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AMA

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VOL.54, NO.4, AUTUMN 2023

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EDITORIAL

The war between Russia and Ukraine continues. Ukraine and Russia were originally same Slavic ethnicity, though it is very strange how this happened. In the days of the Soviet Union, Russia and Ukraine were indispensable partners who helped each other. But now they are at war with each other. The history of mankind is indeed a history of wars. There may be various causes, but in short, wars are fought because people put their own interests first.

In this small planet, wars have occurred in various places. The most recent is the war in Palestine between Israel and the Hamas people.

Religious differences are also a major cause of war. Religious wars have been fought many times in the past. The idea that one's own view is the most correct and that other views are unacceptable is what causes wars.

Ukraine is a grain-producing country and exports a lot of grain to Africa and other countries. Now the people in Africa are in great trouble because grain cannot reach Africa in a proper manner due to the war between Russia and Ukraine. This war must be stopped as soon as possible.

The author once visited Ukraine during the time of the Soviet Union. I visited the largest tractor production plant in Ukraine. Ukraine was a very important region in promoting agricultural mechanization in Russia and other regions. Many factories were destroyed in the war, and the production of tractors and other equipment is not running as smoothly as in the past. This war must be ended soon in order to promote mechanization of agriculture.

We in the agricultural machinery industry are in the business of cultivating crops and nurturing life. Humans cannot live without other living things. In other words, we must live in harmony with other life systems on this earth. War is absolutely outrageous. The mechanization of agriculture is necessary for this harmonization work. We must all work together to develop new agricultural mechanization to harmonize with other life systems. We are in an era of unmanned agricultural robots, and I hope that these new mechanized technologies will bring about a better harmony between human beings and all life systems on the earth.

Yoshisuke Kishida
Chief Editor
January, 2024

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Design, Development and Evaluation of Bed Planter-cum-mulcher for the Sowing of Zero Till Wheat (*Triticum aestivum*) and Maize (*Zea mays*)

by

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Abstract

A tractor operated (45 kW) bed former-cum-residue mulcher was developed at ICAR-Central Institute of Agricultural Engineering Bhopal. Inclined plate metering system of planter was tested for planting maize and wheat on sticky belt system in laboratory. Precision indices for planting maize and wheat were found 17 and 22, respectively with forward speed of 3 km/h. Based on sticky belt result a bed planter-cum-residue mulcher was designed and developed. A field experiment was also conducted for the evaluation of planter-cum-residue mulcher for sowing wheat and maize under zero till and residue laden conditions. Seed row to row spacing at 200 mm for wheat under broad bed treatment TW1 (4,650 kg/ha) gave significantly higher yield as compared to other treatment. Wheat yield in treatments TW3 (3,840 kg/ha) with row spacing of 230 mm was found at par with control treatment TW5 (3,830 kg/ha) where normal zero tillage sowing, with row spacing of 200 mm (in Malwa Plateau region farmers keep 200 mm row to row spacing for wheat), was carried out. Experiments with maize revealed that the performance of maize crop was better in broad bed treatment TM2, where row spacing of 500 mm was maintained, as compared to narrow bed treatments and farmers' practice with the same row spacing, keeping the seed rate (20 kg/ha) uniform in all treatments. It was also found that all bed planted maize crops performed better as compared to traditionally planted maize under zero tillage conditions.

Keywords: Bed configuration, zero tillage, maize, wheat, sticky belt test, planter etc.

Introduction

Introduction of bed sowing system provides infiltration, drainage and a significant proportion of large pores for healthy aeration with more roots. Providing an appropriate bed height from the base enables sufficient hydraulic gradient to stimulate lateral drainage. First time formation of permanent bed is carried out using conventional tillage to loosen the soil so as to form the bed with sufficient height, suitable for seeding/planting the initial crops. Subsequently, only reshaping is required to form appropriate bed without any tillage operation (Morrison et al., 1990) and the frequency of reshaping dictated by the type of soil and crop being cultivated (Morrison and Gerik, 1983). Wheat is planted in two row at 200 mm apart and maize in single row at, 750 mm apart on the permanent bed

(Agustin Limon et al., 2000, 2002 and 2006 and Govaerts et al. 2005). Devkota et al. (2013 and 2015) used 900 mm spacing between furrows for the permanent bed system having beds height of 150 mm and top width of 600 mm. They sowed four rows of wheat with 220 mm row spacing and two rows of maize with 450 mm row spacing in their study. Jat et al. (2009, 2013) used bed planter and formed the beds having top width and height at 370 and 150 mm, respectively, and separated by 300 mm wide furrows. The centre to centre distance of the two adjoining furrows was 670 mm. Wheat was sown in two rows and maize on one row per top width during their research experiment on permanent bed system. They have conducted experimentation on the soil quality and grain yield with different tillage method and level of residue retention and found it to be superior as compared to the control treatments.

To facilitate conservation agriculture a straw cutting device is needed in front of the shovel for reshaping the bed which also allows free passage for the furrow opener without accumulation of residue, and leaves the desired levels of crop residue on the surface. The bed width and number of seed row per bed are the most important parameters for permanent bed system to ensure adoption by the farmers as per the farm need and yield potential of grain.

Top width of the bed can be varied according to the environmental conditions. In dry environment, the wider width bed system can be selected to achieve sustainable yield and the width of bed can be reduced if environment improves (Sweeney and Sisson, 1988, Iragavarapu and Randall, 1997). However, in any case, the wheel traffic of the power source may be selected to match the bed width and vice versa to avoid soil compaction in the area where crop is grown (Morrison and Gerik, 1983). Most of the machines available in India can be used to make either broad or narrow bed for a particular permanent bed system. Most of the commercially available machines are designed for fixed width bed system. Bed planters available are not designed to meet the requirements of broad and narrow bed with a single machine. Review of literature shows that bed geometry depends upon crop requirement. Therefore, there is a need for a machine which can achieve optimization of bed geometry enabling the farmers to make broad as well as narrow bed as per need. The same machine could be equipped with modular planting units for maize with a particular row to row and seed to seed spacing and the same machine could be used planting of wheat by increased number of modular units of seed and fertilizer metering.

Material and Methods

Design of Rotary Unit

Designing of rotary mulcher is the most critical component for the development of tractor drawn bed planter-cum-mulcher. Strength is necessary to take into account the maximum peripheral force of working blades. It is determined by plant cutting force of rotary knives, which is in fact the inertia of stalk without any support to the plant. In order to achieve a clean cut, speed of knives must be sufficiently high (20-60 m/s). The range of cutting speed by flailing is very important when the impact cutting occurs without the use of counter shear. The common range of cutting speed in impact cutting for most of the plant materials is 30-40 m/s. Blade speed of traditional forage harvester is 45 m/s whereas vertical disc mower tends to operate at 60 m/s. The reduction in cutter speed also reduces re-cutting with the mower. Power requirement of flail mower is significantly higher than sickle cutter bars. A general formula (Eq. 1) for the energy requirement using flail cutting is:

$$P_{mow} = C_1 + C_2\ M_f \qquad [1]$$

Where,

M_f = Mass feed rate of residue material (kg/s)

C_2 = Constant of power requirement (kW)

C_1 = Feed rate energy requirement (kJ/kg)

Typical values of C_1 and C_2 are 10 kW and 4 kJ/kg.

It has been reported that a minimum critical cutting speed of 20 m/s is required for grasses and wheat straw, with energy requirement decreasing by 25% as cutting speed was increased from 20 to 60 m/s. Therefore, American Society of Agricultural and Biological Engineering D497 (ASABE 2013) data have recommended the following equation (Eq. 2) for calculating the power requirement of a flail cutting maize stem.

$$P_{mow} = 8.2 + 2.13M_f \qquad [2]$$

$$M_f = (Y\omega_s V_f) / 10$$

Y = Maize forage yield, wet basis (kg/ha)

ωs = Swath width cut by mower (m)

Vf = travel speed (m/s)

Let

ωs = 1.6 m

Y = 4000 kg/ha

Table 1 Design parameters and their values

Sl. No.	Design parameter, unit	Value
1.	Top width ridger, mm	500
2.	Bottom width of ridger, mm	250
3.	Depth of furrow, mm	150
4.	No. of ridger bottoms	04
5.	Unit draft of ridger bottom on soil, N/mm^2	0.049
6.	No. of ridger bottoms	04
7.	No. of furrow opener	06
8.	Draft of ridger bottoms, kN	11
9.	Draft of furrow openers, kN	1.5
10.	Design draft of machine, kN	18.75
11.	Operating speed of planter, km/h	4.0

Vf = 1.11 m/s

Then,

M_f= (4000 ×1.6×1.11)/10000

M_f= 0.71 kg/s

So power requirement on flail mower

$P_{mow} = C_1 + C_2M_f$

P_{mow} = 8.2 + (2.13 × 0.71)

P_{mow} = 10 kW

Calculation of Draft and Power Requirement

Draft and power requirement of tractor was calculated using design parameters, shown in **Table 1**. The number of ridger bottoms for making three beds would be four. For top width of 500 mm, bottom width of 250 mm and furrow depth of 1,500 mm, the cross section of the furrow was found 5,625 mm^2 and the total area of cross section works out to 0.225 m^2 for four bottoms. Total draft of ridger planter was 177 kN using factor of safety 3, which included draft of ridger bottoms and draft of furrow openers. The size of tractor was calculated based on the power requirement for pulling the planter and rotating the flail of the mulcher which is calculated using formula described in Eq. 3. The tractor of capacity 45 kW power was selected for this planter-cum-mulcher machine.

Calculation of Power Requirement

Drawbar house power is calculated using Eq. 3 assuming speed of operating 4.0 km/h and the brake house power was 60% of total drawbar horse power (Mani and Panwar, 2009).

Therefore,

Drawbar house power = [Draft (Kg) × Speed (m/min)] / 4500 [3]

= [1800 × 4 (1000/60)] / 4500 = 26.67 hp

Now we know drawbar horse power of tractor is about 60% of BHP

So, size of tractor required = (26.67/60) × 100 = 45 hp = 33.5 kW without mulcher

Power requirement for mulcher P_{mow} = 10.0 kW

Hence, power of tractor required for pulling planter and mulcher together = 33.5 kW + 10 kW = 43.5 kW

Total draft of ridger bottoms was calculated assuming a 4 bottom ridger planter is to be designed with top width = 500 mm, bottom width = 250 mm, depth of furrow = 150 mm and number of ridger bottoms for making three beds = 4. The area of cross section of furrow is calculated using Equ. 4. Finally, total draft of ridger bottoms was calculated using Eq.5 assuming unit draft of soil as 0.005kg/mm^2. Then after, Total draft of ridger planter for six row. Total draft of six furrow opener was calculated assuming draft for each furrow opener for planting is 0.25 kN (Altuntas et al., 2006). Design draft of machine assuming factor of safety 1.5 was finally calculated using Eq. 6.

Area of cross section of furrow = [(Top width + Bottom width) / 2] × Depth of furrow [4]

= [(50 + 25)] / 2 × 15 = 56250 mm^2

Total area of cross section = No. of bottoms × Area of one furrow

= 4 × 56250 mm^2 = 225000 mm^2

Taking unit draft of soil as 0.005 kg/mm^2

Therefore, Draft of 4 ridger bottom = area × unit draft [5]

= 225000 × 0.005 = 1125 kg = 11 kN

Therefore,

Draft of 6 furrow opener = 6 × 0.25 = 1.5 kN

Total draft of ridger planter = Draft of ridger bottoms + Draft of furrow openers

= 11 + 1.5 = 12.5 kN

Then design draft of machine = Total draft of ridger planter × Factor of safety [6]

= 12.5 × 1.5 = 18.75 kN

Fig. 1 Developed bed planter-cum-mulcher in operation

Development of Tractor Drawn Bed Planter-cum-mulcher

Development of bed planter-cum-mulcher (**Fig. 1**) was done in Prototype Production Centre, ICAR-CIAE, Bhopal. Y-type blades made of high tensile steel were selected for cutting crop residue on the field. Roller type multiple bed maker was developed which reduces the draft requirement of tractor in vertisol as compared to commonly made drag type bed maker because of its rolling action. The metering system of seed and fertilizer are powered with the roller type bed maker via chain and sprocket. The triangular spikes attached on the periphery of conical roller provide sufficient friction to rotate the roller over the soil surface.

Seed Uniformity Test

Seed uniformity test was done on a sticky belt set-up (Kumar et al., 2017). The set-up consisting of two rollers of 300 mm diameter each mounted at a distance of 1,000 mm; having speed variability between 0 to 4 km/h was used for laboratory test.

The missed index, multiple index, quality of feed index and precision index described by Kachman and Smith (1995) were taken for conducting seed uniformity test for both maize and wheat. The Missed Index shows skipped seeds and it is defined as the percentage of spacing greater than 1.5 times the theoretical spacing. The Multiple Index indicates dropping of multiple seeds and it is defined as a seed spacing percentage that is less than or equal to one-half of the target seed spacing. The quality feed index demonstrates a single seed drops and is the percentage of spacing between half and

1.5 times the theoretical seed spacing. The precision index was calculated as given by Bracy et al. (1999) and is defined as the coefficient of variation of the spacing after neglecting the missed and multiple indexes. Kachman Smith (1995) and Bracy et al. (1999) reported that the value of precision index cannot be greater than 29%. The front views of seed plate are sown in (**Fig 2**). The number of cell of metering plate for wheat and maize was 22 and 11, respectively.

