller

For the modification of the stripping roller, two circular discs of 210 mm diameter, 1 mm thickness and peripheral thickness of 20 mm were fabricated and welded parallel with the shaft of 25 mm diameter along with their centres. Distance between the discs from their inner face was kept 340 mm. Jigsaw of 380 mm length, 1 mm thickness and 60 mm breadth was used as stripping element. Spacing between two tips of teeth of saw was 13 mm. To fix this jigsaw on roller, wooden planks of 380 mm length, 24 mm thickness and 45 mm breadth were used. Jigsaw was bolted on wooden slats along the length of slats. Total eight sets of jigsaw and wooden slat bolted on the periphery of roller. A drive shaft of 25 mm in diameter carrying the stripping roller, welded on each side of the discs ran through the axis of stripping roller. The drive shaft was mounted on pedestal bearings and fitted to a driven pulley through a V-belt by an electric motor. (Plate 3.2)

Plate 3.2 Modified Stripping Roller

Stripping roller cover, made of 1mm GI sheet was used to cover the stripping unit. For feeding the plants for stripping, 90 × 470 mm opening was given in the cover at operator side. A movable window pan was provided below the opening to clean the pod collection unit and discharge chute. After stripping the pods moves towards shelling unit through a pod collection unit and discharge chute which was located just below the stripping roller. (Plate 3.3)

Plate 3.3 Stripping Roller Cover

3.6.2 Pod Collection Unit and Discharge Chute

The pod collection unit and discharge chute was made of 0.5 mm thick GI sheet, was placed below the stripping roller to receive the stripped pods and shredding. Chute shape and inclined wall facilitates stripped material to slide easily and to send it to the shelling unit. Dimensions of pod collection unit were 490 × 485 mm with 280 mm depth. The inclination angles for discharge chute was 42°5’24''(42.09°), for side walls was 51°50’24''(51.84°) and front wall of discharge chute was 65°56’24''(65.94°). (Fig. 3.2)

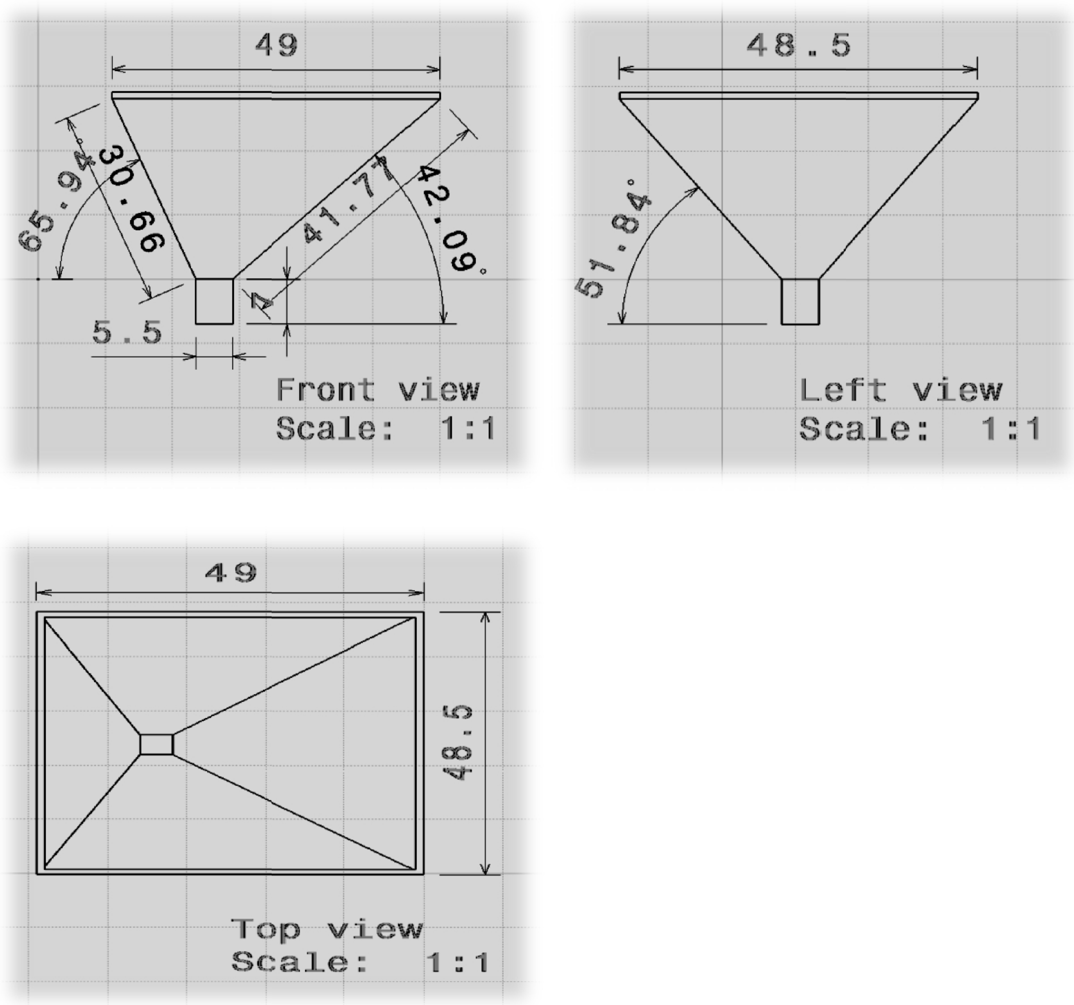


Fig 3.2 Orthographic View of Pod Collection Unit and Discharge Chute

3.6.3 Testing of Stripping Unit

In BIS Standard IS 3327:1965 the procedure for testing a pedal operated paddy thresher is mentioned. This procedure was modified and adopted for testing the stripping unit of the machine. The details are given as follows:

3.6.3.1 Size of Stripping Cylinder

The stripping length of the stripping cylinder was kept 380mm as per BIS specification. According to BIS Standard IS 3327:1965 one person can operate the thresher for a threshing length of 450 mm and for two operators this length is specified to be 700 mm.

3.6.3.2 Setting the Strength of Stripping Element

To check the strength of stripping element a load of 30 kg was hung from the wooden slats attached with the stripping roller. The slats with stripping element did not come off because it was tightly fitted to the stripping roller with arrangement of nuts and bolts.

3.6.3.3 Procurement of Chickpea for Testing

Freshly harvested chickpea plants were procured from the local market. The moisture content of chickpea pods observed to be 70.12% (wb). The variety of chickpea was identified in the Department of Plant Breeding and Genetics. The variety was JG322.

Plate 3.4 Fresh Green Chickpea

3.6.3.4 Determination of Theoretical Capacity of the Stripping Unit

A bunch of green chickpea plants weighing about 250 g was fed to the stripping unit. It took about 30 seconds to strip the pods from the entire bunch. Operator took another 5 seconds to turn left and feed another bunch. In this way 25 kg of plants were stripped at a stretch, in one hour.

3.7 Modification of Shelling Unit

Before modification the green chickpea pod stripping cum shelling machine had three shelling rollers. Shelling of pods was based on the principle of rubber roll sheller. But due to three rollers, it was very difficult to maintain their different speed ratio and it added more weight to machine. The pods were used to come in contact between these rollers for only two times, thereby desired shelling was not obtained.

3.7.1 Fabrication of Shelling Unit

Shelling unit comprised of an abrasive roller and a stationery concentric drum over it. The cylindrical drum was made of 4 mm thick PVC material with dimensions of 380 mm length and 230 mm diameter, was procured from local market (Plate 3.5). Inside the drum 3 mm thick dotted type rubber mate was pasted which absorbed additional force and prevented the kernels from physical damage. The drum was hanged on the frame with help of bolts and nuts below the pod collection unit and discharge chute, so that the detached pods could fell inside the drum by action of gravity. 50 × 50 mm opening was given on the drum at feeding end for feeding of pods into shelling unit and 50 × 50 mm opening was given on the drum for outlet. Two adjustable angles were given on machine frame towards length side of drum, which made the drum stable during shelling operation.

Plate 3.5 PVC Drum

Shelling roller of 170 mm diameter and 305 mm length was made of aluminum, fabricated in local market. Shelling roller was in cylindrical shape. The corrugated metal sheet of width 3.81 mm having horizontally 8 holes and vertically 5 holes per 25.4 mm (1 inch) was pasted on the peripheral surface of shelling roller. The corrugated metal sheet was used for increasing the effect of shelling. A drive shaft of 25 mm diameter carrying the shelling roller, which was welded on each side of the roller, ran through the axis of shelling roller. The drive shaft was mounted on pedestal bearings and fitted to a driven pulley through a V-belt by an electric motor. (Plate 3.6)

Plate 3.6 Shelling Roller

The shelling roller was placed inside the drum in such a way that the clearance between roller surface and inner periphery of drum could be adjusted. A 7 mm thick jute rope was wrapped on the shelling roller in helical form with 68 mm pitch space, so that unshelled pods, shelled kernel and husk could be sent to the outlet. According to the size of the pods the gap was adjusted by nuts which were used in bolts to hang the drum. Both ends were packed during shelling operation. (Plate 3.7)

Plate 3.7 Shelling Unit

3.8 Cleaning Unit

After shelling the husk of pods, unshelled pods, whole kernel, leaves and broken were separated in cleaning unit by centrifugal blower. Blower had the four blades fan of 280 mm length and 100 mm width which were made of GI sheet of 1 mm thickness. The diameter of the blower was 285 mm and blower ran by the pulley and belt.

