Design and Development of Semi-automatic Vertical Flow Pulse Thresher

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ABSTRACT-*Vertical flow thresher was developed for complete threshing of a variety of pulses having diverse physical characteristics like different shape & size of seeds, pods & plants and crushing of entire crop residues into powdery mass suitable for animal feed simultaneously. Threshing & crushing mechanisms are totally different from axial flow threshers. Significant features are 99% threshing efficiency without breakage of seeds irrespective of different types of pulses, such as black gram, green gram, horse gram and red gram with >90% germination of threshed seeds. Combined threshing & crushing actions are executed by multiple progressive shears between a set of radial rotary beaters and a stationary beater inside a vertical hopper. The crops flow vertically downwards into shear zones by scissoring actions of the beaters and gravity. Therefore power consumption is reduced drastically and this machine is operated by 2.0 hp single phase electric motor for threshing of 150 to 250 kg seeds or 400 to 500 kg dry crops per hour. Winnowing of seeds is carried out by a winnower-cum-grader which can be attached to the thresher during need. Configuration and performance of this novel vertical flow thresher for threshing of different types of pulses are presented and discussed.*

Keywords-Progressive shears in point contacts, threshing different pulses, vertical flow, high efficiency without seed breakage.

1. INTRODUCTION

Different cereals such as rice, wheat, maize, sorghum (jowar), millet (bajra & ragi), oat etc are used as staple food in India and many developing countries. A variety of general pulses like black gram, green gram (Moong), horse gram (Kulthi), red gram, arhar, lentil, etc are consumed along with cereals every day to supplement proteins. Physical characteristics of these pulses such as shape, size & type of seeds, pods & plants are quite different from each other. Annual production of pulses in India is about 16 million ton [16] which is negligible compared to cereal production. Axial flow multi-crop threshers consuming 10 to 30 HP powers [4, 5, 10] are not effective for complete threshing & crushing of a variety of pulses having diverse physical characteristics. Some researchers had attempted to modify axial flow threshers for threshing few pulses besides cereals by adjusting some parts & parameters [3, 4, 5, 8, 10, 14]. Production of moong, black gram, horse gram, red gram, lentil etc are comparatively very less when compared to production of cereals by an individual farmer. Therefore such high power consuming axial flow thresher could not be farmer's friendly and effective for general pulses.

Generally the plants of pulses are leafy and short height within 8 inch. These are grown in less rain fed areas. The physical properties of the plants are different from each other. In few places of coastal Orissa, India the black gram plants are creeper in nature and 1 to 2 meters long. The dry plant of horse gram and lentil are soft & strong but not brittle and its stem does not break easily, whereas the dry plant of black gram and its pods are brittle which break easily. The pods of green gram are brittle but its stem & root are thick and strong which take more time for mutilating. The dry plant of red gram is short and strong, not brittle and not breaks easily. The beans or pods of these pulses are thin. The seeds or grains of the pulses are also different from each other. The seeds of black gram and green gram (Moong) are partly spherical and partly cylindrical, whereas the seeds of horse gram are flat and circular. The seeds of red gram are not completely spherical but somewhat irregular. The Bulk density of the grains of black gram and green gram varies from 1251 to 1305 kg/m^3.

Traditional threshing methods commonly practiced by the farmers are stamping (treading) by heavy animals, rolling the roller/ tractor or by beating the dry crops by heavy stick. Due to such improper threshing 10 to 15% seeds are lost in