Table 2 Different treatments according to bed configuration for wheat crop

Treatments	Bed configurations	Independent parameters
TW1	Broad bed with 6 rows	1. Germination per m^2 2. Plant per m^2
TW2	Broad bed with 4 rows	3. No. of tillers 4. Plant height, mm
TW3	Narrow bed with 3 rows	5. Root length, mm 6. Root weight, g
TW4	Narrow bed with 2 rows	7. No. of Spikelets 8. Grain yield, kg/ha
TW5	Control (Farmer practice)	9. Straw yield, kg/ha

Table 3 Variation of different indices with speed for wheat seed during lab test

Treatments	Bed configuration	Independent parameters
TM1	Broad bed with 2 rows	1. Germination per m^2 2. Plant per m^2
TM2	Broad bed with 3 rows	3. No of cobs, per m^2
TM3	Narrow bed with 1 row	4. Average cob weight, g
TM4	Narrow bed with 2 rows	5. Root weight, g 6. Grain yield, kg/ha
TM5	Control (Farmer practice)	7. Straw Yield, kg/ha

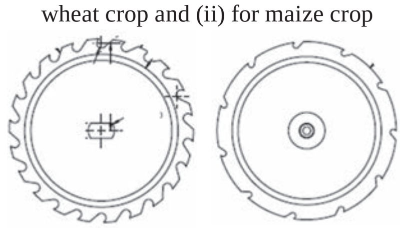
Field Experimentation

Experimental trials were carried out at research field of ICAR-Central Institute of Agricultural Engineering Bhopal, which is in Madhya Pradesh of central India. It has a subtropical climate, a hot summer with cool and dry winters. The annual rainfall of Bhopal is 1,090 mm with the onset of monsoon during the third week of June and withdraws in the last week of September. The soil of the experimental field is clay with 32% sand, 22% silt and 44% clay. The study was conducted for wheat-maize cropping system. The length and width of each plot of treatment was 40 m and 10 m, respectively

Field Experimentation of Wheat and Maize Crop

Field experiment for evaluation of bed former-cum-residue mulcher was carried out during 2015-16, 2016-17 and 2016-18 with wheat and maize crops (**Fig. 3**). Size of the experimental plot for each treatment wasWheat crop of Malwa Shakti variety was sown in maize harvested field with residue load 7.5 t/ha during 2016-17. During the three experimental years, wheat sowing was done in the last week of November and harvested in the first week of April. Initially before field experiment, the soil test was done and accordingly the dose of fertilizer NPK with ratio 100:60:40 were applied. The maize of variety DMRH1301 was sown in the first week of July in wheat harvested field with residue load of 3.5 t/ha and harvested in the last week of October in all three experimental years. Both the crops were sown using the developed machine with different bed configurations. Different treatments were followed according to bed configuration which is shown in **Tables 2** and **3** for wheat and maize crops,

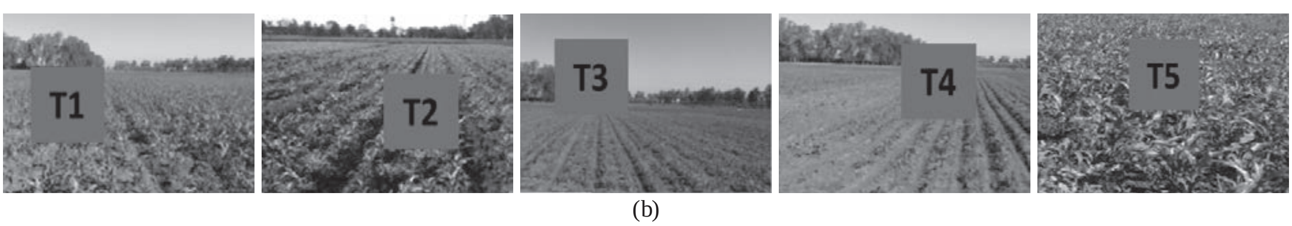
Fig. 2 Front views of seed plate (i) for wheat crop and (ii) for maize crop



(i) (ii)

Fig. 3 Field experiment on (a) wheat and (b) maize

(a)



(b)

respectively. After dry sowing of wheat, first irrigation was given 05 days after sowing. A total of four replications were undertaken. Significant differences in the crops attributes among the treatment were analysed by calculating least significant difference (LSD) at 5% level of significance by using Duncan's Multiple Range Test with the help of SPSS10.0.

Measurement of Crop Attributes

Major crop attributes such as germination count, number of plants per square meter, number of tillers per plant, plant height, root length, root weight, number of spikelets, grain yield, straw yield and average number of cobs per sqm were recorded. The data were collected randomly from one square metre size of experimental plots. Number of spikelet in the case of wheat crop and number of cobs in the case of maize crop were counted at harvesting stage in 5 random locations in the field. Plant height was measured for 30 randomly selected plants at harvesting stage. Plant height measurement was taken from the base of the plant to the tip of ear head. Crop was manually harvested in 5 random locations, each of 1 m^2 area and the harvested crop per unit area was manually threshed. The threshed grains and straw were weighed and grain yield and straw yield per hectare was calculated. Root weight was also taken from the samples of harvested crop.

Results and Discussion

Performance of Metering Devices for Wheat and Maize Crop

Measurement of Missed Index (MI), Multiple Index (DI), Quality of Feed Index (FI) and Precision Index (PI) for wheat and maize under laboratory conditions was calculated and presented in **Tables 4** and **5**. Maximum missed index for wheat seed was found to be 0.20 at speed of 4.0 km/h and minimum was 0.10% at 1.0 km/h. Higher missing index was found at speed 4.0 km/h may be due to the inability to pick up the wheat seed at higher speed. The highest multiple index was found to be 0.14 at a speed of 4.0 km/h and minimum of 0.08 at 1.0 km/h. Minimum feed index was 0.66 at a speed of 4.0 km/h and maximum of 0.82 at 1.0 km/h. Maximum precision index was found to be 0.25 and minimum was 0.21 at speed 4.0 and 1.0 km/h, respectively. Results of experiments conducted for wheat seed with inclined plate on sticky belt is given in **Table 6**. Precision index achieved for wheat seed ranged between 0.21 to 0.25 which is not sufficient and suitable for wheat planting, but it is acceptable in the case of good for drilling/seeding of wheat seed. The missed index for maize crop varied from the minimum of 0.17 to a maximum of 0.26 at speed range from 1.0 to 4.0 km/h. and the multiple index varied 0.06-0.11 for the same speed range. Minimum feed index was 0.63 at 4.0 km/h and the maximum was 0.77 at 1.0 km/h. Seed precision index for maize seed was found to vary between 0.15 to 0.19. These experiments demonstrated that wheat and maize seed could be placed within an acceptable range using the selected metering device.

Table 4 Variation of different indices with speed for wheat seed during lab test

Speed (km/h)	Feed Index	Multiple Index	Miss Index	Precision Index
1.0	0.82^{c}	0.08^{a}	0.10^{a}	0.21^{a}
2.0	0.80^{c}	0.09^{a}	0.11^{a}	0.22^{a}
3.0	0.76^{b}	0.10^{b}	0.14^{b}	0.22^{a}
4.0	0.66^{a}	0.14^{c}	0.20^{c}	0.25^{b}

Note: Values labelled same letter in the same column are not significantly different at 5% level of significance.

Table 5 Variation of different indices with speed for maize seed during lab test

Speed (km/h)	Feed Index	Multiple Index	Miss Index	Precision Index
1.0	0.77^{d}	0.06^{a}	0.17^{a}	0.15^{a}
2.0	0.72^{c}	0.08^{b}	0.20^{b}	0.17^{b}
3.0	0.69^{b}	0.08^{b}	0.23^{b}	0.17^{b}
4.0	0.6^{a}	0.11^{c}	0.26^{c}	0.19^{b}

Note: Values labelled same letter in the same column are not significantly different at 5% level of significance.

Effect of Different Treatments on Wheat Crop Field Performance

Different crop attributes of wheat

Table 6 Effect of different treatments on wheat crop performance (average of three years pooled data)

Treatment	Field capacity (ha/h)	Fuel consumption (l/ha)	Plant per m^2	No of tillers	Plant height (mm)	Root length (mm)	Per plant root weight (gm)	No. of spikelets	Grain yield (kg/ha)	Straw yield (kg/ha)
TM1 (BB4)	0.40^{b}	14.0^{a}	63^{a}	8.67^{a}	781.7^{b}	187.3^{d}	5.09^{a}	53.63^{a}	4,150^{a}	5,100^{a}
TM2 (BB3)	0.40^{b}	14.2^{a}	46^{b}	6.33^{b}	766.6^{c}	244^{a}	4.85^{c}	48.47^{c}	3,580^{c}	4,090^{c}
TM3 (NB2)	0.37^{b}	14.0^{a}	66^{a}	5.67^{c}	818.2^{a}	212.7^{c}	2.82^{c}	48.53^{c}	3,840^{b}	4,750^{b}
TM4 (NB1)	0.38^{b}	14.0^{a}	44^{b}	6.67^{bc}	761.4^{c}	220^{b}	4.36^{b}	51.12^{b}	3,510^{c}	3,970^{d}
TM5 (Control)	0.52^{a}	13.0^{b}	68^{a}	4.2^{d}	800^{a}	200^{c}	3.80^{c}	47^{c}	3,830^{b}	4,050^{d}

Note: Values labelled same letter in the same column are not significantly different at 5% level of significance.

are shown in **Table 6**. Field capacities of bed planter-cum-mulcher for sowing of wheat under both broad and narrow bed conditions are not significantly different at 5% level of significance. However, field capacity of 9 row seed-cum-fertilizer drill in treatment TW5 (0.52 ha/h) was significantly higher as compared bed planter-cum-residue mulcher under broad bed and narrow bed treatments TW1, TW2, TW3 and TW4 (37 to 40 ha/h) in zero till conditions. Grain and straw yield showed distinct effect of bed geometry, configuration and spacing between two rows. Average grain yields were 4,651, 3,580, 3,841, 3,509 and 3,825 kg/ha for TW1, TW2, TW3, TW4 and TW5, respectively. Average straw yields were 5,099, 4,091, 4,754, 3,965 and 4,050 kg/ha for treatments TW1, TW2, TW3, TW4 and T5, respectively. The grain yield in broad bed treatment TW1 (4651 kg/ha) with seed spacing of 200 mm gave significantly higher yield as compared to other treatments. Grain yield in Treatments TW3 (3,841 kg/ha) with row spacing of 230 mm was found at par with control treatment TW5 (3,825 kg/ha) where conventional zero tillage sowing, with seed spacing of 200 mm (in Malwa Plateau region farmers keep 200 mm row to row spacing for wheat), was done. These results revealed that broad bed sowing of wheat crop under no-till conditions performed better as compared to conventional zero tillage on same seed spacing and seed rate in vertisols. Field experiments of wheat sowing in clayey soil condition demonstrate that broad bed has performed better as compared to narrow beds and flat bed zero till conditions. Treatments TW1 and TW3 were having same number of rows in same width of sowing, however, broad bed treatment TW1 (4,651 kg/ha) performed better as compared to narrow bed treatment TW3 (3,841 kg/ha). In vertisols, edges of narrow bed tends to collapse from both sides during first irrigation and wheat seeds were exposed at both the extremes which leads to poor germination and resulted loss of yield.

Hence, zero till wheat crop performed better on broad bed as compared to narrow bed under vertisols. In vertisols, zero till sown wheat on broad bed TW1 (4,651 kg/ha) gave significantly higher yield as compared to zero till wheat sowing of conventional practice TW5 (3,825 kg/ha). Similar kinds of results were observed by Singh et al., 2,016 with raised bed system of 1,200 mm top width and 150 mm deep bed. Management of broad bed of 1,500 mm width is easy because it is equal to the spacing of tractor tyres. For better utilization of tractor power on permanent bed sowing of wheat crop, 13 row seed drill (middle furrow can be replaced with channel maker) can be taken for covering two broad bed simultaneously with 6 row sowing on each bed. The benefits of permanent bed system have been reported also by Shrivastava et al. (2017), Das et al. (2018), Sandhu et al. (2019) under similar bed configurations.

Effect of Different Treatments on Maize Crop Performance

Crop attributes of maize crop are show in **Table 7**. Field capacity of bed planter-cum-residue mulcher for sowing maize under both broad bed and narrow bed conditions are not significantly different at 5% level of significance. However, field capacity of traditional maize planting in treatment TM5 (0.48 ha/h) was significantly higher as compared bed planter-cum-residue mulcher under broad bed and narrow bed treatments TM1, TM2, TM3 and TM4 (37 to 40 ha/h) in zero till conditions. Fuel consumption in treatment TM5 (12 l/ha) was significantly lower as compared to bed planted treatments (13.8-15 l/ha) at 5% level of significance. Maize grain yield was significantly higher in treatment TM2 (4,220 kg/ha) as compared to other treatments at 5% level of significance. However, maize straw yield in treatments TM2 (11,410 kg/ha) and TM3 (11,600 kg/ha) were at par and significantly higher ($P < 0.05$) as compared to treatment TM1 (10,120 kg/ha) and TM4 (10,670 kg/ha). Similar results were observed by Mollah et al. (2009), Akbar et al. (2010) and (2016), Ram et al. (2012), Das et al. (2018). Maize experiment revealed that the performance of maize crop was found better in broad bed treatment TM2, where row spacing of 500 mm was kept, as compared to narrow bed treatments and farmers' practice with same seed spacing keeping uniform seed rate of 20 kg/ha in all treatments. It was also found that all bed planted maize crops performed better as

Table 7 Effect of treatments on maize crop performance (average of three years pooled data)

Treatment	Field capacity (ha/h)	Fuel consumption (l/ha)	Germination per m^2	Plant per m^2	No of cobs per m^2	Av cob weight (g)	Per plant root weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)
TM1 (BB4)	0.39^b	14.0^a	10^b	10^b	19^b	378^b	41^b	4,120^b	10,120^b
TM2 (BB3)	0.40^b	13.8^a	19^a	18^a	22^a	343^d	36^b	4,220^a	11,410^a
TM3 (NB2)	0.37^b	14.5^a	17^a	11^b	16^c	365^c	40^b	4,100^b	11,600^a
TM4 (NB1)	0.37^b	15.0^a	12^b	11^b	16^c	395^a	57^a	4,100^b	10,670^b
TM5 (Control)	0.48^a	12.0^b	18^a	17^a	15^c	328^d	31^c	3,700^c	10,550^b

Note: Values labelled same letter in the same column are not significantly different at 5% level of significance.

compared to traditionally planted maize under zero tillage conditions.

Conclusions

Developed planter with inclined plate metering device can be used for drilling wheat as well as planting of maize seeds on broad (1,500 mm) as well as narrow beds (750/500 mm) under zero till and residue conditions. This planter-cum-residue mulcher can be used at a speed of 3 km/h for planting maize with mulching of wheat residue on broad as well as narrow beds under zero till conditions. These results revealed that for same seed spacing and seed rate, broad bed sowing of wheat and maize, under no till conditions perform better as compared to normal zero tillage sowing in vertisols. Field experiments of wheat and maize sowing in clayey soil conditions also revealed that broad beds performed better as compared to narrow beds and flat bed under zero till conditions. Under narrow bed conditions, in vertisols, narrow bed tends to collapse at the ends during first irrigation and wheat and maize seeds get exposed which leads to poor germination and consequently, loss in yield.

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Design, Development and Performance Evaluation of a Continuous Type Coconut Dehusker

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Abstract

India is one of the leading producers of coconut in the world. Dehusking is the primary post-harvest operation done in coconuts to remove the husk from the nut and it is a laborious process, which adds to the cost of production in the coconut processing industry. A study was undertaken to develop a coconut dehusking machine for easy and effective removal of husk from coconut without causing much damage to the nut. For the development of coconut dehusker, various required engineering properties of matured coconuts viz., average dimensions such as length of 200 mm, diameter of 145 mm, husk thickness of 33 mm at pedicel end, 22 mm at both centre and apex ends were determined. The average moisture content of green coconuts was observed as 45.6% (w.b.) and the shell diameter of the dehusked green coconuts as 89 mm. The maximum husk penetrating force for matured green and dry coconuts were observed as 166 N and 196 N, respectively at a thickness of 33 mm. Also, the maximum husk separating force was determined as 430 N and 520 N for green and dry coconuts respectively. Hence, a study was undertaken to develop a coconut dehusker based on the principle of exerting shear force by the rotating roller blades to cause tearing effect over the husk surface. The effective dehusking was achieved when the roller speed of 18 rpm was found to be suitable for both green and dry coconuts of various sizes with the maximum dehusking efficiency of 97%.