3.9 Experimental Plan

Different variables selected for the evaluation of the performance of the machine are as below:

S. No.	Variables	Level	Values
1.	Feed Rate (kg/hr)	7	12,24,30,36,42,48,60
2.	Stripping roller speed (m/s)	15	1.86 to 3.42
3.	Shelling roller speed (m/s)	15	2.46 to 4.49

3.10 Calculation of Stripping Efficiency

Stripping efficiency was calculated by using the following expression:

$$\eta\ (\text{stripping})\ \% = \left[1 - \frac{\text{Weight of pods left on plants after stripping}}{\text{Weight of pods before stripping}}\right] \times 100$$

3.11 Calculation of Shelling Efficiency

Shelling efficiency was calculated by following expression:

η (shelling) % = [1- (wt. of unshelled pods / wt. of total pods after stripping)] x E_{wk} x 100

Where,

Coefficient of wholeness (E_{wk}) = [wt of whole kernels / (wt. of whole kernels + wt. of brokens)]

3.12 Calculation of Overall Machine Efficiency

Overall machine efficiency can be calculated by the following formula:

η (stripper cum sheller) % = stripping efficiency x shelling efficiency x machine effectiveness (E_m) x 100

Where,

η (stripping) = [1- (no. of unstripped pods / total no. of pods in plant)]

η (shelling) = [1- (no. of unshelled pods / total no. of pods for shelling)] x E_{wk}

machine effectiveness (E_m) = [1- (no. of waste pods / total no. of stripped pods)]

and,

Coefficient of wholeness (E_{wk}) = [wt of whole kernels / (wt of whole kernels + wt of brokens)]

3.13 Workmanship and Finish

To improve the durability of machine component all the wooden and metallic part were painted with corrosive risk preventive paint. The rollers are free from any misalignment during rotation. Also cleaning of corrugated metal sheet is necessary for the better action of shelling. Hence the rollers free from above two defects because these may impair its service ability.

3.14 Safety Measures

All the metallic and wooden edges of the machine were rounded. A feeding trough was attached to the body of the machine in front of stripping unit in which only space for feeding of green chickpea plants was provided.

3.15 Measurement of Physical Properties of Chickpea Pods

One hundred pods were selected randomly and engineering properties such as length (a), width (b), thickness (c), mass (m), volume (V), true density (T_D), geometric mean diameter (D_g) and surface area (S) were measured. (Sahay and Singh, 2001)

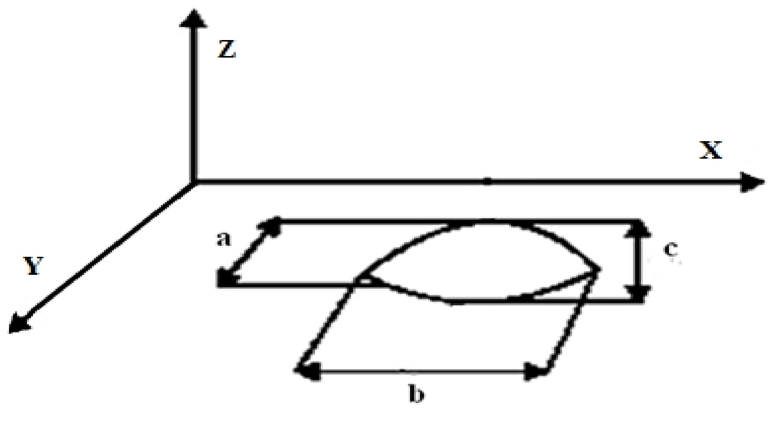


Fig 3.3 Illustration of Measurement of Geometric Dimensions

Geometric Mean Diameter,

$$D_g = (a\ b\ c)^{1/3} \quad (3.1)$$

Sphericity

$$S = (a\ b\ c)^{1/3} / a \quad (3.2)$$

3.15.1 Determination of Angle of Repose

The angle of repose is the angle between the base and the slope of the cone formed by vertical fall of the granular material on a horizontal plane. The size, shape, moisture content and orientation of pods affects the angle of repose.

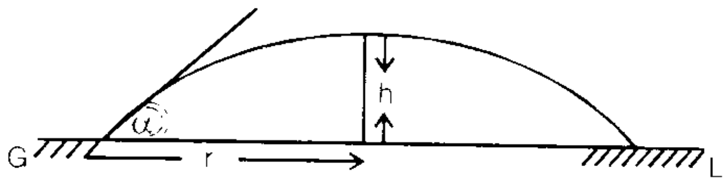


Fig 3.4 Angle of Repose

Angle of repose was calculated by making the regular heap by dropping the chickpea pods through funnel over smooth surface. The height and diameter of the heap were measured by measuring tape. Angle of repose was measured by using the following relationship:

$$\text{Angle of repose (degree)} = \tan^{-1} (\text{height / radius}) \quad (3.3)$$

3.15.2 Coefficient of Friction

Coefficient of friction was computed by using inclined plane. Metal sheet of the pod collection unit and discharge chute and the corrugated metal sheet used on shelling roller were placed one by one on the movable plane. Chickpea pods were then placed over the surface the movable plane was then gradually lifted to a position where by the pods had just started sliding down to the plane. The plane was clamped at this position and angle of friction was measured. The same procedure was repeated thrice. The coefficient of friction was determined by using the following relationship:

Coefficient of friction,

$$\mu = \tan \theta \quad (3.4)$$

Where,

μ = Coefficient of friction,

θ = Angle of friction,

3.15.3 Bulk Density

The bulk density is the ratio of mass of group of individual particle and space occupied by the entire mass, including the air space and was determined using following relationship. It was measured by a 1000 ml measuring cylinder. Chickpea pods were poured inside the cylinder and shaked 10 times manually to fill the pore spaces. (Mohsenin, 1986)

$$\text{Bulk Density} = \frac{\text{mass of sample (g)}}{\text{volume of flask occupied by the sample (cm}^3\text{)}} \quad (3.5)$$

3.15.4 True Density

The True density was determined using the toluene (C_7H_8) displacement method. 500ml toluene was used in place of water, because it is not absorbed by crop material. The volume of toluene displaced was found by immersing chickpea pods of known mass in the toluene. (Mohsenin, 1986)

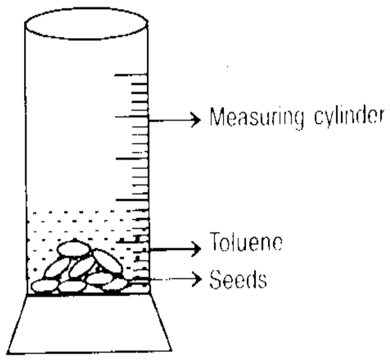


Fig 3.5 Illustration of True Density

$$\text{True density (g/cm}^3\text{)} = \frac{\text{Weight of sample (g)}}{\text{Volume displaced (cm}^3\text{)}} \quad (3.6)$$

3.16 Equipment and Instruments

3.16.1 Electronic Weighing Balance

Digital electronic weighing balance (Manufactured by-Citizen, Model No:CY-3600 (Plate 3.8A) with maximum-360 g and minimum-10 mg weighing capacity was used for weighing green chickpea pods. The least count of machine was 0.001 g.

Plate 3.8A

Digital electronic weighing balance (Manufactured by–Citizen) (Plate 3.8B) with maximum-30 kg and minimum 20 g weighing capacity was used for weighing green chickpea plants. The least count of balance is 1 g.

Plate 3.8B

Plate 3.8 Electronic Weighing Balance

3.16.2 Digital Vernier Caliper

Length, width and thickness of chickpea pods were measured by using a digital vernier caliper (Make – Workshop Innovation Ltd) with least count 0.01mm. (Plate 3.9)

Plate 3.9 Digital Vernier Caliper

3.16.3 Digital Tachometer

The speed of the rollers was measured by contact type digital tachometer (Make – Systems and Controls Ltd., Bangalore). Operating range of digital tachometer was 30 - 5000 rpm. (Plate 3.10)

Plate 3.10 Digital Tachometer

3.16.4 Inclined-Plane Apparatus

An inclined-plane apparatus was used to determine coefficient of friction for pods to pod collection unit and discharge chute and shelling roller abrasive surface. (Plate 3.11)

Plate 3.11 Inclined-Plane Apparatus

3.16.5 Hot Air Oven

Hot air oven (Make – Labtech Instrument, Indore) was used to measure the moisture content of chickpea pods, which have digital thermostat to control and measure the temperature and its operating temperature range between 50°C to 300°C. (Plate 3.12)

Plate 3.12 Hot Air Oven

RESULTS AND DISCUSSION

Experiments were conducted to evaluate the physical properties of the green chickpea pods and the performance of the modified green chickpea pod stripping cum shelling machine in the Department of Post Harvest Process and Food Engineering, College of Agricultural Engineering, Jabalpur. The results obtained are presented in the following sections.

4.1 Physical Properties

4.1.1 Size and Unit Mass of Green Chickpea Pods

100 green chickpea pods were selected for the determination of unit mass and physical dimensions (viz. length, width and thickness). The moisture content of green chickpea pods was found 70.08% (w.b.). Geometric mean diameter and sphericity was calculated by the Eq. 3.1 and Eq. 3.2 respectively. Table 4.1 represents the obtained data. Length of the fresh green chickpea pods ranged between 21.14 to 27.10 mm with average length of pod was 24.28 mm. The SD was calculated to be 1.26 mm. Width and thickness of the pods ranged between 9.07 to 11.51 mm and 9.85 to 12.48 mm, respectively, with average width and thickness of pod were 10.63 mm and 11.24 mm, respectively (Appendix A-1). SD for width and thickness were 0.52 mm and 0.60 mm, respectively.

Table: 4.1 Length, width, thickness, weight, geometric mean diameter and sphericity of sample of 100 green chickpea pods at 70.08% moisture content (w.b.)

	Length (mm)	Width (mm)	Thick-ness (mm)	Unit mass (g)	Geometric mean diameter (mm)	Sphericity
Range	21.14-27.10	9.07-11.51	9.85-12.48	0.52 to 1.23	12.77-15.15	0.54-0.63
Mean	24.28	10.63	11.24	0.89	14.28	0.58
SD	±1.26	±0.52	±0.60	±0.20	±0.58	±0.02

Geometric mean diameter and sphericity for the pods were found to be 14.28 mm and 0.58, respectively. The SD of geometric mean diameter and sphericity was found to be 0.58 mm and 0.02, respectively. Clearance between abrasive roller surface and inner periphery of shelling drum and size of the inlet of shelling unit were decided by using the obtained data.

The average mass of green chickpea pod was found to be 0.89 g (Appendix A-2) with a SD of 0.20 g. Results indicates that green chickpea pods used in the present study were relatively medium in size and fairly uniform in weight.

4.1.2 Bulk Density and True Density of Green Chickpea Pods

The bulk density and true density of the green chickpea pods are important parameters for designing of the pod collection unit and discharge chute. Table 4.2 represents the obtained data. Bulk density was calculated by Eq. 3.5. A measuring cylinder of 1000 ml capacity was used to measure the bulk density of green chickpea pods. Average weight of sample was found to be 219.40 g and the bulk density obtained 438.80 kg/m^3. The bulk density of green chickpea pods ranged from 436 kg/m^3 to 440 kg/m^3.