the crop residues, maximum 85% seeds are recovered and 50 to 60% crop residues are crushed to small sizes. Traditional harvesting methods involve up-rooting matured pulse plants from the field, drying the green crop under sun till moisture content is reduced below 10%, and then threshing the dry crop under sun as mentioned above till most of the pods are open and seeds are released from the crop. Then large size stem & root of the plants are separated manually from the powdery mixture of seeds and crop residues. The powdery mixture is then winnowed by artificial air stream or through natural wind to separate seeds from crop residues and finally seeds is sieved manually to separate sand, mud etc. About 85-90% of seeds are collected from crops for human consumption and 10-15% seeds are lost in crop residues as un-threshed pods. Animals also eat away 3-5% seeds during threshing [11]. Loss of seeds in crop residues is estimated to nearly 1-2 million ton pulses per year in India. The powdery crop residue, called 'Bhusa' is an important animal feed. As the crop residue or Bhusa is a mixture of dried green leafy biomass & un-threshed pods with seeds and has nutritious value, most of the farmers feed their bullocks and cows with Bhusa. The traditional methods are highly labour intensive and non-economical. Also cleaning of seeds is not very good, which leads to damage of pulse due to pest infection during storage [7].

In this context, the author[1] has developed a low cost and less power consuming vertical flow Pulse Thresher-cum-Winnower for efficient threshing and cleaning of various types of pulses such as Black gram, Green gram (Moong), Horse gram (Kulthi), Red gram etc irrespective of different shape & size of pod and plant. The machine functions well without changing or modifying any fixture or parts. Main objective of this invention is to remove 100% seeds from the crop in order to increase yield, reduce labour and crush entire crop residues into small pieces suitable for animal feed.

2. MATERIALS AND METHODS

2.1. Existing Axial flow Threshers

All axial flow threshing machines have a threshing drum, which consists of a long cylindrical shaped member to which a series of pegs, knives or rasp bars are attached on its surface. The threshing drum is mounted on two bearings and rotates in a perforated trough like chamber, called the "concave". During threshing, crop is fed between the threshing drum and the concave, where it is subjected to a high degree of impact & frictional forces which detach seeds from pods [5]. The crop moves spirally between the threshing drum and a circular concave for several complete turns, with the help of louvers, which are simple plates attached helically to the casing covering the threshing drum. Schematic diagram is shown in figure-1.