Keywords: Coconut size, maturity, roller speed, dehusking efficiency

Introduction

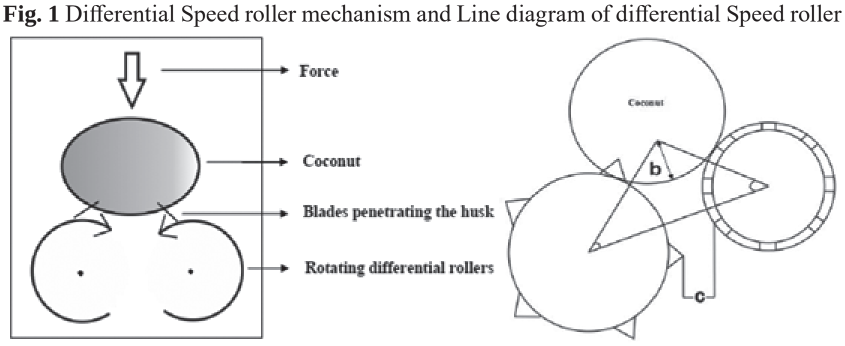
Coconuts are grown in more than 83 countries in the world. In the global market, India is the third largest producer of coconuts in the world next to Indonesia and Philippines, having area of about 2.17 million hectares with annual production of 20,308 million nuts in the year 2019-20 (Coconut Development Board, 2020). Coconut processing in India, mainly comprises of copra production, oil extraction and desiccated coconut manufacture. In India, major part (60%) of the coconut produced is estimated to be used for edible and religious purposes, 3.5% as tender coconut, 35% as milling copra for oil extraction and the balance (1.5%) is processed into products like desiccated coconut and coconut milk.

The main constituents of the coconut are husk (35%), shell (12%) meat (28%) and water (25%). Dehusked nuts are used as a raw material for processing which has meat (50%), water (17%) and shell (33%) by weight approximately. Fresh coconut kernel contains about 4% protein and when it is processed into coconut meal the protein content is increased to 20-25% (Thampan, 1966). Dehusking is one of the primary and important post-harvest operations in coconut processing. Dehusking is a process of the removal of husk which occupies 35% of the total weight of the nut. Adhesion between the fibers in the husk is greater than that between the husk and the shell. Hence, the separation occurs at the shell and husk interface. The husk yields fibre used in the manufacture of coir and coir products such as carpets, safety belts, boards, and asbestos and coir pith (Ghosal and Mohanty, 2011).

The traditional method of dehusking is done by using traditional tools such as parang, hoe, blade or spear (Varghese and Jacob, 2014). The manual dehusking process requires an operator to use his or her strength and skill to bring the coconut sharply down into the blade, twist the coconut to one side, loosen the husk and detach the fibre from the shell. This action is repeated several times until the entire fiber is detached from the shell. This process is not only difficult and dangerous but requires the necessary skill. Attempts made so far in the development of dehusking tools have only been partially successful and not effective in replacing manual methods. The earlier studies reported by Ghosal and Mohanty (2011), Jacob and Rajesh (2012), Candra et al. (2017) were labor intensive, costly and these machines require high capital cost and operation cost. Also, their suitability for dehusking with an increased shelf life of coconut, need to be fine-tuned.

Hence, there is a need to develop a coconut dehusker, which is simple in operation, reasonable in cost, less risky, with a higher rate of dehusking, minimum nut breakage and distortion of the extracted fiber and portable.

Fig. 1 Differential Speed roller mechanism and Line diagram of differential Speed roller



Material and Methods

The coconut dehusker has been developed to work on the principle of exerting shear force by the differential roller blades to cause tearing effect over the outer husk. The counter rotation of rollers grips and shears the husk inturn causes the tearing effect over the husk surface as shown in the **Fig. 1**.

The developed coconut dehusker consists of a motor for power source, a gear box for speed reduction, a driver shaft, a driven shaft, rollers, blades, helical gears for power transmission between rollers, chain drive to transmit power to the driver shaft.

2.1. Design of Rollers

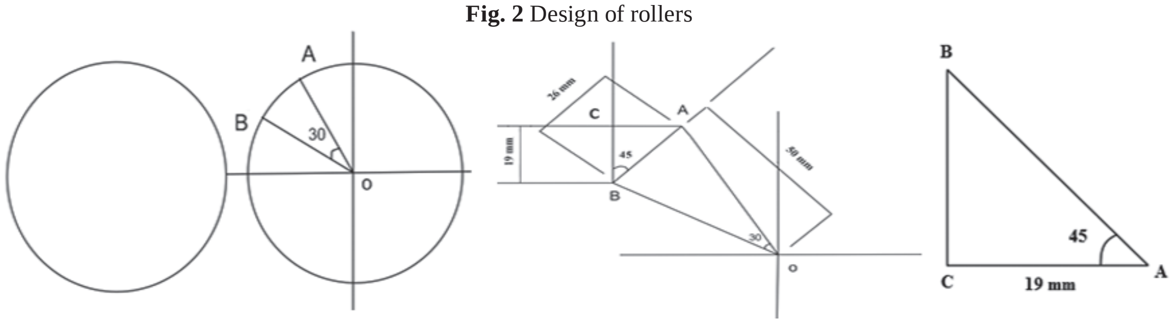
The dehusker consists of two dehusking rollers and a movable roller. Roller diameters were designed by the design procedure followed by Jacob and Rajesh (2012). Rollers were designed in a manner to obtain effective mesh with the coconut by making following assumptions:

i. Coconut contacts the roller at an average angle of 30° of contact sector.
ii. 1/6th of the width of the coconut should be inserted into the intermediate distance between the rollers i.e. approximately 19 mm.
iii. Angle AOB = 30° (**Fig. 2a**).

From the **Fig. 2b**, since the arc AB is considerably small and can be assumed as a straight line. From the assumption the inserted depth of the coconut is 19 mm (AC).

Using the trigonometric relations

Fig. 2 Design of rollers



(a) (b) (c)

(**Fig. 2c**), length of the straight line was found as follows:

$\sin 45° = BC/AB$; $\cos 45° = AC/AB$; $\tan 45° = BC/AC = 1$ [1]

The value of arc AB (L) = 26 mm.

The radius of the roller was found using the equation (2)

$R = L/\theta = 26/30 = 26/(\Pi/6) = 49.6$ mm = 50 mm [2]

Where, R = radius of the roller, mm and L = Length of the arc, mm

Therefore, diameter of the main roller (D_1) is 100 mm. In order to attain differential speed, the diameter of the minor roller was reduced to half the diameter of the main roller and hence, the diameter of the minor roller (D_2) is 50 mm.

2.2. Design of Blades

To increase the contact surface area of the blades with the coconut, the prism shape was selected as shown in the **Fig. 3**.

2.3. Design of Pitch

Pitch is the centre distance between the two blades. Horizontal pitch and circular pitch is the distance between the blades that are horizontally and circularly arranged.

2.4. Design of Horizontal Pitch

Based on preliminary studies maximum length of the coconut was found as 203.2 mm, so the maximum length of the roller is s limited to 355 mm. The designed blades were mounted on the roller in a manner that maximum number of blades to be in contact with the coconut. So that it reduces the load on the blades and increases the dehusking efficiency (Jacob and Rajesh, 2012). Totally 6 numbers of blades are mounted on each row as shown in **Fig. 4**.

2.5. Design of Circular Pitch

The average width of the coconut was found as 145 mm. The diameter of the roller is limited to 100 mm. Totally 5 blades with a circular pitch of 66 mm are mounted around the main roller as shown in **Fig. 5**.

2.6. Drive Calculation

The torque required to dehusk the coconut has been determined. From that torque the drive reduction between the motor and the rollers has been determined.

Torque required to dehusk the coconut = Force × Perpendicular distance [3]

= 520 × 0.6 = 312 Nm.

By taking factor as 1.25, Torque = 390 N m required to dehusk the coconut

Torque developed by the motor = (60 × P) / 2 × 3.14 × N [4]

= (60 × 0.75) / (2 × 3.14 × 1440)

= 4.976 Nm

Reduction ratio = 390 / 4.976 = 79

Speed of the roller unit = 1400 / 79 ≈ 18 rpm

So the dehusking rollers are designed to rotate at average speed of 18 rpm (Appro.). Husk separating force (520 N) measured in Universal Testing Machine was taken for the design calculation. The diameters required for the major roller shaft and supporting roller shaft were calculated by following the standard design procedure.

2.7. Selection of Motor

The force required to dehusk different sizes of green and dry coconuts was determined by using the universal testing machine as 520 N.

2.7.1. Power Required to Dehusk the Coconut

Torque (T_1) = Force required to dehusk the coconut × perpendicular distance from the centre of motor to the point of action of load.

Perpendicular distance from motor to point of action of load = 600 mm = 0.6 m

Torque, $T_1 = 520 \times 0.6 = 312$ N m

Power, $P_1 = (2\pi N_A T_1) / 60$ [5]

$= (2\pi \times 18 \times 312) / 60 = 0.587$ kW

$= 0.786$ hp

The total torque and power required to operate the dehusker was 0.786 hp and hence, One hp single phase electric motor was selected for operating the coconut dehusker. Based on the designed data the coconut dehusker was developed.

Fig. 3 Different views of blade

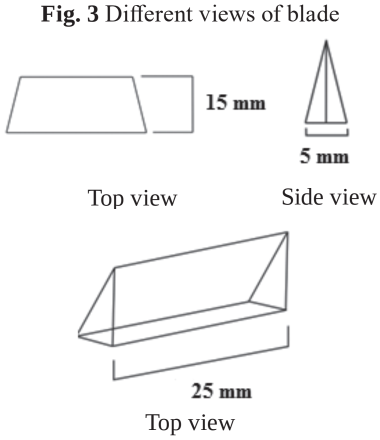


Fig. 4 Horizontal pitch

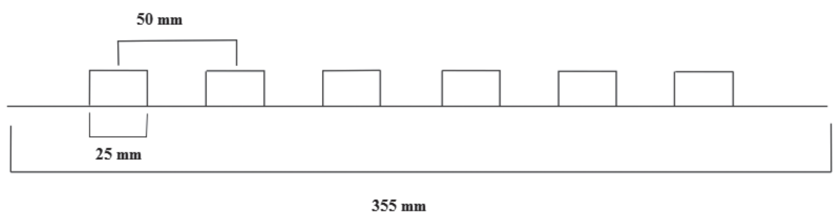
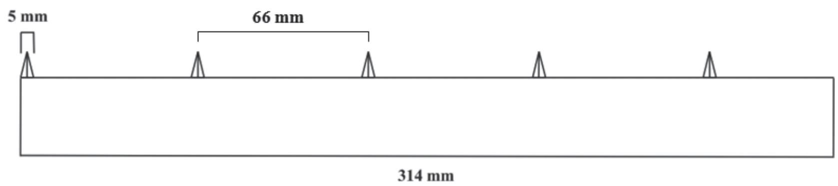


Fig. 5 Circular pitch



2.8. Development of Coconut Dehusker

The coconut dehusker consists of major roller, supporting roller, movable roller, blades, guides, power transmission system, motor and frame as shown in **Fig. 6**. The dehusking unit consists of two counter rotating rollers (Major roller & supporting roller) and a movable roller fixed with rubber wings/plates. The rollers are cylindrical in shape with varying diameters rotating in opposite directions. The varying diameters of dehusking rollers are to attain different rotational speeds. Blades were fixed over the periphery of the rollers. The movable roller was fixed at a perpendicular distance from the counter rotating rollers. During dehusking, the coconut fed into the machine was pressed against the counter rotating rollers by the movable roller plates.

The major roller was made up of 15 mm mild steel blades in the shape of triangular prism welded over the periphery of the mild steel hollow cylindrical roller. The blades were welded over the roller with the circular pitch of 66 mm and horizontal pitch of 50 mm. The dimensions of the major roller were 100 mm in diameter and 355 mm in length. The thickness of the roller was 6 mm.

Supporting roller was made up of 5 mm mild steel square rod and 8 mm rubber rod welded and fixed alternatively over the periphery of the mild steel hollow cylinder. The thickness of the cylinder was 5 mm. The dimensions of the supporting roller were 50 mm in diameter and 425 mm in length.

Movable roller was made up of 275 × 185 × 10 mm rubber sheet fixed over the periphery of the movable roller. The blades were made up of 25 mm length, 15 mm height 5 mm width mild steel bar. The blades were made in the shape of triangular prism. Over the 355 mm length of main roller 25 × 15 × 5 mm blades were welded horizontally with the horizontal pitch of 50 mm. The circumference of the main roller was divided into five axes and welded with the blades at a circular pitch of 66 mm. The clearance between the blade and the supporting roller was 10 mm. The husk after the removal passes through the clearance between the blade and the supporting roller.

The performance of the coconut dehusker (**Fig. 7**) was evaluated based on maturity level (M_1 and M_2), Rotational speed of the rollers (10, 15 and 20 rpm) and coconut size (> 200 mm (G_1), 160-200 mm (G_2) and < 160 mm (G_3)).

2.9. Determination of Dehusking Efficiency

The procedure for determining the dehusking efficiency (per cent) of the newly developed machine was the same as that of finding the per cent husk loss followed by Patil et al. (2014).

Dehusking efficiency, % = $(D_1/D_2) \times 100$

Where, D_1 represents the weight of the husk removed from the nut (g) and D_2 denotes the total weight of the husk present in the coconut (g).

2.10. Statistical Analysis

The datas were analyzed using the statistical package AGRES and analysis of variance tables were obtained. The individual and interaction effect of independent variables on dependent variables were analyzed.

Results and Discussion

3.1. Dimensions of Green and Dry Coconuts

The major, minor and intermediate axes were measured for randomly selected 100 green and dry coconuts. For green coconuts, the values of the major axis (X) ranges from 180 to 240 mm with the mean value of 203 mm, the values for the minor axis (Y) ranges from 131 to 161 mm with the mean value of 145 mm and the values for the intermediate axis (Z) ranges from 121 to 151 mm with the mean value of 140 mm.

For dry coconuts the value of the major axis (X) ranges from 162 to 220 mm with the mean value of 182

Fig. 6 Schematic diagram of the developed Coconut dehusker

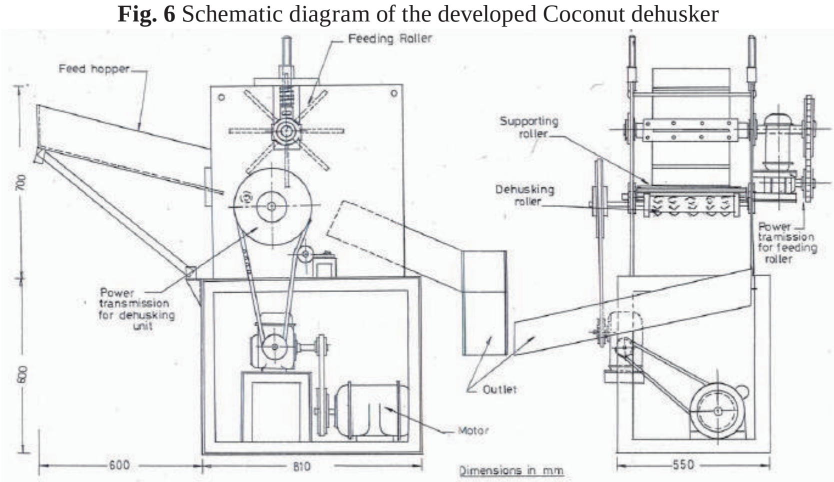
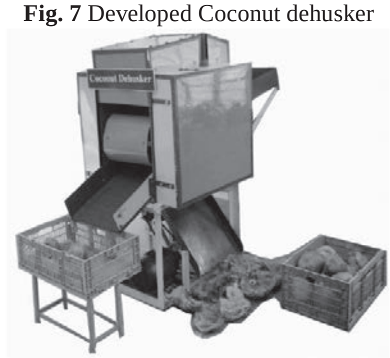


Fig. 7 Developed Coconut dehusker



mm, the values for the minor axis (Y) ranges from 100 to 150 mm with the mean value of 123 mm and for intermediate axis (Z) the values ranges from 98 to 150 mm with the mean value of 120 mm. It can be seen from the table that the average major, minor and intermediate axis values was lesser for dry coconuts than green coconuts. Decrease in the husk moisture was the reason for the reduction in the size of dry coconuts. Greater difference in the mean values of major and minor axes was observed by Alonge (2012) and Patil et al. (2014).