Table: 4.2 Bulk density of green chickpea pod

Samples	**Sample weight (g)**	**Occupied volume in cylinder (cm^3)**	**Bulk density (kg/m^3)**
Sample I	220.00	500	440
Sample II	218.00	500	436
Sample III	219.00	500	438
Sample IV	220.00	500	440
Sample V	220.00	500	440
Mean	219.40		438.80

True density was determined by the method described in section 3.15.4. Table 4.3 represents the obtained data. A measuring cylinder of 1000 ml capacity was used. 500 ml of toluene was used to fill the voids between the pods. Average weight of sample was found 220.00 g and the average volume of pods and toluene was found 771.42 ml. The average value of true density was calculated of 810.55 kg/m^3 whereas, the range of true density was found to vary from 809.12 kg/m^3 to 811.80 kg/m^3.

Table: 4.3 True density of green chickpea pod

Samples	**Sample weight (g)** **W**	**Volume of pods + toluene (cm^3)** **V_1**	**Volume of toluene (cm^3)** **V_2**	**True density (kg/m^3)** **$W/(V_1 - V_2)$**
Sample I	220.00	771.60	500	810.01
Sample II	220.00	771.00	500	811.80
Sample III	220.00	771.90	500	809.12
Sample IV	220.00	771.00	500	811.80
Sample V	220.00	771.60	500	810.01
Mean	220.00	771.42	500	810.55

4.1.3 Determination of Angle of Repose and Coefficient of Friction

Angle of repose was measured by method described in section 3.15.1. The results obtained are presented in Table 4.4. It is evident from the data that the angle of repose for green chickpea pods over GI sheet ranges between 21°26'24" to 27°43'48" with an average of 24°57'.

Coefficient of friction was measured by using inclined plane apparatus. The average value of coefficient of friction for pods to GI sheet and corrugated surface of shelling roller were found 0.605 and 0.638 with a SD of 0.063 and 0.096, respectively. (Table 4.4)

Table: 4.4 Angle of repose (¨) and coefficient of friction of green chickpea pods for GI sheet and shelling roller abrasive surface

S. No.	Angle of repose (¨) for GI sheet	Friction angle (θ), for GI sheet	Coefficient of friction, (tan θ) for GI sheet	Friction angle (θ), for sheller abrasive surface	Coefficient of friction, (tan θ) for sheller abrasive surface
1	27°43’48"	30°	0.57	33°	0.65
2	25°18’36"	35°	0.70	31°	0.60
3	21°26’24"	28°	0.53	30°	0.57
4	23°33’	31°	0.60	39°	0.80
5	26°43’12"	32°	0.62	30°	0.57
Mean	24°57’	31°12’	0.605	32°36’	0.638
SD	±2°30’36"		±0.063		±0.096

(Sample size of 10 chickpea pods)

Values of angle of repose and coefficient of friction were used to decide angle of inclination for pod collection unit and discharge chute walls.

4.2 Description of Modified Machine

Modified green chickpea pod stripping cum shelling machine have three basic units i.e. stripping unit, shelling unit and cleaning unit. The stripping unit has the stripping roller with stripping element of jigsaw. Jigsaw was used as the gap between each teeth of saw trapped the pods and the rotation of stripper offer the required force to detach the pods from the plant during stripping operation. Proper feeding, twist and sweep action on bunch of plant on stripping element, offer the desired detachment of pods with minimum physical damage to the pods.

Stripper roller of 330 mm diameter welded to 25 mm diameter of drive shaft was mounted on pedestal bearing on top of the frame, and driven through pulley and V- belt by an electric motor. After stripping the pods with shredding and leaves, fell into the pod collection unit and discharge chute. Shape of the pod collection unit and discharge chute and action of gravity facilitates the movement of stripped material into the shelling unit.

Shelling unit was located below the pod collection unit and discharge chute. The shelling unit consisted of an abrasive roller of 170 mm diameter and a stationery concentric drum of 230 mm diameter over it. The corrugated metal sheet was fixed over the shelling roller for better shelling efficiency. The thickness of metal sheet used for construction was of size 12 gauge and the metal sheet used for covering of machine is of size 14 gauge. The gap between shelling roller and drum may be adjusted as per the size of pods for shelling. The separation of husk and kernels of green chickpea was effected by abrasive action and shear forces caused on the pods when the roller rotated in the drum. Dotted type rubber mat pasted inside the drum, facilitated minimum physical damage to kernels during shelling operation. Shelling roller welded to a drive shaft of 25 mm diameter was mounted on pedestal bearing at the middle of the frame, and driven through pulley and V- belt.

After shelling the unshelled pods, husk, whole kernels and broken were moved in front of blower of cleaning unit located below the shelling unit. The husk was blown off and the green kernels dropped as the final product.

After modification the height of the machine was reduced from 1.865 m to 1.660 m and weight of the machine was reduced from 140 kg to 90 kg. These reductions made easier stripping operation and transportation of the machine.

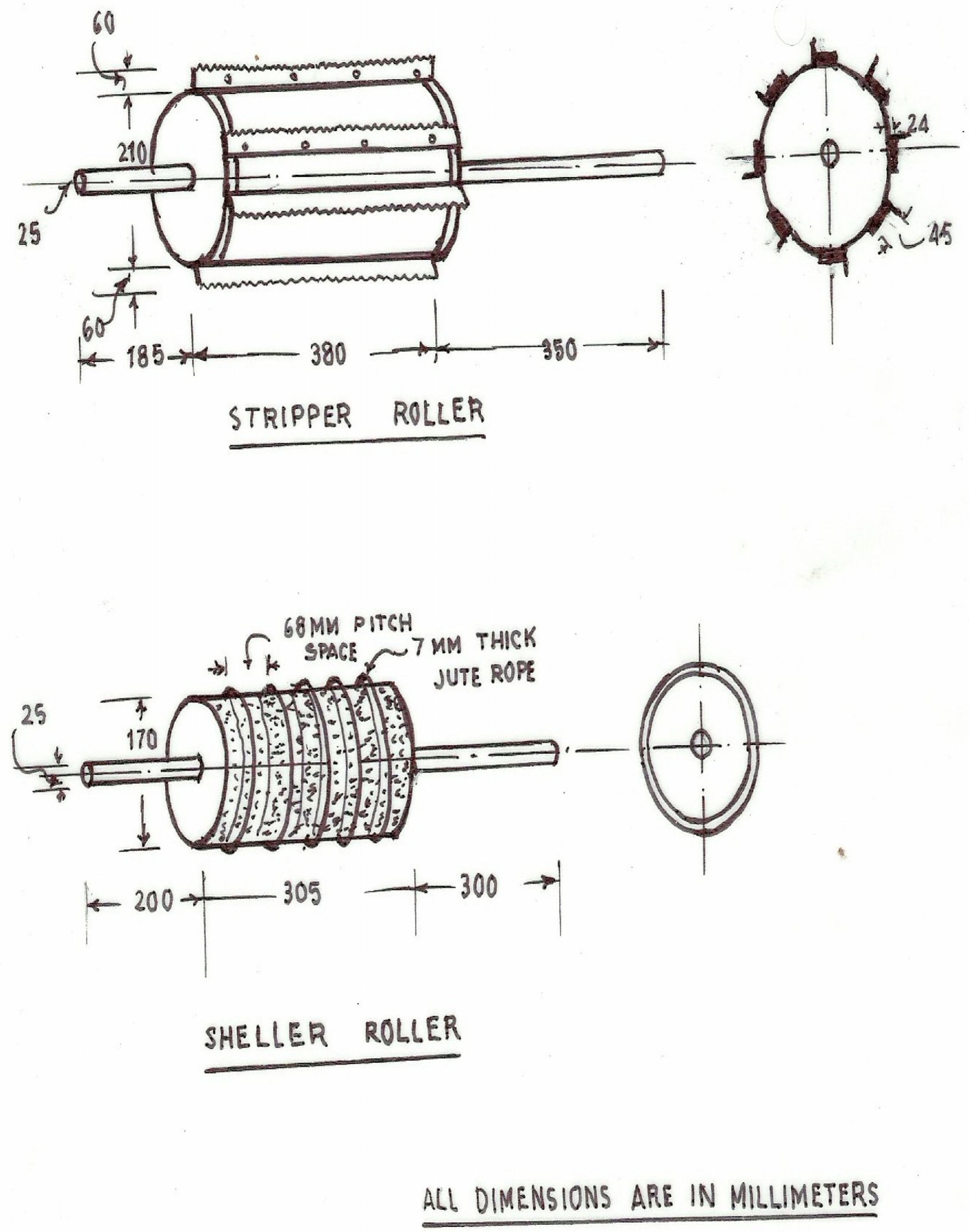
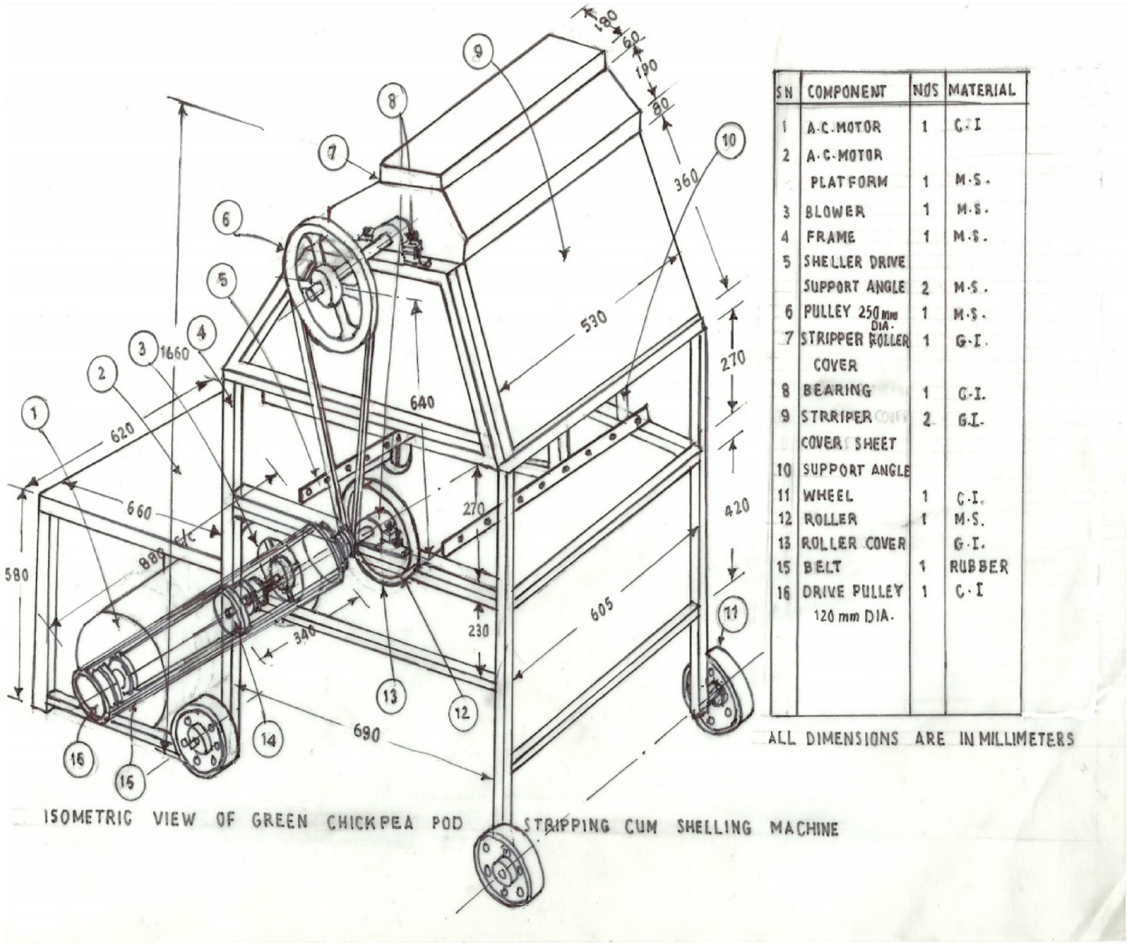