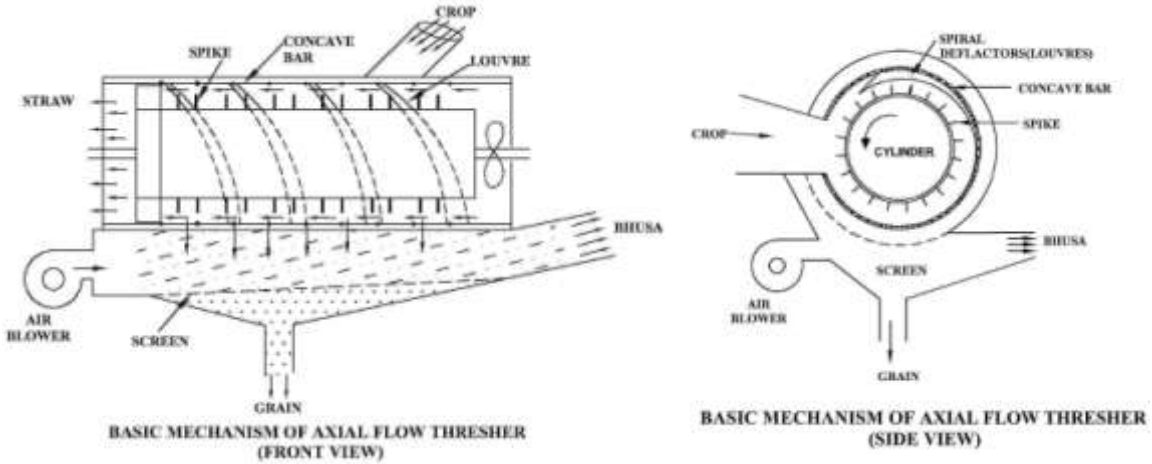


Figure 1: Schematic diagram of Axial Flow Thresher

Crop is thus threshed for a longer duration by the repeated impact of the threshing pegs. In these machines, almost all of the grain is separated from the straw through the concave perforations. Straw is finally ejected through a large straw outlet at the end of the concave. Most of Axial flow threshers are effective for cereals & few other crops like wheat, paddy, soybean, sunflower, barley and maize; but adjustment of its parts & changes of some parameters are necessary during threshing different crops to obtain high threshing efficiency. Some researchers have attempted to modify the axial flow wheat threshers to suit for threshing of a few other cereals, pulses and oil seeds [14]. The major modifications are carried out in construction of concaves, concave clearance, cylinder, size, shape, types and numbers of moving objects (spike tooth, rasp bars etc.) and also rpm of cylinder etc., although the changes are theoretically but practically not feasible for all types of crops. The existing multi-crop axial flow threshers at present are not suitable for a wide variety of pulses having varying moisture content. Again some adjustments or replacements of few parts are essential for threshing of pulses like red gram, pigeon peas etc. as reported in the literatures. However farmers found difficulty in adjusting and

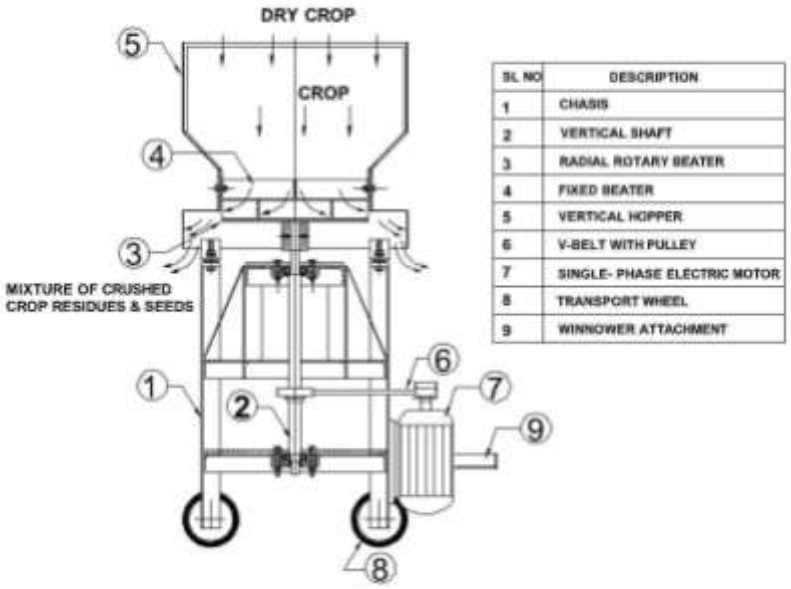
changing the parts during threshing of pulses and cereals. Again the power requirement is very high in these threshers. So the multi-crop axial flow threshers are not popular among the farmers for threshing of general pulses. Therefore it was desirable to develop a new thresher, which is capable of threshing a variety of pulses and widely accepted by the farmers [4].

2.2. Vertical Flow Pulse Thresher

In order to overcome the deficiencies in the existing design of threshers and to eliminate the huge requirement of power, the author[1] has designed and developed a Pulse thresher in Regional Research Laboratory, Bhubaneswar (presently CSIR-IMMT, Bhubaneswar), which is based on a completely new concept i.e. vertical flow. So the new thresher is named as vertical flow Pulse thresher-cum-winnower as it is capable of winnowing or cleaning the grains in addition to threshing the crops of a wide range of pulses with afore mentioned requisites [11]. After conceiving the new ideas, each part of the Vertical Flow Pulse Thresher & Winnower were designed, developed and tested by the author[1] in laboratory. Finally the commercial prototypes of Semi-automatic Pulse Thresher and Winnower were developed and tested in laboratory as well as by the farmers in different villages of Odisha. It was further modified to make it completely automatic in 2nd stage [13]. The semi-automatic Pulse Thresher-cum-winnower is described here. Its schematic diagram & picture are shown in figure-2.