3.2. Husk Thickness

The mean husk thickness of green coconuts at pedicel end, centre and apex end was found as 33 mm, 23 mm and 22 mm. The mean husk thickness of dry coconut at pedicel end, center, and apex end was found to as 22 mm, 13 mm and 16 mm, respectively. From the **Table 1**, it is clear that the maximum amount of husk present in the pedicel end and minimum amount of husk present in the centre part. Pandiselvam et al. (2018) and Varghese et al. (2016) reported similar variations in the husk thickness with all the three points on the coconut.

3.3. Moisture Content

The moisture content of green and dry coconuts were determined as 45.2 % and 25.6%, respectively (**Table 2**). The values observed in this study was found to be similar to the moisture content values reported by Pandiselvam et al. (2018) and Patil et al. (2014) but was found to be higher than the values reported by Varghese and Jacob (2017).

3.4. Husk Penetrating and Separating Force

The maximum husk penetrating force for green coconuts of 166 N was observed at thickness of 35 mm and maximum husk penetrating force for dry coconuts of 196 N was observed at thickness of 35 mm. It is evident that the husk penetrating force dependent on husk thickness and increases with increase in husk thickness. The observed values are found to be similar with the values reported by Patil et al. (2014). Maximum husk separating force for green coconuts of 430 N and for dry coconuts of 520 N was observed. The husk separating force also increases with increase in coconut size. Husk separating force for dry coconut was found to be more than green coconuts. It is evident that decrease in the husk moisture content increases the husk separating force. Varghese et al. (2016) reported the increase in the force with decrease in husk moisture content and the report shows that the dehusking of green coconuts was easier than dry coconuts.

3.5. Performance Evaluation of the Developed Coconut Dehusker

Two different maturity levels such as green (M_1) and dry (M_2) were tested to find out the influence of maturity level on dehusking efficiency and dehusking time and is presented in **Table 3**. The differential speed of the rollers (rpm) was kept in the ratio of 1:1.2. The average rotational speed of the major and minor roller was varied and chosen for studying the performance of coconut dehusker as 13 (S_1), 18 (S_2) and 22 (S_3) rpm. Three different size of coconuts (mm) based on their length as >200 (G_1), 160-200 (G_2) and < 160 (G_3) mm. A three factorial completely randomized block design with three replications were made to statistically evaluate the dehusking efficiency of coconut dehusker is reported in **Table 4**.

Table 1 Husk thickness of green and dry coconuts

	Green coconuts (mm)			Dry coconuts (mm)		
	Pedicel	Center	Apex	Pedicel	Center	Apex
Max.	48	35	32	35	23	29
Min.	15	11	12	14	8	10
Mean	33	23	22	22	13	16

Table 2 Moisture content of green and dry coconuts

	Green coconuts (% w.b.)	Dry coconuts (% w.b.)
Max.	60	50.8
Min.	25.5	13.46
Mean	45.2	25.6

Table 3 Dehusking efficiency for various maturity, roller speed and coconut size

	Dehusking Efficiency (%)		
	S_1	S_2	S_3
M_1	91.9911	94.6433	69.5789
M_2	95.3333	96.3022	61.5356
	G_1	G_2	G_3
S_1	91.7800	93.2500	95.9567
S_2	93.2517	95.8667	97.3000
S_3	80.8467	68.0433	47.7817
	G_1	G_2	G_3
M_1S_1	90.2033	91.3333	94.4367
M_1S_2	92.2633	95.3333	96.3333
M_1S_3	83.1367	74.3700	51.2300
M_2S_1	93.3567	95.1667	97.4767
M_2S_2	94.2400	96.4000	98.2667
M_2S_3	78.5567	61.7167	44.3333

Table 4 Analysis of Variance (ANOVA) on effects of maturity, roller speed and coconut size on dehusking efficiency of coconuts

Treatments	SED	CD (0.05)	CD (0.01)
Maturity (M)	0.05944	0.12057	0.16167
Differential speed of roller (S)	0.07280	0.14767	0.19801
Size of coconuts (G)	0.07280	0.14767	0.19801
MS	0.10296	0.20884	0.28002
SG	0.12610	0.25577	0.34296
MG	0.10296	0.20884	0.28002
MSG	0.17833	0.36172	0.48502

3.5.1. Effect of Maturity and Roller Speed on Dehusking Efficiency

The interaction effect of maturity and differential roller speed showed that M_2S_2 (dry coconuts & 18 rpm) had more dehusking efficiency of 96 %, which was followed by M_2S_1 (95%) and M_1S_2 (94%). The treatment M_2S_3 (dry coconut, 22 rpm) had the lowest dehusking efficiency of 61%.

It is observed that the dehusking efficiency was higher in dry coconuts at the average speed of 18 rpm compared to green coconuts at the same rpm. In dry coconuts, due to the presence of lesser moisture, the husks are tightly packed and also the adhesive force between the molecules of husk are found to be more than the adhesion between the husk and the shell. This causes more dehusking efficiency in dry coconuts.

Lower dehusking efficiency was observed in dry coconuts at the average roller speed of 22 rpm. At higher rotational speed, gripping of dry coconut by the blades did not occur properly. This might be due to the surface roughness of dry coconuts. The presence of moisture enables the easy penetration of husk by blades.

3.5.2. Effect of Roller Speed and Coconut Size on Dehusking Efficiency

The interaction effect between roller speed and size of coconut revealed that S_2G_3 (18 rpm, < 160 mm) has higher dehusking efficiency of 97 % followed by S_1G_3 (12 rpm, < 160 mm) and S_2G_2 (18 rpm, 160-200 mm) with dehusking efficiency of 95 %. The combination S_3G_3 was found to have lower dehusking efficiency of 47 %.

Size of coconut significantly affects the dehusking efficiency. Dehusking efficiency increases with decrease in coconut size. Reduction in the size of the coconut increases the contact of blades with the coconut causes more husk removal. Increase in the dehusking efficiency increases with increase in roller speed. Higher dehusking efficiency was observed in roller speed of 18 rpm than 16 rpm and also at the same time poor dehusking efficiency was observed at 22 rpm. Increase in the speed causes improper gripping of coconut and decreases the residence time of coconut in the machine. Pascua et al. (2018) reported that the dehusking efficiency increases with increase in crank shaft speed. So the very high rotational speed negatively affects the dehusking efficiency.

3.5.3. Effect of Maturity, Roller Speed and Coconut Size on Dehusking Efficiency

The three-way interaction effect of the treatments on dehusking efficiency resulted that $M_2S_2G_3$ (dry, 18 rpm & < 160 mm) had more dehusking efficiency of 98%, which is followed by $M_2S_1G_3$ (dry, 13 rpm & < 160 mm) having dehusking efficiency of 97%. The optimum combination of dehusked green and dry coconuts are shown in **Fig. 8**. The treatment combination $M_2S_2G_2$ (dry, 18 rpm & 160-200 mm) was on par with $M_1S_2G_3$ (green, 18 rpm & < 160 mm). The lowest dehusking efficiency of 44% was recorded by the treatment M2S3G3 (dry, 22 rpm & < 160 mm). In the treatment combination $M_2S_2G_3$ (dry, 18 rpm & < 160 mm) higher dehusking efficiency was observed. Smaller size and lesser moisture favours the increased interaction of blades with the nut and complete removal of husk. In combination of $M_2S_1G_3$ (dry, 13 rpm & < 160 mm), the higher dehusking efficiency was due to the increased residence time of coconuts at lower roational speed.

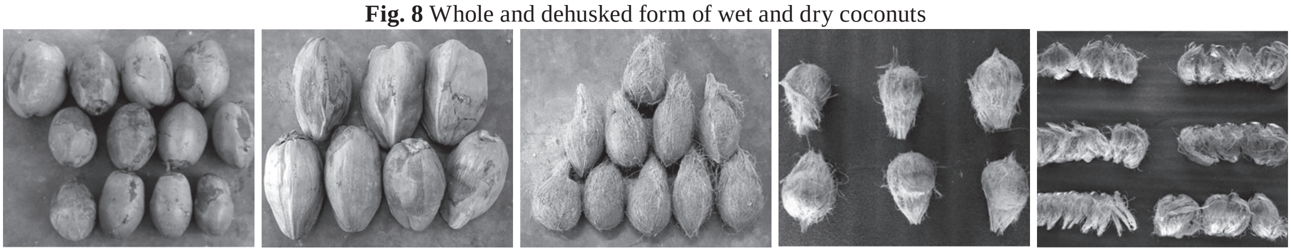
The combination $M_2S_3G_3$ (dry, 22 rpm & < 160 mm) showed lower dehusking efficiency due to the fact that dry coconuts required more dehusking force but higher rotational speed of rollers, reduces the residence time of coconuts with the blades causing poor dehusking efficiency.

It was understood from the **Table 4** that the independent variable viz., maturity, differential speed and size of rollers influenced the dehusking time of coconut dehusker at 1% of significance. While considering the interaction effect, the interaction of maturity level and speed influence the dehusking time significantly and the interaction between differential speed and coconut size also significantly influence the dehusking time at 1% level. In the same way, the interaction between the maturity level and coconut size significantly influenced the dehusking time at 1 percent level. The three factors interaction i.e., maturity, differential speed and coconut size also influenced the dehusking time at 1 % level of significance.

Conclusion

The overall higher dehusking efficiency was observed in the roller speed of 18 rpm both in case of dry and green coconuts. Higher dehu-

Fig. 8 Whole and dehusked form of wet and dry coconuts



sking efficiency was also observed in the roller speed of 13 rpm. Poor dehusking efficiency was observed at the rotational speed of 22 rpm. Among the various treatments the rotational speed of 18 rpm was found suitable for the machine. Higher dehusking efficiency and lesser dehusking time was observed at this speed (18 rpm) for both green and dry coconuts of various sizes.

Acknowledgment

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Development of Low-cost Automatic Sowing Depth Measurement Unit for Groundnut Planter

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Abstract

The depth of sowing of groundnut influences germination, largely by influencing moisture availability and temperature. Sowing depth is one of the indicators of precision seeder in its operation and it significantly affects the output. Several designs of groundnut planters are available commercially with intra and inter row spacing adjustment. There is no provision to adjust and control the depth of seeding, and depth adjustment largely depends on skill of the tractor driver. There are some technologies available to measure the sowing depth on the go, they are either complicated or costly. Hence, it is needed to develop a low-cost sowing depth measurement unit that can caution the driver to maintain the optimum sowing depth. The study involved identification of electronic components for construction of sowing depth measurement unit, development of a laboratory set-up for calibration of developed unit, integration of developed unit with existing groundnut planter, and performance evaluation of developed sowing depth measurement unit in the field. An ultrasonic sensor based sowing depth measurement unit was developed by considering safe sowing depth of 4-6 cm, and was calibrated in customized laboratory set-up. The developed unit was integrated with commercially available groundnut planter and performance was evaluated at three forward speeds (i.e. 0.75, 1.0, and 1.25 m s^{-1}). The performance parameters such as sowing depth, missing index, multiple index, and quality of feed index were measured and analyzed statistically using one way-ANOVA. The mean depth measured through the sowing depth measurement unit were 1.986 (CV: 0.27%), 3.99 (CV: 0.13%), 6.0 (CV: 0.16%), 7.99 (CV: 0.006%) and 9.92 cm (CV: 0.34%) for the actual sowing depths of 2, 4, 6, 8 and 10 cm, respectively. The mean sowing depth of 5.36 (CV: 5.85%), 5.32 (CV: 6.10%), and 5.34 (CV: 7.99%) cm observed at forward speeds of 0.75, 1.0 and 1.25 m s^{-1} respectively. The mean missing index of 5.45, 6.06 and 7.27% were observed at forward speeds of 0.75, 1.0 and 1.25 m s^{-1}, and the missing index increased with an increase in forward speed. At forward speeds of 0.75, 1.0 and 1.25 m s^{-1}, the mean multiple index and quality of feed index of 5.48, 4.24, 2.4% and 89.04, 89.66, 90.3% respectively. The missing index, multiple index, and quality of feed index were not significant at 5% level of significance. The cost of the developed sowing depth measurement unit was, ₹ 1,746.92. The monetary saving with developed sowing depth measurement unit was 980 ₹ ha^{-1}, and payback period was 2 ha. The developed sowing depth measurement unit is cost effective and easy to handle and had potential to maintain uniform sowing depth throughout the field with optimum sowing depth. Hence, the use of the developed sowing depth measurement unit could result in improved germination over conventional groundnut planter.

Keywords: Sowing depth measurement unit, Ultrasonic sensor, Missing index, Multiple index, Quality of feed index.

Introduction

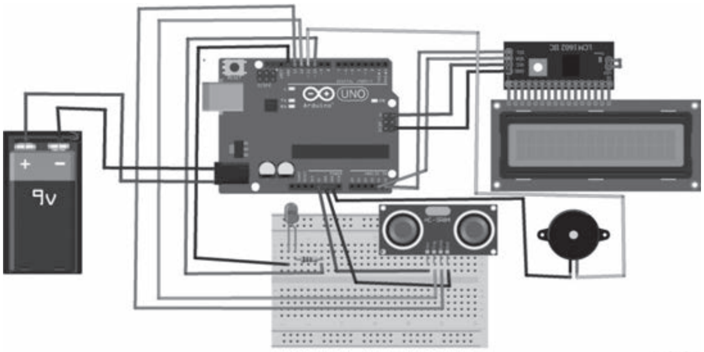
Agriculture is the backbone of Indian economy, about 68% of India population is mainly dependent on agriculture for their livelihood. Indian agriculture sector accounts for 18% of India's gross domestic product and provides employment to 50% of the countries workforce. The projected world population is 8.5 billion by 2030, 9.72 billion by 2050, and the projected world cereal equivalent (CE) food demand is to be around 10.09 billion tonnes in 2030 and 14.88 billion tonnes in 2050[7]. India is the second-largest populous country, with a population of 1.39 billion; the same is expected to increase to 1.64 by 2050 (PRB, 2019). Food grain production increased from 52 million tonnes in 1951-52 to 308.65 million tonnes in 2020-21, whereas, available agricultural land in India was decreased from 61.07% in 1991 to 60.3% in 2020[6]. Hence, it is essential to conserve and optimize use of resources in order to produce more production from the same land.