Fig 4.1 Stripping and Shelling Roller



SN	COMPONENT	NOS	MATERIAL
1	A.C. MOTOR	1	C.I
2	A.C. MOTOR PLATFORM	1	M.S.
3	BLOWER	1	M.S.
4	FRAME	1	M.S.
5	SHELLER DRIVE SUPPORT ANGLE	2	M.S.
6	PULLEY 250 mm DIA.	1	M.S.
7	STRIPPER ROLLER COVER	1	G.I.
8	BEARING	1	G.I.
9	STRRIPER COVER SHEET	2	G.I.
10	SUPPORT ANGLE		
11	WHEEL	1	C.I.
12	ROLLER	1	M.S.
13	ROLLER COVER		G.I.
15	BELT	1	RUBBER
16	DRIVE PULLEY 120 mm DIA.	1	C.I

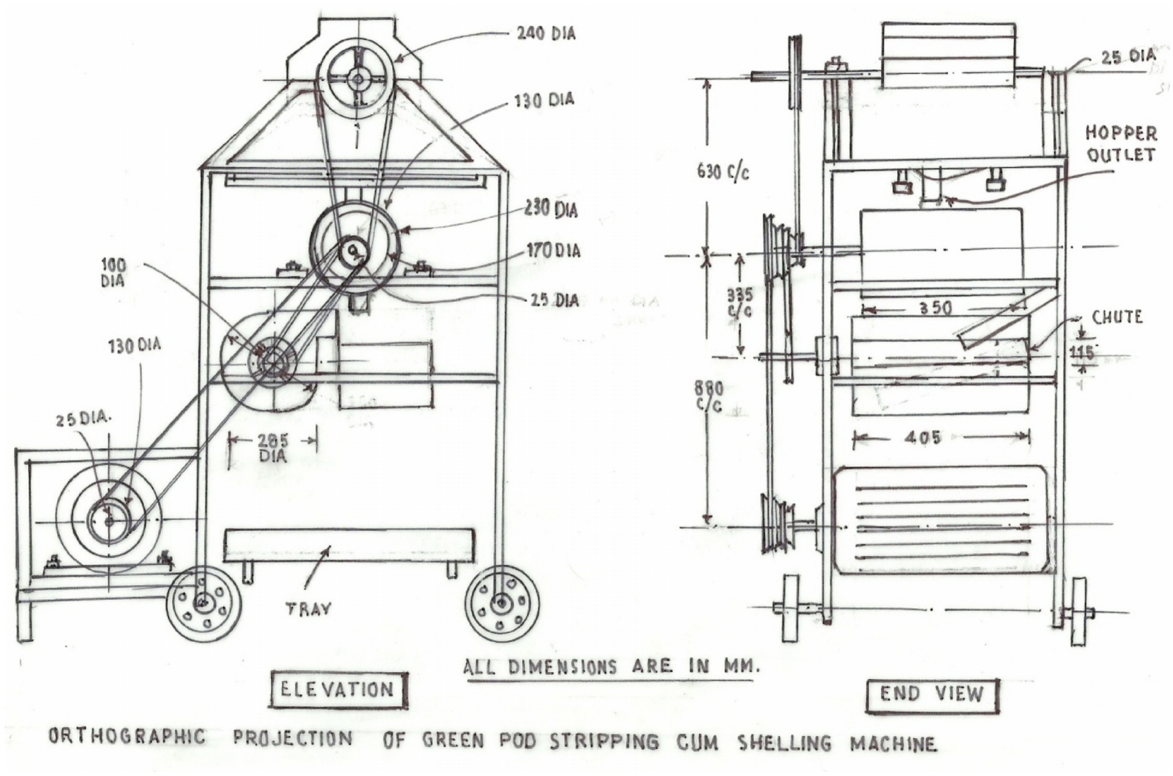


Fig 4.2 Isometric and side views of Modified Green Chickpea Pod Stripping Cum Shelling Machine

Plate 4.1 Modified Green Chickpea Pod Stripping cum Shelling Machine.

4.2.1 Testing of Green Chickpea Stripping cum Shelling Machine

To test the machine, JG322 variety of chickpea was procured from the local market. The stripping and shelling unit was tested for running it continuously for one hour. Performance of the stripping and shelling unit was checked separately. A bunch of green chickpea plants was held before stripper. It took about 40 seconds to strip the pods from the entire bunch. Operator took another 20 seconds to turn left and feed another bunch. In this way bunch of the plants took 1 minute for stripping. The pods after stripping were collected at the pod collection unit and discharge chute and weighed to find out stripping efficiency and these collected pods were sent to shelling unit manually to find out the shelling efficiency. For calculating the overall machine efficiency, total number of pods was counted before stripping and shelling and both operations i.e. stripping and shelling were performed simultaneously.

4.2.1.1 Stripping Unit

The stripping unit was designed for a capacity of 46.32 kg/hr and it was fabricated and fixed as per the procedure laid out in BIS Standard IS 3327:1965. The actual capacity was observed to be 36 kg/hr. The actual capacity was quite low compared to the theoretical capacity of 46.32 kg/hr (calculated in section 3.1.1 of chapter 3). This may due to the reason that theoretical capacity was calculated on single plant basis and at no load condition offering zero resistance to the movement of plant inside the stripping unit.

The materials for construction of various components of the stripping cylinder suited well for required operation and no break down was observed. The slates were made of wood, the shaft and discs were made up of mild steel. The stripping element was jigsaw, made of iron and chrome alloy ball pedestal bearings were used. The setting strength of the stripping element with wooden slats was also found to be in conformation with predecided setting strength of 30 kg.

4.2.1.2 Shelling Unit

The shelling unit also operated flawlessly for one hour. Different adjustment of gaps could also be done as per requirement. The shelling unit was tested as per the Indian standard specification for paddy dehusker no. IS 8824:1977. The roller and cover drum were made of aluminum and PVC material and also no break down was observed during shelling operation.

4.3 Performance Evaluation of the Stripping Unit

4.3.1 Effect of Stripping Roller Speed on Stripping Efficiency

To determine the effect of stripping roller speed on stripping efficiency, 15 samples of green chickpea plants at feed rate of 24 kg/hr were stripped at different speed of stripping roller (Appendix B-1). From the Table 4.5 and Fig. 4.3, it was observed that the stripping efficiency increased with increase in the stripping roller speed. The stripping efficiency was 92.48% at stripping roller speed of 1.86 m/s and it increased to 100% at stripping roller speed of 3.11 m/s. However, the stripping efficiency started decreasing with further increment in stripping roller speed. The stripping efficiency at 3.11 m/s stripping roller speed was 100% and it reduced to 92.89% and further 87.63% at stripping roller speed of 3.31 and 3.42 m/s respectively. The decrease in the stripping efficiency with increase in stripping roller speed after a certain level may be because of the difficulty encountered by the operator to sweep and twist the feed on stripping element.

Table 4.5 Effect of stripping roller speed on stripping efficiency

S. No.	Stripping roller speed (m/s)	Stripping efficiency (%)
1	1.86	92.48
2	1.95	93.20
3	1.98	94.03
4	2.09	91.80
5	2.22	92.30
6	2.28	94.32
7	2.38	96.89
8	2.60	97.60
9	2.83	99.12
10	2.93	99.55
11	3.04	100.00
12	3.11	100.00
13	3.17	99.32
14	3.31	92.89
15	3.42	87.63