2.2.1. Mechanisms of Vertical Flow Thresher

The principle of threshing in the vertical flow Pulse thresher is completely different than any other threshers developed so far in the world. The pulse thresher comprises a set of simple moving beater, a fixed beater and a cylindrical hopper. Primarily combination of these three components executes threshing and crushing operations of different pulses without adjusting any parts or parameters. A number of flat plates welded symmetrically and radially on a circular disc constitute the moving beater or moving blade. The moving beater is fixed at one end of a shaft which is mounted vertically on the chassis of the machine through a set of bearings. The fixed beater is rigidly fixed inside the cylindrical hopper. The hopper with fixed beater is mounted vertically on the chassis over the moving beater, and all these three parts have a single vertical axis. The moving (rotary) beater is partly submerged inside one end of the hopper.



SL NO	DESCRIPTION
1	CHASIS
2	VERTICAL SHAFT
3	RADIAL ROTARY BEATER
4	FIXED BEATER
5	VERTICAL HOPPER
6	V-BELT WITH PULLEY
7	SINGLE- PHASE ELECTRIC MOTOR
8	TRANSPORT WHEEL
9	WINNOWER ATTACHMENT

Figure 2: Vertical Flow Pulse Thresher

The vertical clearance between surfaces of moving & fixed beater creates progressive shears. The shaft with moving beater rotates by a 2 hp electric motor / engine. The combination of fixed beater, moving beater and hopper create progressive shear actions and impacts, which crush the dry crops into small pieces and breaks its pods to remove the seeds. During threshing of materials, dry crops of pulses flow vertically drawnwards into the shear zone under influence of progressive scissoring actions executed by fixed & rotary beaters and also by gravity. Then the crushed materials obtain kinetic energy from the moving beaters and strike hard on a secondary peripheral drum inside the thresher, so that the balance unbroken dry pods if any break further to obtain complete threshing. The discharge of threshed materials from the thresher is obtained by centrifugal forces attained from the moving beater. The threshed materials release out of the thresher through the bottom opening of the cylindrical hopper. The threshing and crushing operations are carried out together. Progressive shear actions take place at multiple point contacts unlike line contacts in axial flow threshers. Threshing period is also quite short compared to axial flow threshers. The unique design and combination of the beaters execute nearly 7000 shear actions per minute in a narrow progressive shear zone, so the power requirement for threshing

has been reduced drastically. The energy consumption is too less (appx. 1 kwh) due to small shearing zone along a narrow slit. However a 2 or 3 hp prime mover is provided to counter the overloading of the crops into the threshers.

2.2.2. Mechanisms of winnower

A set of winnower is connected to the pulse thresher for separation and cleaning the seeds from the crop residue. The winnower comprises of an air blower, an air nozzle and a vibrating sieve. Both the thresher and winnower are operated by the same electric motor or engine. The blower & nozzle are placed below the vibrating sieve and create a rectangular thin air jet of high aspect ratio. The threshed materials are generally charged manually on the reciprocating sieve where small size materials are fluidized under the sieve and large size materials (crop residues without seeds) are removed on top of the sieve. The flat air jet behaves like a wide sheet of air spreading throughout the area below the vibrating sieve. The air jet is little under-developed at exit of the nozzle, so that it can expand fully to obtain uniform velocity below the sieve for better cleaning efficiency. The flat air jet carries the dust, chaps and crop residues to a distant place leaving behind clean seeds on the ground in a heap below the vibrating sieve. In this way complete threshing and winnowing of the seeds of pulses are carried out. Both threshing and cleaning operations can be carried out together or separately as per the need of the farmer. Schematic diagram of winnower is shown in figure-3. Schematic diagram & picture of Pulse thresher-cum-winnower are shown in figure-4.