The oil seed production in India was increased from 5.16 million tonnes in 1950-51 to 33.42 million tonnes in 2019-20. Among oil seeds, groundnut is important crop in terms of export commodity. India is the second largest producer of groundnut in the word with annual production of 9.81 million tonnes in the year 2019-20, which is 15% of share in the world. Gujarat is the largest groundnut producing state with production of 4.64 million tonnes, followed by Rajasthan, Tamil Nadu, and Andhra Pradesh .Andhra Pradesh stand in fourth place in groundnuts production during 2019-20 with0.848 million tonnes, which was 83.33% more than the production registered in 2018- 19 (0.462 million tonnes)[2].

Groundnut sowing methods were classified into three categories, i.e. (i) Sowing with planters (ii) Dropping the seed with hand in the furrow formed by the country plough, and (iii) Hand dibbling. Among all sowing practices, there is no mechanism to detect the sowing depth and to control the sowing depth of groundnut. The depth of sowing of the seed influences germination largely by influencing moisture availability and temperature. In light soils, the seeds are sown to a depth of 5 to 7 cm and in heavier soils to a depth of 4 to 6 cm. The importance of sowing at the optimum depth has been shown by a number of researchers where sowing too shallow or too deep results in poor germination and yield losses. Sowing depth is one of the important indicators of precision seeder in its operation and it has very big effect on the output. In order to ensure the quality of crop planting, more and more people pay attention to the precise control of sowing depth[14]. The depth of sowing can be measured by manually digging the soil furrow after planting and measurement of sowing depth from the ground level. Thus, automating the process is important to improve the effectiveness and efficiency of measurement as manual measurement process requires a large amount of work, time and highly susceptible to errors.

Several studies have been conducted for regulating seeding depth. Most of them employed a depth control system utilizing sensors, actuators, and controllers[11]. Hydraulic cylinders are often employed as actuators for depth control since the tractor provide more hydraulic power than electric power and ultrasonic sensors were useful for measuring relative ground height and stubble height. Different types of sowing depth measurement techniques such as, ultrasonic sensor based sowing depth measurement system[15][9], soil profile sensor based sowing depth measurement system[4], machine vision based sowing depth detection system[3], and Ground Penetrating Radar (GPR) based sowing depth measurement system[10] have been developed. The developed sowing depth measurement systems are costly and not popularized in developing countries like India due to complexity. Keeping in view of importance of maintenance of proper sowing depth a need was felt to develop a low cost and simple sowing depth measurement unit that can measure the sowing depth of groundnut on the go with the objectives: (i) To identify electronic components for automatic sowing depth measurement unit, (ii) To develop a laboratory set-up for sowing depth measurement, and (iii) To integrate the developed unit with the groundnut planter and evaluate the performance.

Fig. 1 Functional components of sowing depth measurement unit



Material and Methods

2.1 Development of Sowing Depth Measurement Unit

In order to detect the depth of sowing, an electronic components based sowing depth measurement unit was developed. The objective was to measure the sowing depth of groundnut in the field on the go, for maintaining optimum sowing depth throughout the field. Accordingly, sowing depth measurement unit required an ultrasonic sensor to measure the sowing depth, a piezo-electric buzzer and LED to alert the tractor driver, a microcontroller to regulate entire measurement unit, an LCD to display sowing depth, and a battery for power supply. The various components were integrated with the help of breadboard and jumper wires, **Fig. 1**. Battery (9V) supply the power to various components of unit. The ultrasonic sensor is used to detect any object distance from the sensor, piezo electric buzzer and LED were used to indicate buzzer and blinking. The LCD with I2C adapter was used to display ultrasonic sensor reading.

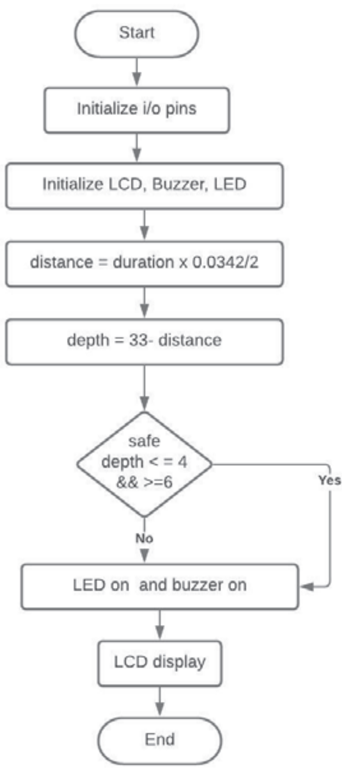
Table 1 Plan of experiment for calibration of sowing depth measurement unit in laboratory

Variables	Levels	Details	Measured Parameters
Depth of furrow	5	2, 4, 6 , 8, and 10 cm	a) Actual depth, cm
No.of replications	3		b) Measured depth, cm

2.2 Development of an Algorithm for Sowing Depth Measurement Unit

The recommended sowing depth of ground nut in heavy soils is 4 to 6 cm. An algorithm was prepared by considering safe sowing depth range of 4-6 cm. When the sowing depth is below 4 cm and above 6cm piezo electric buzzer produced sound and LED was illuminated. A program was developed in C^{++} language by using developed algorithm, as shown in **Fig. 2**.

Fig. 2 Algorithm for sowing depth measurement unit



2.3 Development of Laboratory Set-up for Calibration of Sowing Depth Measurement Unit

A laboratory experiment was conducted to calibrate the developed sowing depth measurement unit.

2.3.1 Experimental Setup

A customized laboratory setup was prepared to simulate the field condition in the laboratory for calibration of sowing depth measurement unit. A rectangular box of size 60 × 40 cm was constructed. The front side of the box was prepared with 8 mm glass, and remaining three sides were prepared with 12 mm wooden board. A furrow with tyne length of 33 cm was fabricated and attached to a height adjustment column. A triangular shape reference plate of size 20 cm height and 20 cm base was fixed to the furrow opener. The ultrasonic sensor was fixed on the frame as shown in **Fig. 4**, the depth of the furrow opener was adjusted according to the need by using height adjustment provision. The distance between the ultrasonic sensor and reference plate, when zero working depth was H_O, the distance between sensor and reference plate was H_T; then the working depth was d (H_O-H_T), as shown in **Fig. 5**.

2.3.2 Experimental Procedure

The ultrasonic sensor was fixed on sensor mounting bar of sowing depth adjustment frame. The developed sowing depth measurement unit was calibrated as per plan of experiment, **Table 1**.

The experimental design considered for the study was one way -ANOVA. The depth of the furrow opener was changed manually, at each run, the actual depth was measured by taking observation at fixed scale, whereas, the measured depth was noted from the LCD display of developed unit. Each experimental run was repeated three times to reduce error.

2.4 Integration of Developed Sowing Depth Measurement Unit with Groundnut Planter

The developed sowing depth mea-

Fig. 3 Developed sowing depth measurement unit

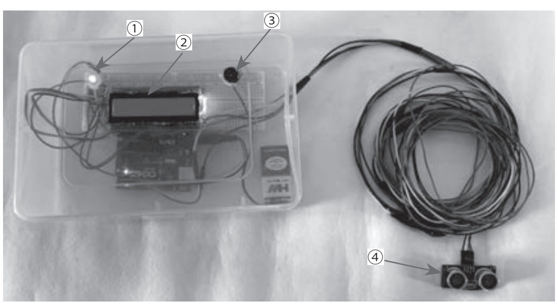
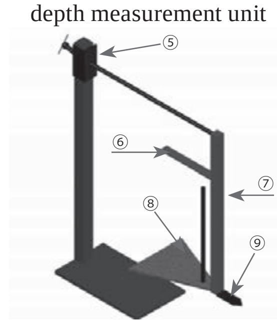


Fig. 4 Laboratory setup for calibration of sowing depth measurement unit



1. LED, 2. LCD display, 3. Piezo electric buzzer, 4. Ultrasonic sensor, 5. Provision for depth adjustment, 6. Sensor mounting bar, 7. Tyne, 8. Reference plate, 9. Furrow opener

Table 2 Plan of experiment for performance evaluation of sowing depth measurement unit in field

Independent parameter	Levels	Details	Measured Parameters
Forward speeds	3	0.75, 1.0, and 1.25 m s^{-1}	a) Sowing depth, cm
No.of replications	5		b) Missing index, %
			c) Multiple index, %
			d) Quality of feed index,%

surement unit was integrated with commercially available four row groundnut planter. The width of the groundnut planter was 1.2 m. The ultrasonic sensor of developed unit was fixed on the main frame of first furrow opener, **Fig. 7**. A reference plate was fixed near to the shoe of the furrow opener. The distance between ultrasonic sensor and reference plate was 33 cm when plate on leveled concrete floor (i.e. zero working depth position). The control box of sowing depth measurement unit was fixed near the steering wheel, at drivers focus view. The driver can observe the actual depth of sowing on the go through LCD display, and piezo electric buzzer and LED can caution the driver when sowing depth was beyond acceptable range.

2.5 Performance Evaluation of Developed Sowing Depth Measurement Unit in Field Condition

The developed sowing depth measurement unit was evaluated in the field for planting of groundnut. The experimental field was located at College of Agricultural Engineering, Madakasira, Anantapur district of Andhra Pradesh with geographical location of 13°56'25''N latitude and 77°18'42''E longitude. The type of soil is red soils (sandy clay loam), annual rain fall of selected location is 577 mm. The experimental plot 50 × 50 m was considered for the field performance study.

2.5.1 Experimental Procedure

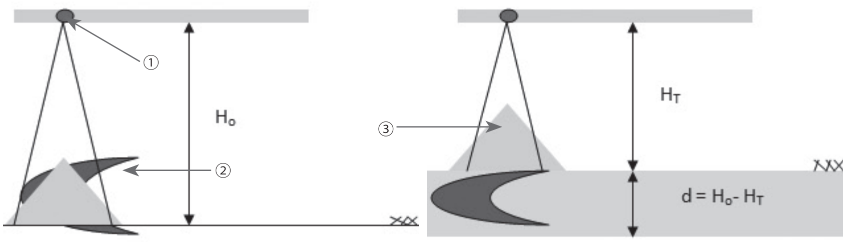
The performance evaluation of developed sowing depth measurement unit was carried out for planting of groundnut (variety: K6) with spacing of 30 × 10 cm. The field performance study was conducted as per plan of experiment, **Table 2**. The performance evaluation was carried out at three forwards speeds of the tractor to investigate the effect of forward speed on performance of sowing depth measurement unit. The experimental design considered for the field performance studies was one way - ANOVA.

The performance parameters were measured by using grid sampling technique. The selected field was divided into 5 grids of 50 × 10 m size. In each grid at a random location 1 m^2 frame was placed and parameters like sowing depth, missing index, multiple index, and quality of feed index was measured.

2.5.1.1 Sowing Depth

Five plants were selected randomly by considering grid sampling procedure and selected plants were removed carefully from the soil. The

Fig. 5 Schematic diagram illustrating various depths; d: computed depth, H_o: zero-working depth position, H_T: sensor height



1. Ultrasonic sensor, 2. Furrow opener, 3. Reference plate

Fig. 6 Calibration of sowing depth measurement unit

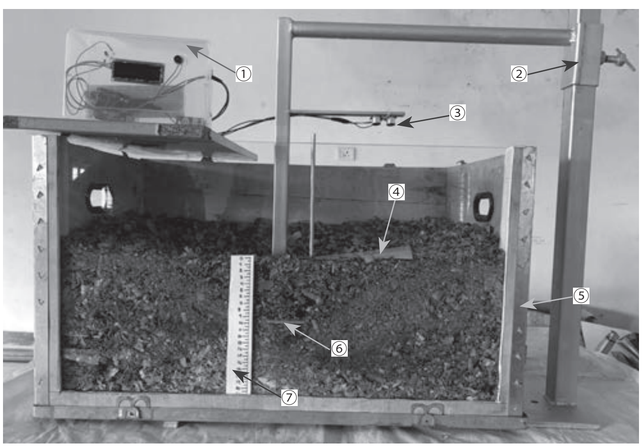


Fig. 7 Integration of developed sowing depth measurement unit with groundnut planter

1. Sowing depth measurement unit, 2. Depth adjustment, 3. Ultrasonic sensor, 4. Reference plate, 5. 60 × 40 cm box, 6. Furrower, 7. Scale, 8. Sowing depth measurement unit, 9. Position of ultrasonic sensor, 10. Reference plate

depth of the seeds to the soil surface was measured in the vertical plane. The mean sowing depth and coefficient of variation were determined by measuring the mesocotyl length of 20 plants (4 plants per grid) to the nearest 1.00 mm length for three forward speeds at 20 DAS.

2.5.1.2 Missing Index

The number of plants with spacing more than 15 cm was counted, and total number of plants in the frame also counted. The missing index is the ratio of number of spacing greater than 1.5 times the theoretical spacing to the number of measured spacing at selected area.

$$I_{miss} = (n_1 / N) \times 100 \qquad [3.3]$$

Where,

I_{miss} is Missing index, %;

n_1 is number of spacing ≥ 1.5 theoretical spacing;

N is total number of measured spacing

2.5.1.3 Multiple Index

The number of plants with spacing 5 cm and below was counted, and total no. of plants also counted. The multiple index is the ratio of number of spacing less than 0.5 times the theoretical spacing to the number of theoretical spacing at selected area. It is indicator of more than one seed within the desired spacing.

$$I_{muiti} = n_2 / N \times 100 \qquad [3.4]$$

Where,

I_{multi} is Multiple index, %;

n_2 is number of spacing ≥ 0.5 theoretical spacing;

N is total number of measured spacing

2.5.1.4 Quality of Feed Index

The quality of feed index (Iq) is the percentage of spacing that are more than half but not more than 1.5 times the theoretical spacing. The quality of feed index is an alternate way of presenting the performance of the misses and the multiples.

$$Iq\ (\%) = 100 - (I_{miss} + I_{multi}) \qquad [3.5]$$

Where,

I_{miss} Index;

I_{multi} multiple Index

Table 3 Performance parameters of groundnut planter with sowing depth measurement unit

Speed, m s^{-1}	Range	Mean	SD	CV
Sowing depth, cm				
0.75	4.9-5.8	5.36	0.313	5.85
1.00	4.8-5.8	5.32	0.324	6.10
1.25	4.9-6.1	5.34	0.427	7.99
Missing index, %				
0.75	3-6.1	5.45	1.21	22.2
1.00	3-9.1	6.06	1.91	31.6
1.25	6.1-9.1	7.27	1.48	26.4
Multiple index, %				
0.75	3-6.1	5.48	1.24	22.6
1.00	3-6.1	4.24	1.51	35.8
1.25	0-3	2.4	1.2	50.0
Quality of feed index, %				
0.75	87.8-94	89.04	2.48	2.78
1.00	87.8-94	89.66	1.51	1.69
1.25	87.9-90.9	90.3	1.2	1.32

Results and Discussion

3.1. Calibration of Sowing Depth Measurement Unit in the Laboratory

A customized laboratory setup was prepared with simulation to actual field condition. The mean depth measured through the sowing depth measurement unit were 1.986, 3.99, 6.0, 7.99 and 9.92 cm for the actual sowing depths of 2, 4, 6, 8 and 10 cm, respectively. The R^2 value of 0.999 indicated that linear regression equation had good fit, and the developed sowing depth measurement unit was measured the depth of sowing accurately, **Fig. 9**. The coefficient of variation for sowing depths of 2, 4, 6, 8 and 10 cm were 0.27, 0.13, 0.16, 0.006 and 0.34 respectively. The CV were very low which indicates the accuracy of measurement in sowing depth is good.