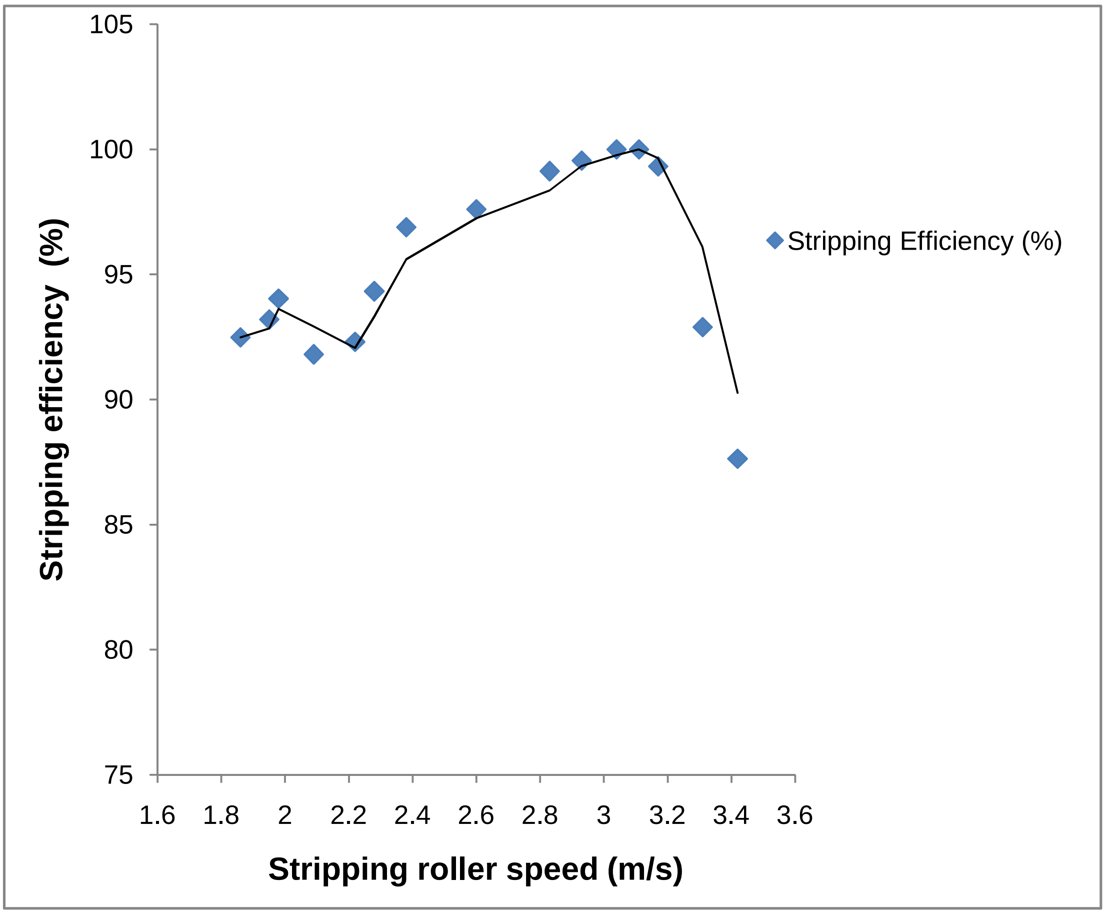


Fig 4.3 Effect of stripping roller speed on stripping efficiency of green chickpea pod stripping cum shelling machine

4.3.2 Effect of Feed Rate on Stripping Efficiency

To determine the effect of feed rate on stripping efficiency five samples of green chickpea plants at feed rate 12, 24, 36, 48 and 60 kg/hr were selected and stripped at five selected roller speed viz. 2.60, 2.83, 2.93, 3.04 and 3.11 m/s (Appendix B-2). From the observations (Table 4.6 & Fig. 4.4) it is clear that the stripping efficiency increased with increment in the feed rate upto a feed rate of 36 kg/hr and thereafter a decrement in the stripping efficiency was observed with an increment in the feed rate. The maximum stripping efficiency (100%) was observed at 36 kg/hr feed rate at a stripping roller speed of 2.93 m/s. The minimum value of stripping efficiency (58.47%) was observed at a feed rate of 60 kg/hr at a stripping roller speed of 3.11 m/s. The decrement in stripping efficiency with an increment with feed rate beyond 36 kg/hr may be because of higher amount of feed leading to difficult twisting and sweeping of green chickpea plants on the stripping element.

Table 4.6 Effect of feed rate on stripping efficiency

	Stripping efficiency (%) at stripping roller speed (m/s)				
Feed Rate (kg/hr)	**2.60**	**2.83**	**2.93**	**3.04**	**3.11**
12	98.38	97.63	99.21	99.89	98.23
24	97.56	98.88	97.89	99.36	99.80
36	96.89	98.83	100.00	99.35	98.86
48	91.14	86.21	85.00	81.02	76.89
60	78.36	71.89	64.38	60.08	58.47

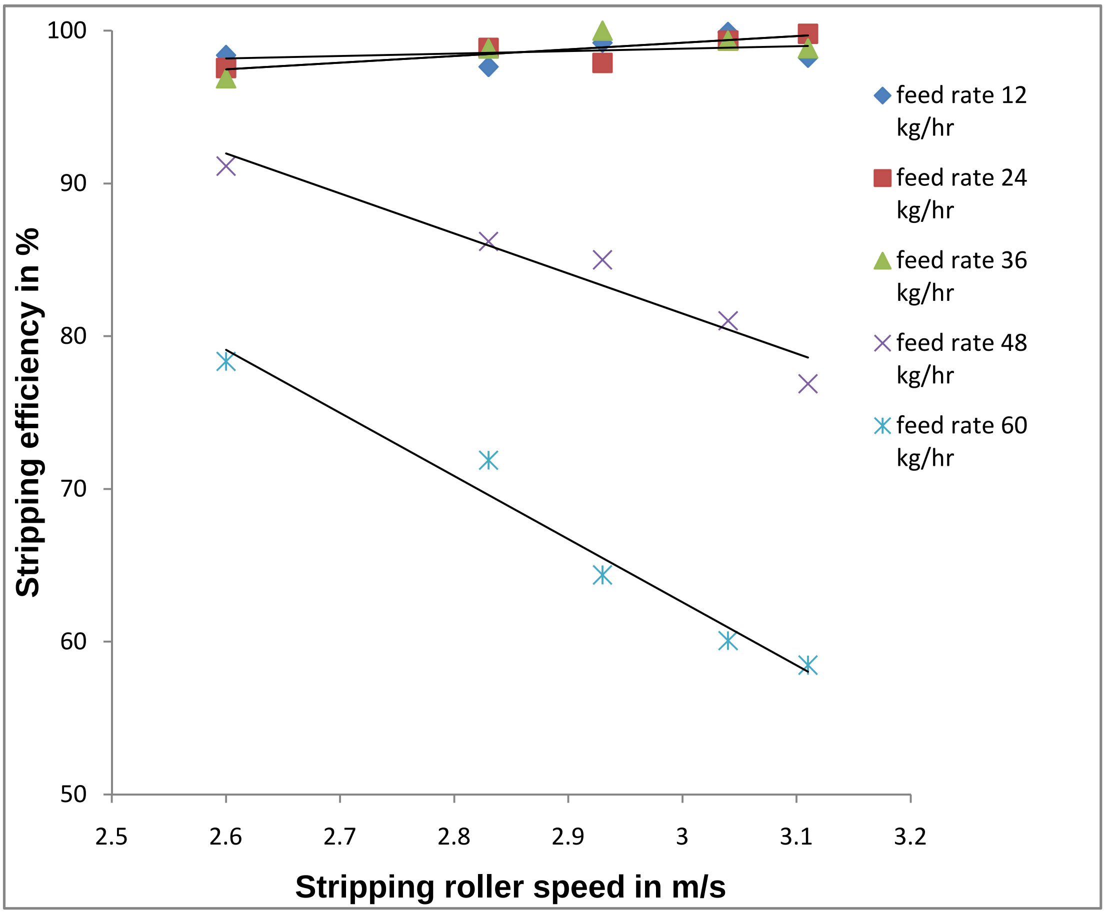


Fig. 4.4 Effect of feed rate on stripping efficiency of green chickpea pod stripping cum shelling machine

4.3.3 Effect of Moisture Content of Pods on Stripping Efficiency

To evaluate the effect of moisture content of pods on stripping efficiency, green chickpea plant at feed rate of 24 kg/hr were stripped at four speed level viz. 2.83, 2.93, 3.04 and 3.11 m/s of stripping roller (Appendix B-3). From the Fig 4.5 it was observed that stripping efficiency initially increased upto 99.63% with increment in stripping roller speed upto 3.04 m/s then stripping efficiency decreased with further increment of stripping roller speed. From the Table 4.7 and Fig 4.6, It was also observed that there is no effect of moisture contents of pods on stripping efficiency but the weight of shredding and twigs increased with decrement in moisture contents of pods and increment in stripping roller speeds. Increased weight of shredding and twigs clogged the outlet of pod collection unit and discharge chute and it might be reduced the machine effectiveness.

Table 4.7 Effect of moisture content of pods on stripping efficiency

M.C. of pods (%) (w.b.)	Stripping roller speed (m/s)	Wt. of shredding and twigs (g)	Stripping efficiency (%)
70.12	2.83	112.23	97.60
	2.93	120.66	97.98
	3.04	132.45	99.32
	3.11	128.46	98.12
62.31	2.83	115.12	96.38
	2.93	125.44	98.00
	3.04	133.41	99.32
	3.11	145.01	98.89
56.56	2.83	120.21	98.16
	2.93	135.56	98.83
	3.04	139.03	99.44
	3.11	151.08	99.10
51.35	2.83	129.89	97.38
	2.93	140.16	98.13
	3.04	148.45	99.63
	3.11	156.32	96.68
47.88	2.83	137.09	98.83
	2.93	146.43	99.00
	3.04	159.63	99.32
	3.11	170.12	97.62

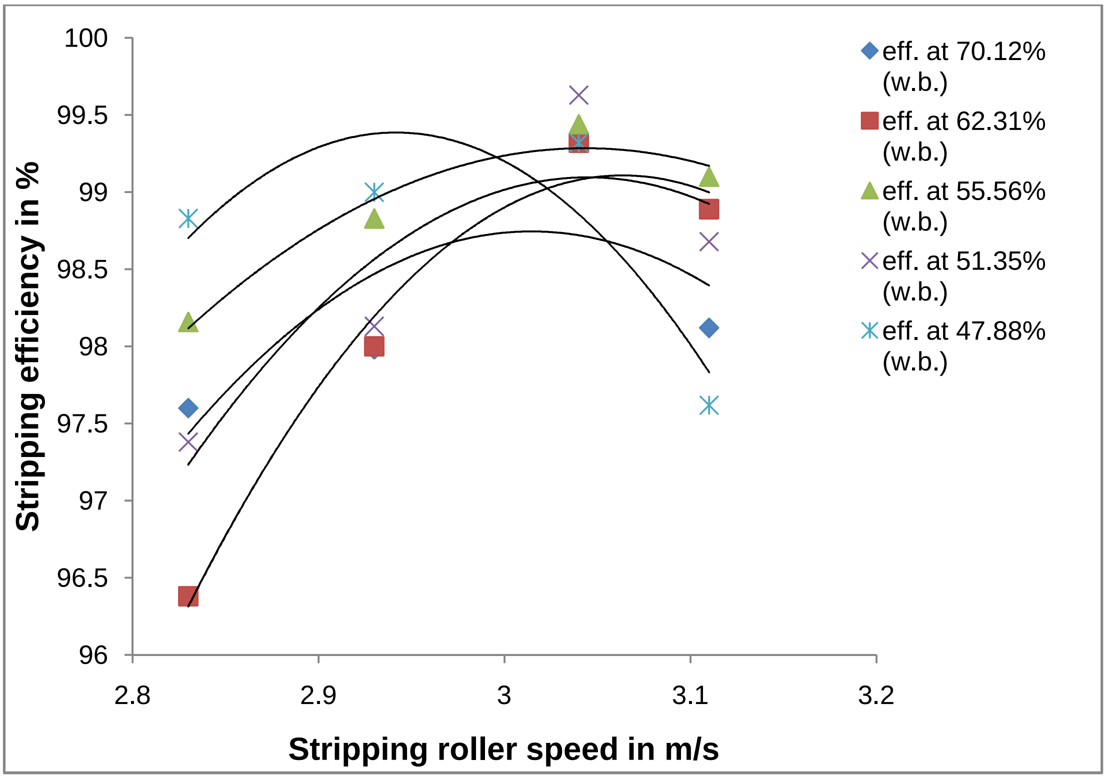


Fig 4.5 Effect of moisture content of pods on stripping efficiency of green chickpea pod stripping cum shelling machine