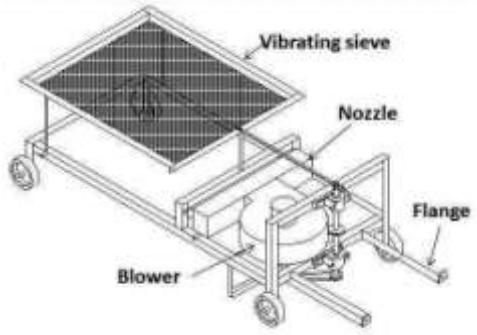


Figure 3: Diagram of Winnower

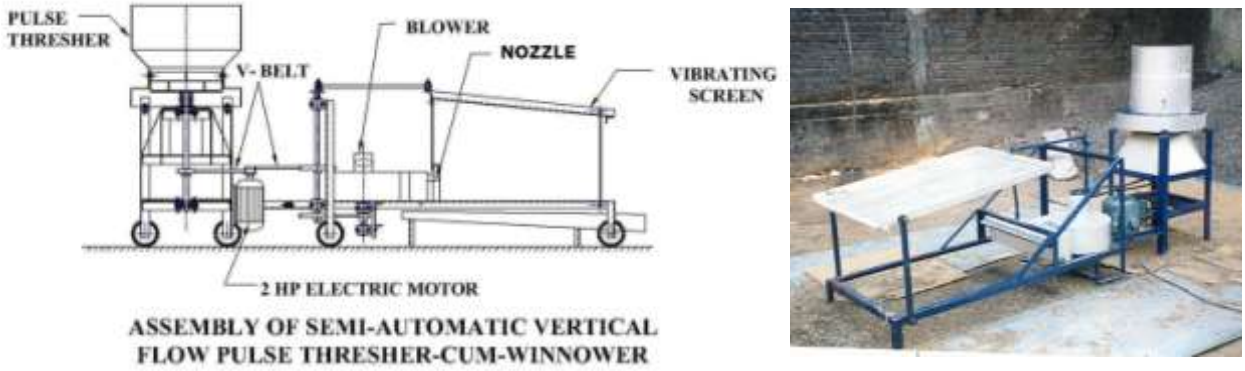


Figure 4: Semi-automatic Vertical Flow Pulse Thresher- cum- Winnower

3. RESULT AND DISCUSSION

3.1. Performance evaluation

The pulse thresher-cum-winnower was tested with different types of pulses such as black gram, green gram, horse gram & red gram in the laboratory and at farmer's places. Based on the test results, the design was optimized and prototypes were fabricated and distributed to Agriculture Department of Govt. of Orissa for extensive field trial and demonstration among the farmers in 20 districts of Orissa, India. The performance of the prototypes was monitored jointly by the author (RRL, Bhubaneswar) and Agriculture department, Govt. of Orissa for a period of one year. The commercial model of the Pulse Thresher–cum-Winnower was developed based on the field results. It was essential to know about internal damage of the seeds. Seeds of different pulses were collected during the trials of the pulse thresher. At the same time seeds from same lot of crop were threshed by hand. Both types of threshed seeds of different pulses were tested for germination and results were compared. Only un-broken seeds were considered for germination test. The Seed Testing Agency, Govt. of Orissa had carried out germination study of different seeds threshed by Vertical Flow Pulse Thresher and by hand threshing from common lot of each pulse. The Seed Testing Agency had certified for safe use of the pulse thresher for germination purpose. The performance of the Semi-automatic Pulse Thresher- Winnower studied in laboratory and villages are shown in Table-3 & Table-4. Performance of threshing & winnowing operations carried out by the Pulse Thresher & traditional methods were compared and the results are shown in Table-5. Results of germination studies of different seeds are shown in Table-6. Performance of the winnower for cleaning of threshed dry crop is shown in table-7. Pictures of threshing & winnowing of pulses carried out at farmer's places are shown in figure-5.


Figure 5: Threshing and Winnowing by Pulse Thresher

Table-3: Laboratory performance of semi-automatic vertical flow pulse thresher-cum-winnower

Parameters	Black gram is	Green gram	Horse gram	Red gram
Average moisture in crop (%)	9.0	10.0	10.0	8.5
Threshing efficiency, (%)	99.60	99.15	99.95	99.10
Winnowing efficiency, (%)	> 99	> 99	100	> 99
Threshing capacity of dry crop, (kg/hr)	390	375	355	420
Winnowing capacity of threshed crop, (kg/hr)	> 600	> 600	> 600	> 600
Seed loss in crop residues, (%)	< 1	< 1	Nil	< 1
Breakage of seed, (%)	< 0.25	< 0.25	Nil	< 0.2
Size of crop residues, (mm)	5 - 80	5 - 80	5 - 100	5 – 60
Quality of crop residues suitable for fodder,(%)	100	100	100	100
Loss of half-filled seeds in un-threshed pods	< 0.2	< 0.2	Nil	Nil

- Average threshing capacity in terms of seed: Depends upon yield of the crop, which varies farmers to farmer. Average: 100 to 250 kg/hr.