3.2. Performance Evaluation of Developed Unit in the Field.

The performance of developed unit was carried out at three forward speeds i.e.0.75, 1.0 and 1.25 m s^{-1}. The performance parameters such as sowing depth, missing index, multiple index and quality of feed index were measured.

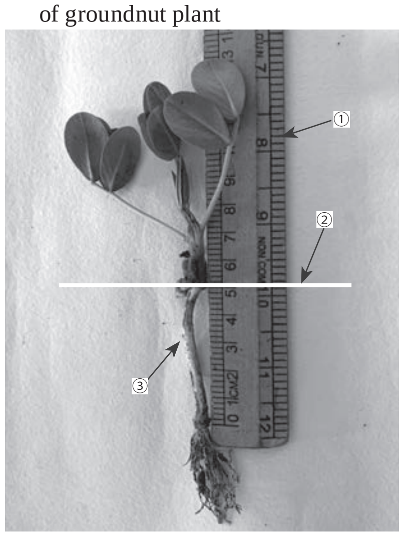
3.2.1 Effect of Forward Speed on Sowing Depth

The mean sowing depth of 5.36, 5.32, and 5.34 cm were observed at forward speeds of 0.75, 1.0 and 1.25 m s^{-1} with coefficient of variation of 5.85, 6.10 and 7.99 respectively, **Table 3**. It is observed that coefficient of variation in sowing depth was minimum at forward speed of 0.75 m s^{-1}, **Fig. 10**. The sowing depth was not influenced ($p = 0.988$) by forward speed of the tractor.

3.2.2 Effect of Forward Speed on Missing Index

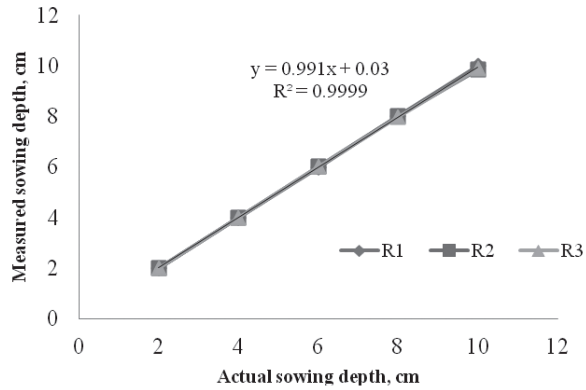
The mean missing index of 5.45,

Fig. 8 Measurement of sowing depth of groundnut plant



1. Scale, 2. Soil surface, 3. Mesocotyl

Fig. 9 Measured values of sowing depth control unit



6.06 and 7.27% were observed at forward speeds of 0.75, 1.0 and 1.25 m s^{-1} with coefficient of variation of 22.2, 31.6 and 26.4 respectively, **Table 3**. It is observed that coefficient of variation in missing index was minimum at forward speed of 0.75 m s^{-1}. The missing index was increased with the increase in forward speed. The same trend in missing index with forward speed was reported by [12][13][5][16][1]. The missing was increased by 11.19 and 33.33% when the forward speed increased from 0.75 m s^{-1} to 1.0 and 1.25 m s^{-1} respectively, **Fig. 11**. However, the variation in missing index with the forward speed was not significant at 5% level of significance ($p = 0.286$), **Table 3**.

3.2.3 Effect of Forward Speed on Multiple Index

The mean multiple index of 5.48, 4.24 and 2.4% were observed at forward speeds of 0.75 m s^{-1}, 1.0 m s^{-1}, and 1.25 m s^{-1} with coefficient of variation of 22.6, 35.8 and 50.0 respectively, **Table 3**. The multiple index was decreased with the increase in forward speed. The same trend in multiple index was reported by [16][8][13][1]. The multiple index was decreased by 27.62% and 56.20% when the forward speed was increased from 0.75 m s^{-1} to 1.0 m s^{-1} and 1.25 m s^{-1}, **Fig. 12**. However, the variation in multiple index with the forward speed was not significant at 5% level of significance ($p = 0.063$).

3.2.4 Effect of Forward Speed on Quality of Feed Index

The mean quality of feed index of 89.04, 89.66 and 90.3% were observed at forward speeds of 0.75 m s^{-1}, 1.0 m s^{-1}, and 1.25 m s^{-1} with coefficient of variation of 2.78, 1.69 and 1.32 respectively, **Table 3**. It is observed that coefficient of variation in quality of feed index was minimum at forward speed of 1.25 m s^{-1}. The quality of feed index was increased with the increase in forward speed. The same trend on effect of forward speed on quality of feed index was reported by [8][13][1]. The quality of feed index was increased by 1.4% when the forward speed increased from 0.75 m s^{-1} to 1.25 m s^{-1} respectively, **Fig. 13**. However, the variation in the quality of feed index with the forward speed was not significant at 5% level of significance ($p = 0.523$).

3.3. Cost-economics of the Developed Sowing Depth Measurement Unit

The overall cost of the developed sowing depth measurement unit was, ₹ 1,746.92. The use of developed sowing depth measurement unit controls the sowing depth throughout the field which resulted in proper germination and growth. If the percent increase in the germination was improved by 5%, there is saving of approximately 16,666 seeds of ground nut, which is equal to 6.5-7 kg of seed. The cost of groundnut seed is 140 ₹ kg^{-1}, hence monetary saving of 980 ₹ ha^{-1}. The developed sowing depth measurement unit payback period is 2 hectares. It can be seen that the developed sowing depth measurement unit if used for 100 ha year^{-1}, there is monetary saving of ₹ 98,000.

Conclusions

It is concluded that the developed sowing depth measurement unit is very cost effective and easy to handle. It is observed that the developed sowing depth measurement unit had potential to maintain uniform sowing depth throughout the field with optimum sowing depth. Hence, the use of the developed sowing depth

Fig. 10 Effect of forward speed on sowing depth

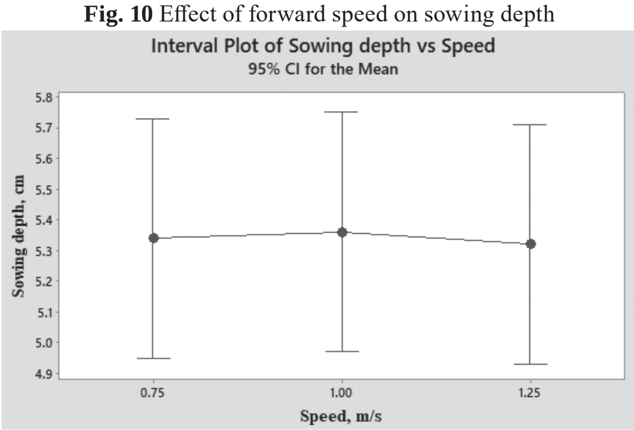
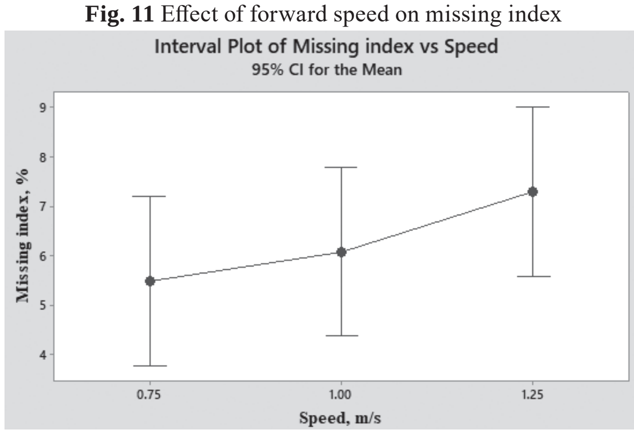


Fig. 11 Effect of forward speed on missing index



measurement unit could result in improved germination over conventional groundnut planter. The farmers can reap the benefits of developed sowing depth measurement unit.

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Fig. 12 Effect of forward speed on multiple

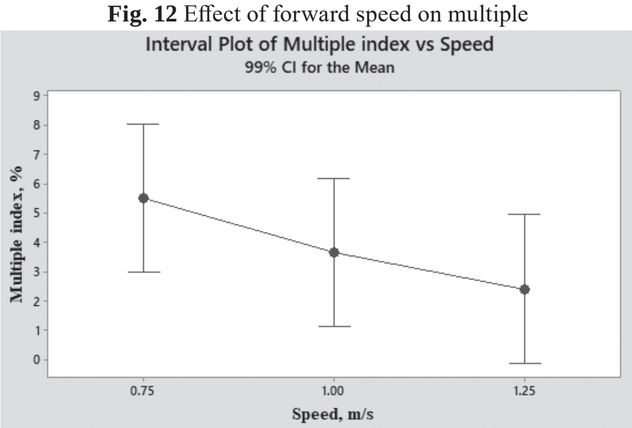
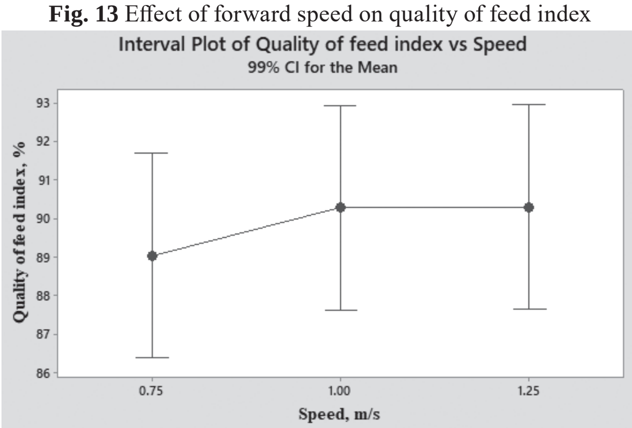


Fig. 13 Effect of forward speed on quality of feed index



Development of Tractor Operated Vertical Axis Rotary Weeder for Inter Row Weed Control

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Abstract

India has witnessed significant expansion of the net cultivable area over the last decade. However, challenges such as low and uneven productivity along with high cultivation costs have increased substantially. Weed management has been reported to incur on an average INR 6000/ha in Kharif crops and INR 4000/ha for Rabi crops summing to 33% and 22% of total production cultivation costs of Kharif and Rabi crops, respectively. Even with traditional weed control practices, farmers incur yield losses up to 15-20%. Weed management is therefore critical for efficient crop production. Several approaches have been adopted for weed management that is typically mechanical, manual, chemical and biological. Mechanical weeding has been reported as the best alternative to manual, chemical and biological weeding methods. Generally weeding operations with rotary tiller, the rotary tiller (horizontal plough) moves in a vertical plane and strikes the ground, causing increased soil resistance, i.e. hard layer pan in line of crops row, which may hinder water leaching and supplement to the root zone of crops, affecting yield. Tractor operated three row vertical axis rotary weeder with tools has been developed and evaluated for weed control. The average WE were observed in the range of 78.8% to 84.2% and yield critical plant damage of 2.16% to 3.1% in the entire range of operating parameters. The TFC and AFC were found in the range of 0.20-0.36 ha/h and 0.16-0.27 ha/h at the FS of 1.3 and 2.25 km/h respectively. However, the FE of 79.79% and 73.75% were observed at 1.3 and 2.25 km/h of FS, respectively.

Keywords: Inter row weeder, vertical axis rotor, tool mechanics, weed management

Introduction

India is the world's fastest developing country and economy majorly contributed by agriculture. Indian context a record food production has been marked in the last decades. In order to maintain high food production, weed management is utmost important. The optimum crop growth is majorly affected by weeds that results in reduced crop yield. Weeds are the non-native plant species that compete with main crop plant for nutrients and other resources and adversely affect the crop yield (Slaughter et al., 2008; Weide et al., 2008). Weed growth rate is typically very high as compared to main crops, dominating the entire field if not treated and managed timely. Example of common obnoxious weeds are Parthenium hysterophorus, Cyperus rotundus, Saccharum spontaneum, Cynodon dactylon and Phalaris minor. Some weeds, such as Paretheninm hysterophours, are poisonous and can cause allergic reactions such as asthma, rashes, puffy eyes, peeling skin, dermatitis, running nose, swelling, and itching of the mouth and nose, etc. on direct or indirect contact. Such weeds also have a high infestation capacity that also adversely affect crop production (Biswas et al., 1999) subsequently increasing production and post-harvest cost (Zimdahl, 2013).

In the context of Indian agriculture, the highest production loss causing agents are weeds (33%) and followed by pathogens (26%), insects (20%), storage pests (7%), rodents (6%) and others (8%). Rangaswamy et al. (1993) observed that weed management single handedly consumes about one third of total cultivation costs. During production cycle, weed management demands over 25% of the total labor (900-1200 man-hours/hectare) (Nag and Dutta, 1979). Weed management has been reported to incur on an average INR 6,000/ha in Kharif crops and INR 4,000/ha for Rabi crops summing to 33% and 22% of total production cultivation costs of Kharif and Rabi crops, respectively (Yaduraju and Mishra, 2017).

Weed management is therefore critical for efficient crop production. Mechanized weed control systems is found to be the most effective and better solution for both dry land and wet land conditions (Gite and Yadav 1990; Tewari et al., 2014 a & b; Chandel et al., 2018; Chethan and Krishnan 2017). A control method that prevents weeds from getting established in a cultivated land is called as preventive weed control method. This method comprises use of certified weed free seeds, weed free seed transportation, weed free farm equipment, and irrigation water screening. These steps limit the transportation of weeds to the cultivation land. In the cultural weed control method, field conditions are maintained such that weeds are less likely to establish and/or increase in number. Common cultural weed control practices include crop rotation, avoiding pasture overgrazing, soil fertility maintenance and use of well-adapted competitive species. The emergence of herbicide-resistant weeds, increasing demand for chemical free food has initiated the need for alternate weed control methods to minimize environmental concerns (Tewari et al., 2014a; Chandel et al., 2018). Although biological methods are entirely natural and do not affect the environment but do not ensure complete weed eradication rather suppresses vigor and weed spreads. Manual weed control is another traditional yet popular method. Manual methods of weed control are the smoothest but demand excessive labor and costs. Besides, manual methods demand continuous human bending and at times exposure to infectious weeds species (Tewari et al., 1993; Tu et al., 2001; Weide et al., 2008; Kumar et al., 2020). Mechanical weeding is the best choice over the manual, chemical and biological weed control methods.

Mechanical approach is the most widely adopted measure for weed control. Such methods deploy farm equipment for weed management. Traditionally, mechanical weeding tools were pulled by the draft animals but are now driven by tractors. A range of mechanical weeding tools and implements are used for burying, cutting and uprooting the weeds for their control (Bleeker et al., 2007; Rasmussen et al., 2008; Kumar et al., 2019). The mechanical weed control in inter row area is more or less solved with commercially available tools. The rotary tiller is more widely used for weeding operation. During weeding operations, the rotary tiller (horizontal plough) moves in a vertical plane and strikes the ground, causing increased soil resistance, i.e. hard layer pan in line of crops row, which may hinder water leaching and supplement to the root zone of crops, affecting yield. (Azadbhakt et al., 2014). Thus keeping the view of above sited problem a tractor operated vertical axis rotary weeder has been designed and developed for weed management.