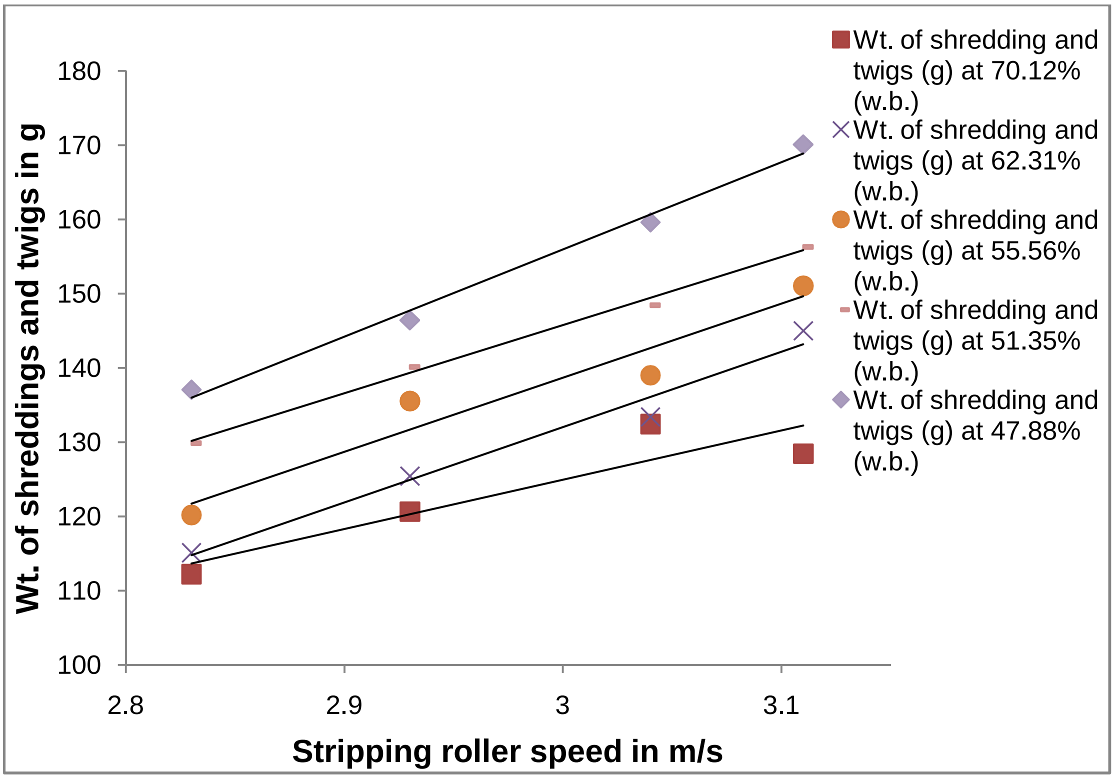


Fig 4.6 Effect on weight of shredding and twigs after stripping at different feed rate of green chickpea pod stripping cum shelling machine

4.4 Performance Evaluation of Shelling Unit

Performance of the shelling unit was dependent upon the shelling roller speed, moisture content of the green chickpea pods and clearance between inner peripheral surface of the drum and abrasive surface of shelling roller.

4.4.1 Effect of Shelling Roller Speed on Shelling Efficiency

Green chickpea pods were stripped at a feed rate of 24 kg/hr and collected. The stripped pods were manually fed through the pod collection unit and discharge chute to the shelling unit to determine the shelling efficiency. The clearance between inner peripheral surface of the drum and abrasive surface of shelling roller was kept 12 mm. The green chickpea pods were shelled at fifteen selected shelling roller speeds. The obtained data is presented in Table 4.8.

From the data it is clear that the shelling efficiency ranged between 76.60 to 92.57%. The maximum shelling efficiency was observed 92.57% at shelling roller speed of 4.19 m/s. The shelling efficiency increased with increase in the shelling roller speed till 4.19 m/s and it started decreasing with further increment in shelling roller speed (Fig 4.7). The shelling efficiency was dependent upon the coefficient of wholeness (Appendix C-1).

Table 4.8 Effect of shelling roller speed on shelling efficiency

Feed (total wt. of pods after stripping) (g)	Clearance (mm)	Shelling Roller speed (m/s)	Coefficient of wholeness	Shelling efficiency (%)
129.77	12	2.46	0.91	76.60
135.86	12	2.58	0.94	79.13
139.26	12	2.61	0.96	81.94
156.17	12	2.75	0.97	82.60
150.45	12	2.93	0.92	81.40
145.99	12	3.00	0.98	83.42
156.64	12	3.14	0.97	83.33
163.30	12	3.43	0.93	86.02
153.38	12	3.73	0.99	88.32
111.54	12	3.87	0.97	89.56
158.00	12	4.00	0.93	91.38
151.25	12	4.09	0.98	92.21
156.09	12	4.19	1.00	92.57
110.16	12	4.36	0.95	87.40
110.41	12	4.49	0.91	83.15

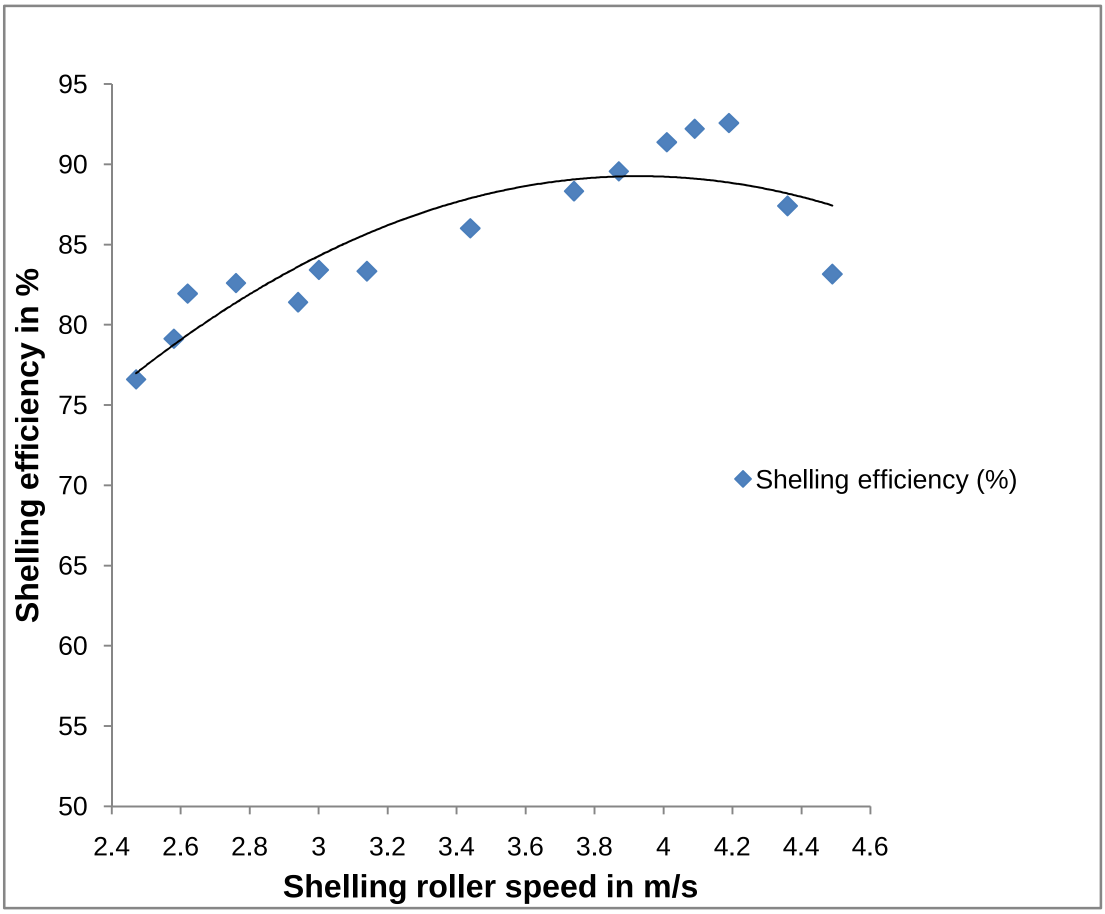


Fig 4.7 Effect of shelling roller speed on shelling efficiency of green chickpea pod stripping cum shelling machine

4.4.2 Effect of Moisture Content of Pods on Shelling Efficiency

To evaluate the effect of moisture content of green chickpea pods on shelling efficiency of green chickpea pod stripping cum shelling machine the pods were stripped from the plants at a feed rate of 24 kg/hr. The stripped pods were then shelled at four selected shelling roller speeds and clearances. From the Table 4.9 it was observed that pods at moisture contents of 70.12 and 62.31% (w.b.) shelled easily at clearance of 12 and 11 mm and shelling efficiency ranged between 84.38 and 91.35%. As the moisture reduced, pods shrinked and shelling was difficult at same clearance, so clearance was reduced to 9 mm, 8 mm and 7 mm for moisture contents of pods at 56.56, 51.35 and 47.88% (w.b.) respectively. The minimum shelling efficiency was observed 58.00% at moisture contents of 47.88% (w.b.). The decrement in shelling efficiency with decrement in moisture content of pods mainly because of increment in weight of broken which led to the reduction in the value of coefficient of wholeness (Appendix C-2).