Table-4: Performance of semi-automatic vertical flow pulse thresher-cum-winnower during field trails in villages.

Parameters	Black gram is	Green gram	Horse gram	Red gram
Average moisture in crop (%)	7 - 10	6 - 10	6.0	10.0
Threshing efficiency, (%)	99.80	99.90	100	99.85
Winnowing efficiency, (%)	> 99	> 99	100	> 99
Threshing capacity of dry crop, (kg/hr)	420	400	450	500
Winnowing capacity of threshed crop, (kg/hr)	> 600	> 600	> 600	> 600
Seed loss in crop residues, (%)	< 1	< 1	Nil	1.0
Breakage of seed, (%)	< 0.20	< 0.20	Nil	Nil
Size of crop residues, (mm)	5 - 100	5 - 100	5 - 100	5 – 75
Quality of crop residues suitable for fodder,(%)	100	100	100	100
Loss of half-filled seeds in un-threshed pods	< 0.2	< 0.2	Nil	< 0.3

- Average threshing capacity in terms of seed: Depends upon yield of the crop, which varies farmers to farmer. Average: 100 to 250 kg/hr.
- Thresher could not function with freshly rooted crop without sun drying.

3.1.1. Comparison between performance of semi-automatic vertical flow pulse thresher-cum-winnower and traditional threshing methods

To compare performance of pulse thresher with traditional harvesting methods, matured crop of black gram was selected for testing in a village. The black gram crop was collected from one land so that physical characteristics, such as size, growth, yield & moisture content of the crop were equal in all the tests. Two traditional harvesting methods, such as threshing by stamping of animals and beating the dry crop by a heavy stick were conducted. The crop was dried under sun for equal period before threshing in pulse thresher and traditional methods. All the tests were carried out together. The performances of different threshing methods are shown in table-5

Table-5: Comparison between the performances of semi-automatic vertical flow pulse thresher-cum-winnower with traditional threshing methods.

Parameters	By pulse thresher	By animal stamping	By beating with heavy stick
Name of pulse	Black gram	Black gram	Black gram
Manpower used	02	02	02
Number of animals used	Nil	04	Nil
Threshing capacity of dry crop (kg/hr)	450	185	115
Recovery of seeds from 100 kg dry crop (kg)	38	34	29
Seed loss in crop residue, (%)	< 1	11.41	24.43
Seed breakage, (%)	< 0.25	Nil	< 0.20
Size of crop residue within 100mm length, suitable for fodder (%)	100	30	15
Increase of yield over traditional threshing methods, (%)	11.76 - 31	---	---

Table-6: Comparison between germination of seeds threshed by Pulse thresher and hand threshing

Name of Pulse	Average moisture content of crops (%)	Germination of seeds (threshed by Pulse thresher) (%)	Germination of seeds (threshed by hand) (%)
Black Gram	9.0	89	92
Green Gram	10.0	90	93
Horse gram	10.0	90	91
Red Gram	8.5	92	94

Table-7: Laboratory performance of winnower for cleaning & separating seeds from dry threshed crop mass

Name of Pulse	Winnowing capacity in terms of dry threshed crop (kg/hr)	Winnowing capacity in terms of seed (kg/hr)	Seed in crop residue (%)	Foreign particles in cleaned seed (%)
Black Gram	720	275	< 0.2	1.5
Green Gram	715	250	< 0.2	1.45
Horse gram	750	300	Nil	0.5
Red Gram	780	315	Nil	1.2

- Rate of winnowing is less in field as it depends upon manual feeding of threshed crop mass over the vibrating sieve by the farmers.
- Winnowing capacity in terms of seed depends upon growth of plant & yield of crop.