Material and Methods

Design of Three Rows Vertical Axis Inter Row Weeder

This sections deal with design considerations to develop tractor operated inter row weeder for wider row crops. Design aspect includes design of vertical axis rotors and its components along with frame, tools and power transmission systems. In addition, the field evaluation of tractor operated weeder has been also considered (Bernacki et al., 1972 a & b; Norton et al., 2004; Khurmi et al., 2008; Bhandari et al., 2009).

a. Optimization of Inter Row Rotor Diameter and Number of Tools Required

The inter row rotor diameter and the number of tools required is one of the major factor which decides the capacity of weeder and power required to operate it. Inter row rotor diameter and number of tools was decided and optimized as per the following formulae below:

$Z_{inter} = D + 2d \tan\Phi$

The effective soil failure zone ($Z_{inter} = Z_f$) can be calculated as $Z_f = S_c - Z_p$

Where, S_c is crop spacing, mm and can take it as 500 mm; Z_f = effective soil failure zone or inter row zone, mm; Z_p = protection zone (150 mm to 200 mm); Z_{inter} = inter row weeding zone; d = depth of operation = 60 mm; D = diameter of inter row rotary; Φ = soil friction angle = 20°; By using the above values the inter row diameter can be calculated and obtained as (D_{inter}) ≈ 300 mm. Minimum number of tools on rotor should be 2 to 3 for stability, $n_1 = 3$ (Bernacki et al., 1972). Considering self-cleaning action of tools, let no. of tools on rotor of inter row can be optimized by using soil failure zone equation of inter row, i.e.

$n_2 = n_1 \times Z_f/Z_p = 6.37$

Thus n_2 will be 6-7, let's take it as 6.

MS Flat of width 30 mm and thickness 5 mm was selected to make rotary frame and high carbon steel for cutting tools. The developed system was simulated in ANSYS software (**Fig. 1**) and found suitable.

Structural analysis of all the solid models of RVA and tools was conducted using the finite element method. This method can be used for effectively predicting the effects of forwarding speed, RVA speed and soil conditions on the stresses produced during weeding operation.

b. Design of Tool

Trapezoidal shape tool was selected for weeding operation (**Fig. 2**). Trapezoidal shape tool has wide top and a narrower base to lower the soil resistance on tool-soil interaction point. The direction of tool rotation is perpendicular to the forward direction of motion. Generally, depth of weeding operation required varies from 20 to 40 mm at three to five weeks after sowing of crop. However, it may require 60 mm depth of operation based on the field and weed condition. Keeping 20 mm clearance from the rotor, 80 mm tool length was selected. The weeder was designed suit to the tractor sizes varies from 30-45 hp. In this design, the design parameters of tools were calculated by considering tractor power as 45 hp, speed operations 3 km/h and rotor rpm as 180 to 220 rpm. Detailed calculations can be depicted from the following descriptions;

Power Available at Rotor Shaft

$P_{PTO} = P_{tractor} \times 0.746 \times \eta_t \times \eta_r \times \eta_l$

Where, P_{PTO} = PTO power, kW; $P_{tractor}$ = tractor engine power, hp; η_t = transmission efficiency, (0.8-0.9); η_r = reserve power of tractor, (0.8-0.85); η_l = power loss (4-6%) at soil tire and tool interaction (0.94-0.96);

P_{PTO} = 23203.5 W

Tilling Pitch

The distance between two consecutive bites of the tools oriented in one plane is called the tilling pitch (l).

$l = v \times 2 \times \pi \times R/u \times n_1$

Where, v is tractor speed; R is rotor radius; u is peripheral speed; n_1 is number of tools

let, u/v = 4 (Bernacki et al., 1972)

u = 2.88 m/s

l = 31.4 mm

Peripheral Force (Ks) of Rotor

Friction coming on tools due to bearing rotation is called peripheral force (Ks).

$Ks = P_{PTO} / u$

Where, Ks = peripheral force Ks = 8056.77 W

Force Acting on Each Tools

The designed peripheral force,

Ke = Ks × CP

Where, CP = overload factor which takes care of fluctuation in the peripheral force during the field operation; CP is generally taken as 1.5 for stone less soil and 2.0 for stony soil.

$Ke = (Ks \times Cp) / (i \times n_1 \times n_e)$

Cp = factor of safety = 2; i = number of rotors; n_1 = number of tools on one rotor; n_e = no. of tools strikes at a time; However, weeder design is based on RVA rotation so assume that

$i \times n_1 \times n_e = 24$

Ke = 671.40 N

Tool Dimensions

The tool is as a cantilever so the only bending force will be an act. Bending equation is given by (Khurmi and Gupta, 2008; Rattan, 2009)

Assume, a/t = 5 and a/b = 3

$M/I = \sigma_b/Y$

Where, M = bending moment acting at tool; σ_b = bending stress, 150 MPa for high carbon steel; I = moment of inertia of tool; Y = distance from neutral axis to the extreme fiber

Y = a/2

$I = ta^3/12$

M = Ke × L

$\sigma_b = MY/I$

$150 = (Ke \times L \times a/2) / ta^3/12$

t = 3.41 mm

The available size of the MS flat of thickness is 3.5 mm; therefore, the thickness of 3.5 mm was selected to fabricate tools.

t = 3.5 mm

Tool Top Width

a/t = 5

a = 21 mm

The available width is 30 mm, so width of 30 mm was selected

Tool bottom width,

a/b = 3

b = 10 mm

So dimensions of tools used for weeding operations were

Top width, a = 30 mm; Bottom width, b = 10 mm; Thickness, t =

Fig. 1 ANSYS simulation of inter-row rotor

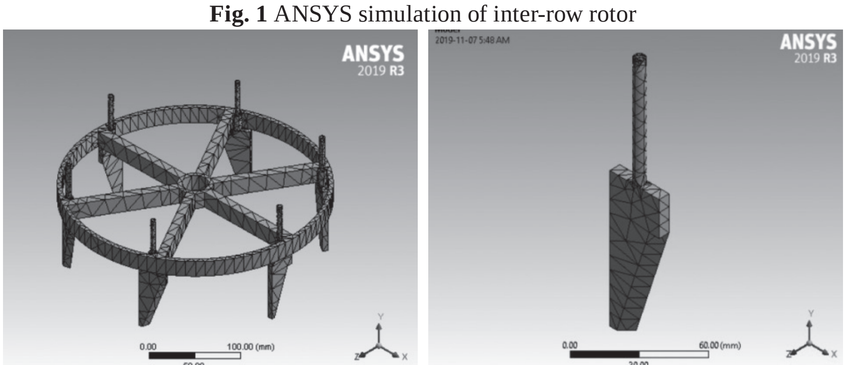
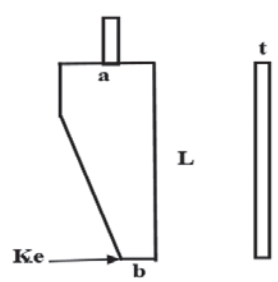


Fig. 2 Force diagram of weeding tool



3.5 mm.

Deflection of Tools

In this case concentrated soil load is acting on free end of the tool. Deflection of free end is given by

$Y = -WL^3/3EI$ (Khurmi and Gupta, 2008)

Here, W = Ke = 671 N; L = 0.08 m; $E = 2 \times 10^{11}$; $I = 1.22 \times 10^{-4}$; $Y = 1.58 \times 10^{-8}$ mm; Safe limit, $Y_{safe} = L/250 = 3.2 \times 10^{-5}$ mm

Here, $Y_{safe} >> Y$, so the design is in safe limit

Design of Shaft of Inter Row Rotors

$P_{PTO} = 23203.5$ W

PTO rpm, $Np_{rpm} = 540$

$P_{PTO} = 2\pi NT_{PTO} / 60$

$T_{in} = T_{pto} = 410.53$

Reduction in PTO gear box - 2.5:1

$T_{out} = 1026.34$ Nm = 1026340.23 Nmm

Total number of tools used in rotor weeders was 24, so torque on individual tools is

$T_{tool} = 42764.17$ Nmm

Single unit inter row rotor consisted six tools, so torque of inter row weeding unit

$T_{inter\ row} = 256585.05$ Nmm

Single unit intra row rotor consisted of three tools, so torque of intra row

$T_{intra\ row} = 128292.51$ Nmm

The shaft diameter was calculated using the following equation.

Assuming MS solid circular shaft with maximum permissible shear stress as 56 N/mm^2 (Khurmi and Gupta, 2008)

T = (π/16) × torsional stress × (diameter of shaft)^3

$T = (\pi/16) \times \tau \times d^3$

Shaft diameter of inter row rotor, d_1

$d_1 = 28.58$ mm

The available size of the MS solid shaft is 30 mm; therefore, the shafts of inter-row rotors of 30 mm were selected to fabricate.

c. Design of Bevel Gear Box for Power Transmission from PTO to Rotor Unit

Bevel gears are very efficient in transmitting power between angularly disposed of shafts at a constant velocity ratio. As we have to transmit power between two perpendicular shafts, bevel gears were selected. For designing the bevel gear pair first, the required gear ratio was decided. Then design torque was calculated on the basis of the overload factor. Based on the designed torque and gear ratio, the pinion pitch diameter was selected. After selecting the pinion pitch diameter, number of teeth on bevel gear was selected.

PTO rpm, $N_{prpm} = 540$

Targeted rotor speed = 180-220 rpm

So input rpm of pinion, $Ni = N_p$ = 540 rpm

Output rpm of gear, $No = N_g$ = 220 rpm

Reduction in gearbox, Gear ratio

$N_p/N_g = T_g/T_p$

$T_g/T_p \approx 2.5$

$T_g = 2.5\ T_p$

$T_g = 40$ (Let, $T_p = 16$)

Input torque, $T_{in} = T_{pto} = 410.53$ Nm

Let, m = Module of the gear

Tooth profiles of the gears are of 14.5° composite form.

Since the shafts are at right angles, so pitch angle for the pinion,

$\theta_{p1} = \tan^{-1}(1/VR) = \tan^{-1}(T_p/T_g)$

$\theta_{p1} = 21.80$

Pitch angle of the gear,

$\theta_{p1} = \theta_s - \theta_{p1}$

θ_s = shaft angle = 90°

$\theta_{p2} = 68.20$

Formative no. of teeth for the pinion

$T_{EP} = T_p.\ \sec\theta_{p1} = 17.23$

Formative no. of teeth for gear

$T_{Eg} = T_g.\ \sec\theta_{p2} = 107.70$

Tooth form factor for pinion and gear

$Yp = 0.124 - (0.684/T_{EP}) = 0.084$

$Yg = 0.124 - (0.684/T_{Eg}) = 0.117$

$S1 = \sigma_{op} \times Yp = 7.14$ (σ_o is allowable static stress for carbon steel)

$S2 = \sigma_{og} \times Yg = 6.43$

S1 > S2 so the pinion is weaker, thus the design should be based upon the gear.

Torque in gear

$T_G = 2.5 \times T_P = 1026.32$ Nm = 1026320 Nmm

Tangential load on the gear

$W_t = T / (Dg/2) = 2T_G/mTg$ = (5131.6/m) N

Pitch line velocity, V

$V = \Pi \times Dg \times Ng/60 = \Pi \times m \times Tg \times Ng/60 = 0.46$ mm/s

Taking velocity factor,

Cv = (6/6 + 0.46 m)

Length of pitch cone element

$L = Dg/2\ \sin\theta_{p2} = 21.54$ m mm

Let face width (b) as 1/3 of the length of the pitch cone element (L)

b = L/3= 7.18 m

Tangential load on the gear,

$W_T = (\sigma_{og} \times Cv) \times b \times \Pi \times m \times Yg \times [(L - b) / L]$

5131.6/m = 55 × (6/6 + 0.46 m) × 7.18 m× Π × m × 0.117 × (21.54 − 7.18/21.54)

5131.6/m = 583.21 m^2/(6 + 0.46 m)

583.21 m^2 = 30789.6 + 2360.53 m

m = 4.10 ≈ 5 (Nearest module)

m = 5

b = 7.18 × 5 = 35.9 ≈ 36 mm

Gear diameters,

Dp = mTp = 80 mm

$D_G = mT_G = 200$ mm

Check for Dynamic Load

Pitch line velocity

V = 0.46 m = 2.3 m/s

Tangential tooth load on gear

$W_T = 1026.32$ N

Tooth error, e = 0.015 mm for 5 module

K = 0.107 for 14.50

Modulus of elasticity for cast iron, $Ep = E_G = 84$ N/mm^2

Deformation or dynamic factor

$C = (K \times e \times Ep \times E_G) / (Ep + E_G)$ = 96 N/mm

Dynamic load on the gear

$W_D = W_T + [21v\ (bc + W_T)] / [21v + \sqrt{(bc + W_T)}]$

$W_D = 3727.60$ N

Flexural endurance limit (σ_e) for gear material cast iron

σ_e = 84 MPa = 84 N/ mm^2

Static tooth load or endurance strength of the tooth

$Ws = \sigma_e \times b \times \pi \times m \times Y_G$

Ws = 5554.78 N

$Ws > W_D$, therefore the design is satisfactorily from the stand point of dynamic load.

Check for Wear Load

Surface endurance limit is

σ_{es} = 630 MPa = 630 N/mm

Load stress factor

$K = (\sigma_{es})^2 \times \sin\Phi / 1.4 [(Ep \times E_G) / (Ep + E_G)]$

K = 2.68

Ratio factor

$Q = (2 T_{EG}) / (TE_G + TEp)$

Q = 1.72

Maximum or limiting load for wear

$W_w = Dp \times b \times Q \times K = 13275.64$ N

$W_w > W_D$, Therefore, the design is satisfactorily from the standpoint of wear. Therefore, a PTO gearbox was fabricated with pinion teeth 16 and gear teeth 40.

d. Chain and Sprockets Design

Chain drives can maintain an exact speed ratio during power transmission as they do not slip. Furthermore, at slower speeds, the chain drives can transmit a large amount of power.

Chain length

The chain length of PTO gearbox shaft to inter-row rotor gearbox shaft

Chain length (Lc) in terms of links

$Lc = (2S_{cd})/Pc + 16$

S_{cd} = Center to center distance between sprockets (mm) = 270 mm

Pc = chain pitch (mm) = 19.05 mm

Nst = number of teeth on driving sprocket =16

L_c = 44.34 links

So length of chain = Lc × m = 844.67 ≈ 845 mm

(a) Chain Length from Inter Row Centre Gear Shaft to Intra Row Fixed Shaft

Chain length (Lc) in terms of links

$Lc = (2S_{cd})/Pc + 16$

Lc = 65.54

So length of chain = Lc × m = 1248.6 ≈ 1250 mm

Total chain length for shaft of two units of intra row rotors = 2 × 1250 = 2500 mm

(b) Chain Length from Intra Row Fixed Shaft to Intra Row Rotor Shaft

Chain length (Lc) in terms of links

$Lc = (2S_{cd})/Pc + 16$

Lc = 41.53

So length of chain = Lc × m = 791.2 ≈ 800 mm

Total chain length for shaft of two units of intra row rotors = 2 × 800 = 1600 mm

PTO speed − 540 rpm

Rotor speed − 180-220 rpm

Speed ration − 2.5

Teeth on sprocket of PTO central shaft 16, tp = 16

T_{PTO} = 410.53 Nm

$T_p = 2.5 \times T_P$ = 1026.32 Nm

Speed ratio of chain drive = 1.4 to 2:1

Standard pitches range are 19.05 mm to 25.40 mm.