Table 4.9 Effect of moisture content of pods on shelling efficiency

M.C. of pods (%)(w.b.)	Feed (total wt. of pods after stripping) (g)	Clearance (mm)	Sheller speed (m/s)	Coefficient of wholeness	Shelling efficiency (%)
70.12	123.29	12	3.73	0.91	87.32
	118.24	12	3.87	0.93	88.15
	116.10	12	4.00	0.92	89.62
	130.60	12	4.09	0.96	91.35
62.31	109.24	11	3.73	0.86	84.38
	116.22	11	3.87	0.87	85.74
	125.39	11	4.00	0.88	87.18
	114.57	11	4.09	0.89	88.30
56.56	117.37	9	3.73	0.78	74.88
	123.41	9	3.87	0.78	76.37
	120.55	9	4.00	0.82	80.36
	129.85	9	4.09	0.85	81.18
51.35	108.34	8	3.73	0.71	65.08
	128.66	8	3.87	0.71	67.36
	123.96	8	4.00	0.68	67.44
	116.07	8	4.09	0.73	69.72
47.88	130.65	7	3.73	0.62	58.00
	116.37	7	3.87	0.63	61.39
	110.39	7	4.00	0.63	62.10
	112.82	7	4.09	0.65	63.15

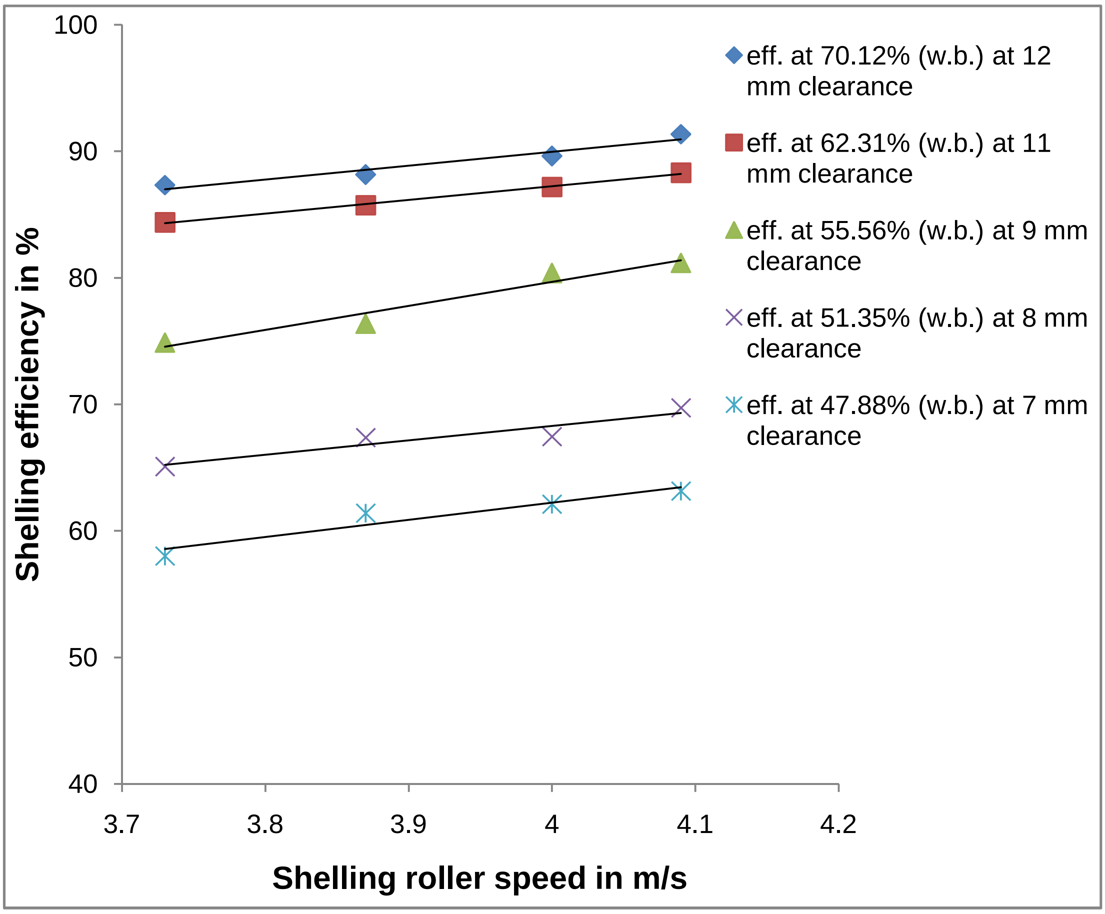


Fig 4.8 Effect of moisture content of pods on shelling efficiency of green chickpea pod stripping cum shelling machine

4.5 Overall Performance of the Machine

Overall machine performance included stripping efficiency, shelling efficiency and machine effectiveness. Performance of the blower for cleaning unit was not taken in present study.

Overall performance of the machine was calculated by conducting trials at five selected feed rates viz. 24, 30, 36, 42 and 48 kg/hr at five stripper roller speeds (2.83, 2.93, 3.04, 3.11 and 3.17 m/s) and five shelling roller speeds (3.73, 3.87, 4.00, 4.09 and 4.19 m/s). The calculated values of overall machine efficiencies are shown in Table 4.10. From the table it is evident that at a given set of stripping roller and shelling roller speed the overall machine efficiency increased with an increment in the feed rate upto a certain limit and then started decreasing with further increment in the feed rate e.g. at 2.93 m/s stripping roller speed and 3.87 m/s shelling roller speed the overall machine efficiency was 83.77 at a feed rate of 24 kg/hr and it increased to 85.51 and further to 87.75% at feed rates of 30 and 36 kg/hr respectively. However, the overall machine efficiency started decreasing from 87.75 to 69.08% when the feed rate increased from 36 to 48 kg/hr. Similarly, at 3.17 m/s stripping roller speed and 4.19 m/s shelling roller speed the overall machine efficiency was 80.26 at a feed rate of 24 kg/hr and increased to 82.51 and further to 86.39% at feed rates 30 and 36 kg/hr respectively. The overall machine efficiency started decreasing from 86.39 to 55.36% when the feed rate increased from 36 to 48 kg/hr. The initial increment in overall machine efficiency with the increment in the feed rate may be because of higher stripping efficiency (Appendix D). The decrease in overall machine efficiency with further increment in feed rate after a certain limit (36 kg/hr) may be attributed to lower stripping efficiency (Appendix D).

At a certain feed rate the overall machine efficiency initially increased with increment in stripping roller speed and shelling roller speed and it started decreasing with further increment in stripping roller and shelling roller speeds e.g. at 2.83 m/s stripping roller speed and 3.73 m/s shelling roller speed the overall machine efficiency at 36 kg/hr feed rate was 81.68 and it increased to 89.69% at a stripping roller speed 3.04 and shelling roller speed 4.00 m/s.

From the Fig 4.9 it is clear that the maximum overall machine efficiency (89.69%) was obtained at a feed rate of 36 kg/hr for stripping roller speed of 3.04 m/s and shelling roller speed of 4.00 m/s. For feed rates 42 and 48 kg/hr the overall machine efficiency decreased with increase in stripping roller and shelling roller speeds. The minimum overall efficiency was obtained for stripping roller and shelling roller speed of 3.17 and 4.19 m/s respectively at a feed rate 48 kg/hr. The probable reason for decrement in overall machine efficiency was poor stripping and shelling efficiencies (Appendix D).

Table 4.10 Overall machine efficiency at selected set of speed of stripping & shelling roller

Feed rate (kg/hr)	Overall machine efficiency (%) at roller speed (m/s) of					
	Stripper	**2.83**	**2.93**	**3.04**	**3.11**	**3.17**
	Sheller	**3.73**	**3.87**	**4.00**	**4.09**	**4.19**
24		81.99	83.77	84.92	86.79	80.26
30		84.96	85.51	89.12	84.04	82.51
36		81.68	87.75	89.69	88.01	86.39
42		83.34	77.85	76.96	72.29	73.04
48		77.38	69.08	62.44	63.74	55.36

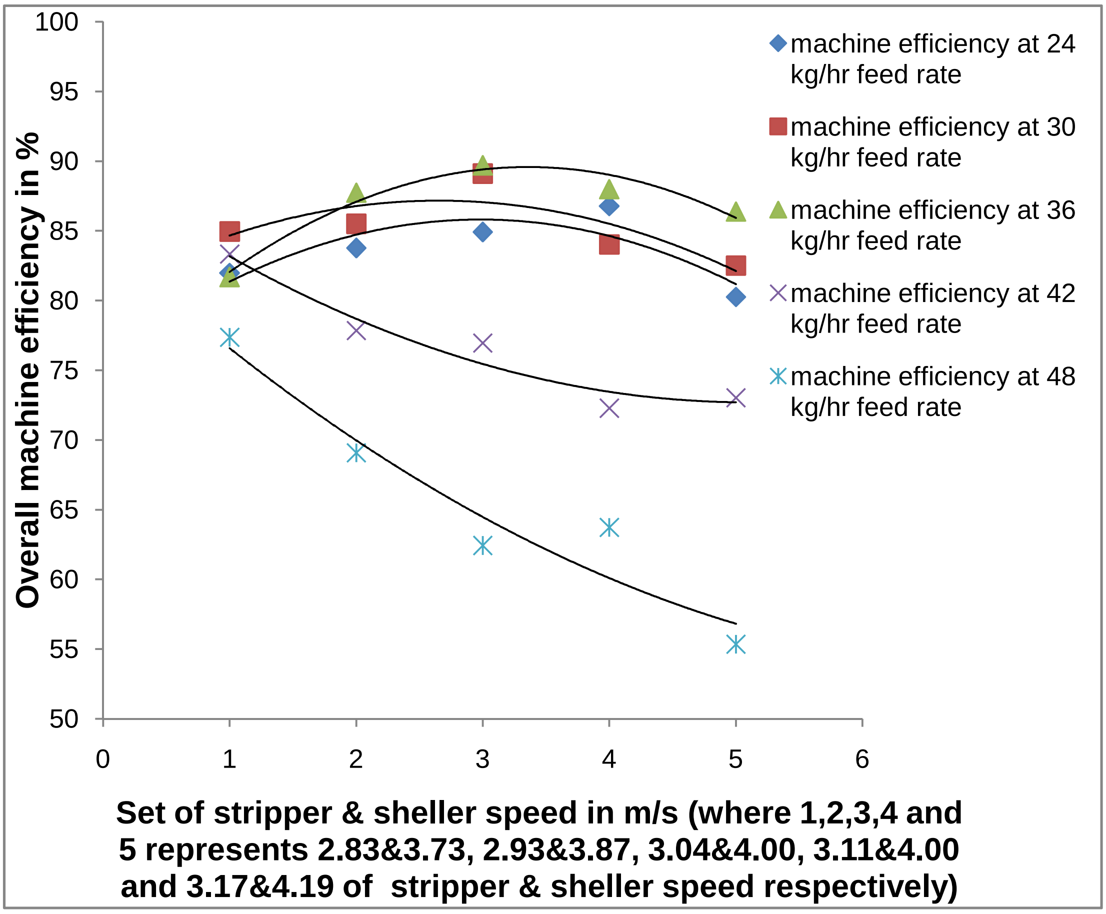


Fig 4.9 Overall machine performance at different feed rate and at selected stripping and shelling roller speed of green chickpea pod stripping cum shelling machine