3.2. Operating parameters and advantages

The parameters like speed of rotary beater, shear clearance between rotary & fixed beaters and bottom opening between hopper & rotary beater plate control the performance of threshing of pulses. These parameters are optimised which cannot be altered easily during operation. Different types of pulses were threshed with these optimised & fixed parameters without adjustment/ changing of any parts of the thresher. It is ascertained from test results in table 3 to 5 that these optimised parameters were found appropriate for efficient threshing of different pulses having diverse physical properties.

Besides above parameters, threshing efficiency is also dependent upon moisture of the crop. It is found from laboratory & field test results in table 3 to 5 that moisture content should be less than 10% to obtain optimum efficiency, crushing of entire crop residues into animal fodder and continuous operation of the thresher without jamming the beaters.

Seed breakage and seed loss in crop residues depends upon shear clearances between beaters & hopper and annular discharge opening area. All these parameters are optimised & fixed in the machine. It is found from table 3 to 5 that seed loss & seed breakage are negligible during threshing.

The crops do not undergo high frictional & impact forces during threshing in vertical flow pulse thresher, unlike axial flow threshers. Residence time of crop inside shear zone is very less. Therefore 60 to 80% power requirement is reduced when compared with axial flow threshers. Thresher and winnower are detachable, handy, less weight, mobile in nature. The winnower can be used for cleaning of a variety of food grains, cereals etc beside pulses.

The Seed Testing Agency, Govt. of Odisha as a third party, had carried out germination study of the seeds of different pulses threshed by pulse thresher and by hand threshing to assess internal damage of the seeds for comparison. Germination efficiency of both type of seeds are almost equal and more than 90%, shown in table-6. Therefore internal structure of seeds does not change during threshing by vertical flow pulse thresher and it is as good as seeds collected by hand threshing. It is confirmed from test results that vertical flow thresher is very safe for germination purpose.

From test results it is found that vertical flow pulse thresher is well suitable for efficient threshing of a variety of pulses with nearly 100% seeds recovery with negligible seed breakage and 2 to 3 times faster than traditional threshing methods. Entire crop residues are converted into powdery animal fodder. Drudgery & labor are also greatly reduced. Average yield of 10% seeds was increased over traditional methods.

Main hurdle observed during field trails was poor voltage of electricity power supply in many villages. The electric motor could not operate in rated speed. Therefore voltage step-up transformer (Invertor) was needed to operate the pulse thresher. Many farmers had suggested replacing electric motor by oil engine for above problems. Some rich farmers had also suggested for development of a fully automatic pulse thresher with built-in winnower operated by oil engine.

3.3. Extensive demonstration & commercialisation:

Before commercialisation of the semi-automatic pulse thresher-winnower, it was essential to assess efficacy and acceptability of the machine among the farmers in different geographical conditions. Moreover growth, size and yield of plant & seed of different pulses also vary as per geographical & land conditions. Therefore 14 sets of pulse threshers were demonstrated & operated by the farmers for one year in different villages of 14 districts of Odisha under direct supervisions & monitoring of Agriculture Department, Govt. of Odisha. After successful demonstration & field trails, technology of Semi-automatic Pulse thresher-Winnower was transferred to four entrepreneurs for mass production & marketing. Government of Odisha had approved 25% cost of this machine as subsidy to the farmers for extensive propagation in Odisha as well as to reduce seed loss & drudgery of farmers and increase production of pulses by the farmers.

4. CONCLUSIONS

Based on performance results and extensive field trails & demonstrations in villages of different districts of Odisha, the break-through novel design of semi-automatic vertical flow pulse thresher-cum-winnower was found highly efficient for threshing of a wide variety of pulses having diverse physical characteristics with >99% threshing efficiency, <1% seed loss in crop residues, almost nil damage of seeds, >90% germination, crushing of entire crop residues into powdery animal fodder, 2.0 hp power requirement and increase of 10% yield of seeds over traditional methods.

5. ACKNOWLEDGEMENT

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