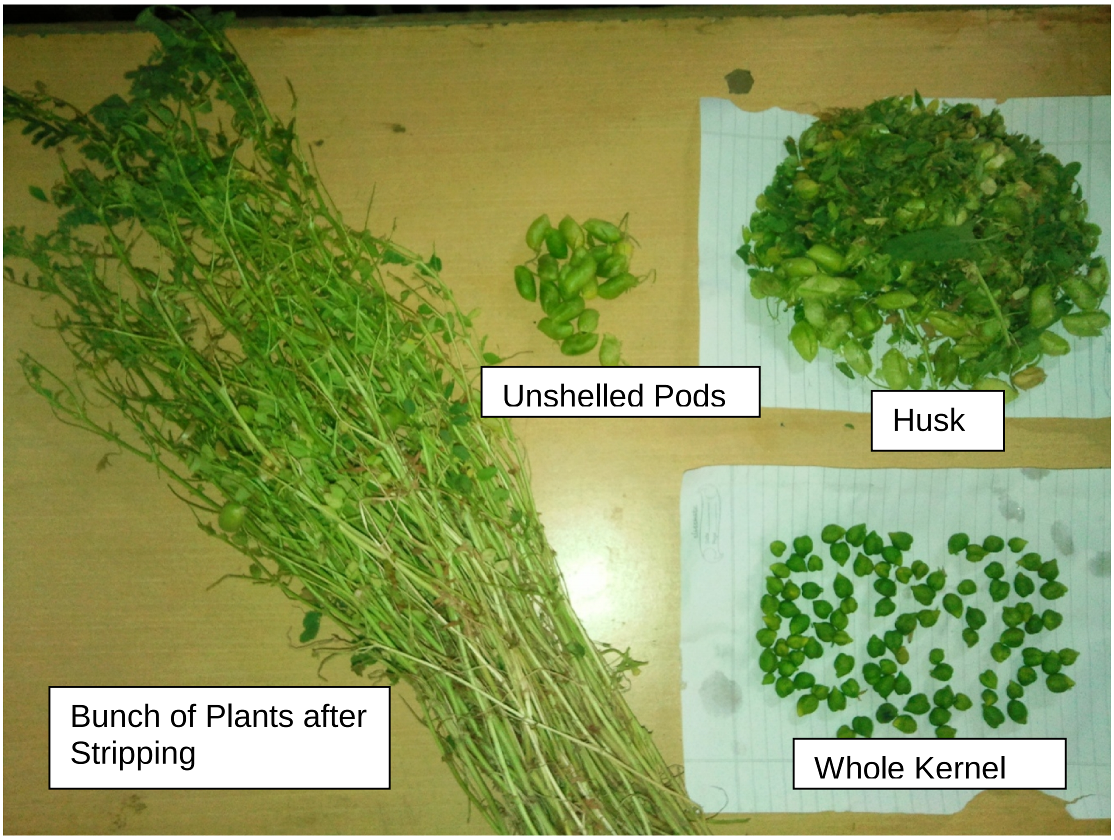


Plate 4.2 Mass fractions of various end products

4.8 Economic Analysis of Green Chickpea Pod Stripping cum Shelling Machine

Rational choice of agricultural machines is necessary as a condition of high efficiency of farm mechanization. When making decision about purchasing of machine the potential buyer takes into consideration several factors. One of most important is the price of the machine. The price determines first of all the investment cost, but it also affects such elements of operation costs like depreciation, interest and storage. However, not always more expensive machine creates higher unitary costs. Sometimes operation costs of advanced, more reliable and productive machine are lower as compared to a less expensive, but also less reliable and less productive one. Therefore, the choice of machine should be preceded by a careful economic analysis.

Following assumptions have been made when building the model. The maximal hours of machine work during the useful life amounts to 2000. 10 years standard useful life has been assumed. Therefore, the annual use of at least 200 hours was necessary so that each machine could work out 2000 hours during its useful life. In a case of annual use higher than 200 hours, the number of years of the useful life becomes relatively lower. Instead, in a case of a lower annual use of machines, the useful life can be prolonged up to maximum 20 years, followed by the increase of the coefficient of repair costs related to the price of the machine by 30%. This increase has to be assumed so that the growth of repair costs as a result of prolonging the useful life of machine could be taken into account. In the range from 10 to 20 years of the useful life the increase of value of the coefficient of repair costs related to the price of the machine, fluctuates between 0% and 30%. The increase is proportional to the prolongation of the useful life. In a case of annual use lower than 100 hours, the cost of depreciation grows. There are two reasons of the wear of machines. One is a waste of elements and damages during the work. Decrease of hours worked causes costs related to this factor to decrease. This fact has been taken into account in the model in the form of reduction of the value of the coefficient k, proportionally to the decrease of the annual use of the machine. Another reason is the deterioration of materials caused by environment factors. This has also been taken into account by above-mentioned increasing the value of coefficient of repair costs related to the price of the machine, in a case of prolonging the useful life of machines.

Input Information and assumptions:

Cost of Machine (Rs.)	-	50000.00
Life of Machine	-	10 yr.
Interest Rate (per annum)	-	15%
Salvage Value	-	10%
Operation Time	-	8 hr/day
Semiskilled Labour	-	200 Rs./day
Raw Material	-	20 Rs./kg

Power (motor)	-	0.75 kW
Cost of Housing	-	500 Rs./month
No. of labour required	-	1
Main Product recovery	-	30%
By product recovery	-	70%
Market rate of pod detachment and dehusking	-	5 Rs./kg
Operation period	-	100 days/year
Electricity charge	-	6.50 Rs./kW-hr
Maintenance cost	-	2000 Rs./year

Financial Analysis:

Working Capital Requirement (Rs.)	=	Labour Charges for 6 days + Stock purchased for 6 days + Electricity charge for one month + Housing For one month
	=	6 X 200 + 1728 X 20 + 281.25 + 500
	=	36541.25
Annual fixed cost (Rs.)	=	Depreciation + Interest + Maintenance cost + Housing cost + Interest on working capital
	=	5000 + 7500 + 2000 + 6000 + 5481.20
	=	25981.20
Capital Investment (Rs.)	=	Cost of equipment + 30% of working capital
	=	50000 + 10962.40

	=	60962.40
Hourly Variable cost (Rs.)	=	Labour cost + Material cost + Electricity maintenance
	=	25 + 36 x 20+ 6.5 x 0.75
	=	749.875
Annual Variable cost (Rs.)	=	Hourly Variable cost x No. of operation hour per year
	=	749.875 x 800
	=	599900
Total Annual cost (Rs.)	=	599900 + 25981.20
	=	625881.20
Cost of operation (Rs./hr) (Including material cost)	=	625881.20 / 800
	=	782.35
Processing Cost (Rs./kg)	=	(cost of operation - material cost) / capacity
	=	62.35 / 36
	=	1.73

SUMMARY AND CONCLUSIONS

A green chickpea pod stripping cum shelling machine was modified and its performance was evaluated. The stripping and shelling units were modified to detach the green chickpea pods from the plants then remove the green chickpea kernels from husk or pod with minimum damage. Use of jigsaw as a stripping element was a new concept to detach the pods from the plant. The shelling unit consisted of an abrasive roller and a stationery concentric drum over it. Increased path of travel for pods in between shelling roller's abrasive surface and drum facilitated increased shelling efficiency. Use of dotted type rubber mate prevented from physical damage to the kernels. The stripping unit of the machine was constructed, tested as per BIS NO.3327-1965 and the shelling unit was tested as per BIS NO.8824-1977. The performance of the machine was evaluated using different feed rate, different speeds of stripping and shelling rollers and at different moisture content of pods. The important conclusions are drawn as follows:

1. Average size and sphericity of the green chickpea pods were 44.28 mm and 0.58 respectively at 70.12% moisture content (w.b.).

2. Average weight of 100 green chickpea pods were 89 g at 70.12% moisture content (w.b.). It was also found that some pods were kernel less with 50 mg to 0.4 g of weight.

3. Bulk density of green chickpea pods was 438.80 kg/m^3 while the true density was 810.55 kg/m^3 at 70.12% moisture content (w.b.).

4. The stripping efficiency of green chickpea pod stripping cum shelling machine varied between 87.63 to 100% dependent upon feed rate, size, wt. & maturity of the pods and twist and sweep action on bunch of chickpea plant on stripping element.

5. The shelling efficiency of green chickpea pod stripping cum shelling machine ranged between 76.60 to 92.57%. The shelling efficiency was dependent upon size of the pods, shelling roller speed, coefficient of wholeness and moisture content of pods.

6. Overall machine efficiency ranged between 80.20 to 89.69% at 70.12% moisture content of pods.
7. Overall machine performance dependent on machine effectiveness and feed rate.
8. The capacity of the machine is 36 kg/hr.
9. The cost of processing was 1.73 Rs./kg.

SUGGESTIONS FOR FUTURE WORK

1. After stripping provision of grading and separating of pods from shredding and twigs should be given.
2. For the better cleaning and clear fractions, a metal sheet having holes same as the green kernels may be placed such that slope should be given to it in the direction of air, also the speed of blower should be increased.

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