Depth of operation during weeding operation is low so the pulsating load is low so value of pitch is 19.05 mm selected.

Roller chain speed

V= Pnz/60 × 1000 m/s

P = 19.05, n = 216, z = Tp = 16

V = 1.09 m/s

Driving force in chain (Fu)

Fu = 2 × P × 1000 × T/Z × P

Fu = 128292 N

Driving force,

Ft = Power transmitted / speed of chain = P/V

P = 23203.5 W

Ft = 21287.61 N

Tension in chain due to sagging

Fs = k × mg × x

m = mass of the chain in kg/m length

Chain length from PTO shaft sprocket to Inter row shaft sprocket = 840 mm

mg = 8.23

x = Centre distance, m

K = 2

Fs = 2 × mg × x = 13.82 N

Total tension (Fc) in tight side of the chain,

Fc = Ft + Fs

Fc = 21.30 kN

Now, to meet the design requirement a duplex chain with 19.03 mm pitch (12 B) was selected as per IS-2403-1991.The minimum breakage load Fb of chain is 57.8 kN, which is more than the calculated value. Therefore, the chain is safe from breakage.

e. Design and Selection of Others Components

Arrangements were made to attach the front lateral of the mainframe of weeder with three-point linkage of tractor. The frame was subjected to both bending and twisting moments. The cross-section of the beam was taken as a hollow square pipe. MS hollow square section of width 50 mm and 5 mm of wall thickness was used for the fabrication of the frame. Towed ground wheels of two units having equal diameter were attached to the shaft provided in the mainframe to maintain the depth of the weeding unit. The total weight of the machine was supported by three-point linkage and ground wheels. Ground wheels were attached to the mainframe along the length at a distance of 1,010 mm from the centre of the frame. The diameter and width of the ground wheel were decided as 370 mm and 100 mm, respectively. Driving shaft of the weeding unit was considered to work under moderate duty. Hence, it was supported on a frame with extra light series of ball bearings with housing. Considering the number of shafts for transfer of power in horizontal and vertical direction suitably bearing selection was made. The input shaft of PTO gearbox consisted of roller ball bearing (6207) and output shaft (6207) of two units bearing. The implement receives the PTO power at its PTO gearbox and this power is transmitted to the central bevel gearbox through a chain drive. There are two more bevel gearboxes on the implement on the right and left side of this central bevel gearbox taking power from the central bevel gearbox through universal joints.

f. Field Evaluation of Developed Weeder

The performance of selected power weeder was evaluted under field conditions on the basis of the following parameters. The parameters were calculated on the basis of the given formula (Gupta, 1981, Tewari et al., 1993).

Forward Speed of the Tractor

A stopwatch was used to note down the time (s) taken in covering a known distance during the operation. The forward speed (km/h) of the tractor was determined by Equation 1.

Forward speed of tractor = (Distance × 3.6) / time [1]

Field Efficiency

To determine the field efficiency of the weeder time was noted both at the beginning and at the end of operation.Time lost while turning was noted. The area of weeding was measured using a measuring tape. Equation 2 & 3 were used to determine the field efficiency. The theoretical field capacity and field efficiency of the weeder were determined as follows:

$$AFC = A / (Tp + Tc) \quad [2]$$

$$TFC = (W \times S) / 10 \quad [3]$$

$$F_e (\%) = (AFC / TFC) \times 100 \quad [4]$$

Where, AFC = actual field capacity, ha/h; A = area covered, ha; T_p = productive time, h; T_c = unproductive time, h; TFC = theoretical field capacity, ha/h; F_e = field efficiency, %; W = width of machine, m; S = forward speed, km/h

Weeding Efficiency

Weeding efficiency is the ratio of number of weeds removed from the field to the number of weeds present there before weeding in a one-unit area. Number of weeds was counted in each plot before and after the weeding operation. The weeding efficiency of the weeder was calculated by 1 × 1 m frame. Equation 5 was used to calculate the weeding efficiency.

$$WE (\%) = (W_1 - W_2) / W_1 \times 100 \quad [5]$$

Where, WE = weeding efficiency, %; W_1 = number of weeds/m^2 before weeding; W_2 = number of weeds/m^2 after weeding

Plant Damage

Plant damage is the ratio of the number of plants damaged in a row during weeding to the number of plants present in that row before weeding, expressed in percentage. Equation 6 was used to calculate the plant damage.

$$q (\%) = n_1/n_2 \times 100 \quad [6]$$

Where,

q = plant damage (%),

n_1 = number of plants damaged in a row length after weeding,

n_2 = number of plants in a row length before weeding

Superficial Plant Damage

It is similar to plant damage but it only considers plants whose only leaves are damaged during weeding operation. Superficial plant damage is the ratio of the number of plants whose only leaves parts were damaged in a row during weeding to the number of plants present in that row before weeding, expressed in percentage. Equation 7 was used to calculate the superficial plant damage.

$$SFD (\%) = n_1/n_2 \times 100 \quad [7]$$

Where,

SFD = superficial plant damage (%),

n_1 = number of plants whose only leaves were damaged in a row length after weeding,

n_2 = number of plants in a row length before weeding

Yield Critical Damage

It is similar to plant damage but it only considers plants that are completely uprooted during weeding operation. Yield critical damage is the ratio of the number of plants completely uprooted in a row during weeding to the number of plants present in that row before weeding, expressed in percentage. Equation 8 was used to calculate the yield critical damage.

$$YCD (\%) = (n_1/n_2) \times 100 \quad [8]$$

Where,

Q = yield critical damage (%),

n_1 = number of plants completely uprooted in a row length after weeding

n_2 = number of plants in a row length before weeding

Quality of work done (Q_1)

This term refers to the quality assessment of the performance of the weeder in terms of the complete removal of weeds without harming the crop. This may be expressed as follows:

$$Q_1 = [1 - (P_d/P_t)] \times WE \quad [9]$$

Where,

P_t = total number of plants along a crop row length before the weeding operation

P_d = total number of plants completely damaged in the same row length after the weeding operation

WE = weeding efficiency

Quantity of Work Done (Q2)

This parameter refers to the actual area weeded per unit time by the weeder and is expressed as

$$Q_2 = (Wb \times S) / T\ XFe \quad [10]$$

Where,

W_b = width of cut of the weeding tool, m

S = total forward displacement covered during any trial, m

T = total time taken to cover the above displacement, s

Fe = field efficiency (%)

Slip of the Tractor

Distance traveled by tractor per unit time without engaging the weeder (V_t) was noted down. Distance traveled by tractor per unit time after engaging the weeder (V_a) to the depth of weeding was noted down. The percent slip of the tractor was determined by Eqn. 3.37.

$$\text{Slip of the tractor, } S (\%) = [1 - (V_a/V_t)] \times 100 \quad [11]$$

Where,

V_a = actual velocity of the tractor (km/h)

V_t = theoretical velocity of the tractor (km/h)

Field Parameters Considered for Evaluation

Tractor operated weeder consisted of three vertical axis rotor with nine tools on each rotor. The distance between rotors was 650 mm. Weeder was mounted on tractor three-point linkage and PTO power was given to each rotor with arrangement of universal joint and chain sprockets for rotational power. The tractors operated inter row weeder was tested in chili planted field. The chili crop was planted in one acre of land at different plant row spacing (RS) of 500 and 600 mm. Performances of the developed tractor operated inter row weeder was evaluated in the field for chili crop at different forward speed (FS) and row spacing (RS). The inter row weeder was tested as per the research plan at depth of 40 mm. Developed weeding system was attached with tractor three-point linkage and operated by tractor PTO through a universal joint to PTO gearbox through chain and sprockets arrangements. The rpm of weeder rotor was maintained at 180. The weeder was evaluated at different FS of 1.3 km/h and 2.25 km/h respectively. The three-point linkage dynamometer was used to measure the draft of the system (Tewari et al., 2012). The weeding operation was conducted at 21 DAP. Field testing of inter row weeder is shown in **Fig. 3**.

Table 1 ANOVA for the weeding efficiency

Source of Variation	SS	df	MS	F	P-value
FS	112.8	1	112.8	6.29	0.029
RS	102.11	1	102.11	5.7	0.036
FS × PS	156.79	1	156.79	8.75	0.013
Error	42.89	8	5.36		
Total	371.71	11			

Results and Discussion

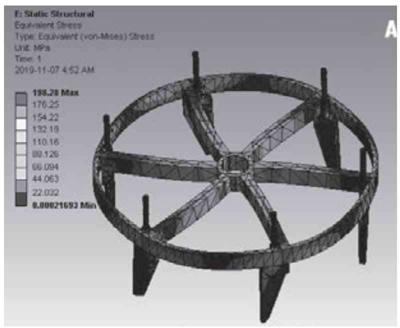
Simulation and Structural Analysis of Designed Tool

A vertical axis rotor with tools for inter row weeding was designed and fabricated. A set of three rotors was made up of mild steel (MS) with a diameter, width and thickness of 300 mm, 30 mm and 5 mm respectively. The solid shafts diameter was 30 mm. The HCS flat of length 80 mm, thickness 3.5 mm and width 30 mm was selected for fabrication of tools. The rotors shafts were fabricated with solid MS material with a length 340 mm and diameter of 30 mm. To transmit power between two perpendicular shafts, bevel gears were selected. PTO gearbox was fabricated with pinion teeth of 16 and gear teeth of 40 to transmit the PTO power to individual rotors. Duplex chain with 19.03 mm pitch (12 B) was selected for transmit PTO power to bevel gear box as per IS-2403-1991. MS hollow square section of width 50 mm and 5 mm of wall thickness was used for the fabrication of the frame, length and width was 2 m and 600 mm respectively. A universal joint is used to transmit the power between two non-parallel shafts of individual rotors. Towed ground wheels of two units having equal diameter were attached to the shaft provided in the mainframe to maintain the depth of the weeding unit. The total weight of the machine was supported by three-point linkage and ground wheels. The diameter and width of the ground wheel were decided as 370 mm and 100 mm, respectively.

Finite element analysis was carried out to investigate the stresses acting on the tools. Stress distribution and displacement in the tools were checked by carrying out the structural analysis. High carbon steel is the most common material for making high-grade tools; some industries use cast iron also. Thus, a high carbon steel tool was selected for this analysis. The material selected was high carbon steel having a yield strength of 490 MPa, tensile yield strength 635 MPa, poison ratio of 0.3, elastic modulus 1.97 x e11 N/mm^2 and density of material 7.50 × 10^{-9} Tonne/mm^2. The tool had generated 6588 elements and 2709 nodes. The maximum equivalent stress of tool was found to be 1.09 × 10^{-7} to 464.94 MPa. The maximum possible working width of the tool near pre-calculated width was selected as working width. Kinematic parameters such as forward speed, RPM and related other parameters like working width, soil force were used in the simulation. The maximum value of equivalent stress was found to be 198.28 MPa and total deformation was found to be 1.2697 mm. Hence designed structure can perform reliability. Equivalent stress of optimized tool is shown in **Fig. 4**.

Fig. 3 Field evaluation of tractor operated weeder

Fig. 4 Equivalent stress of optimized tool



Weeding Efficiency

The average soil moisture of field was found to be 17% during the weeding operation. The average cone index of the field was measured to be 315 kPa. The WE was calculated for inter row zone. The ANOVA of different independent parameters (FS and PS) and WE is presented in **Table 1**. The results revealed that the individual effect of FS, RS and their interaction has a significant effect on WE at 5% level of significance. It is evident from **Table 1** that FS ($F_{1,8}$ = 6.29, p = 0.029) and RS ($F_{1,8}$ = 5.7, p = 0.036) has a significant effect on WE. The average maximum WE was observed as 84.2% (SE: ±1.58%) at PS of 600 mm and FS of 1.3 km/h. The minimum weeding efficiency was 78.8% (SE: ±0.88%) at plant spacing 500 mm and speed of operation 2.25 km/h. Effect of FS and RS on weeding efficiency is shown in **Fig. 5**.

Plant Damage

The results revealed that the individual effect of FS and RS and their interaction on the plant damage (PD) had a significant effect at 5% level (**Table 2**). It was evident from the ANOVA table that FS ($F_{1,8}$ = 6.5, p = 0.027) had a highly significant effect on PD of weeder as compared to the RS ($F_{1,8}$ = 8.28, p = 0.015). It is revealed from ANOVA table that interaction effect of FS and RS ($F_{1,8}$ = 4.94, p = 0.048) had significant effect on PD, which means that PD is affected by FS and RS combine for an entire range of operating parameters.

The general trend shows that YCD was found to be increased with an increase in FS. The average value of YCD at FS of 1.3 and 2.25 km/h was found to be 2.16% and 3.1% (SE: ±1.52%), respectively for RS of 500 mm and also the average value of YCD was 1.33% and 2.61% (SE: ±1.12%), respectively for RS of 600 mm. The average value of SFD at FS of 1.3 km/h and 2.25 km/h was found to be 8.17% and 10.78%

Table 2 ANOVA for the PD of inter row weeder

Source of Variation	SS	df	MS	F	P-value
FS	521.93	1	521.93	6.5	0.027
RS	665.31	1	665.31	8.28	0.015
FS × PS	397.16	1	397.16	4.94	0.048
Error	120.22	8	15.02		
Total	1,584.41	11			

(SE: ±2.14%), respectively for RS of 500 mm and also the average value of SFD was 4.5% and 6.54% (SE: ±3.19%), respectively for 600 mm of RS. Effect of forward speed and row spacing at plant damage is shown in **Fig. 6**.

Measurement of Others Performance Parameters

The weeder was also evaluated for draft, slip, fuel consumption, field efficiency, etc. The value of draft was observed to be as 790 N (SE: ± 16.40 N) and 965 N (SE: ±18.24 N) for a 40 mm DO at FS of 1.3 km/h and 2.25 km/h, respectively. Slip was found to be in the range of 10 to 12% due to lower load on tractor. The average turning time was 16 sec and 8.52 sec for the FS of 1.3 km/h to 2.25 km/h respectively. The TFC and AFC were found in the range of 0.20-0.36 ha/h and 0.16-0.27 ha/h at the FS of 1.3 and 2.25 km/h respectively. However, the FE of 79.79% and 73.75% were observed at 1.3 and 2.25 km/h of FS, respectively. The fuel consumption were recorded in the ranges of 3 to 3.5 L/h. The quality and quantity of work done were calculated. It was found that quality and quantity work effected by FS. The quality of work in the range of 86.61 to 79. 56% at the FS of 1.3 and 2.25 km/h respectively. However, the quantity of work done of 0.16 ha/h and 0.27 ha/h were observed at FS of 1.3 and 2.25 km/h, respectively. The reported quality of work done of manually operated weeder was in the range of 63 to 83% (Tewari et al., 1993). The effect of speed on draft, field capacity and field efficiency is shown in **Fig. 7a** & **b**.

Conclusions

The developed weeding machine

Fig. 5 Effect of FS and RS on weeding efficiency

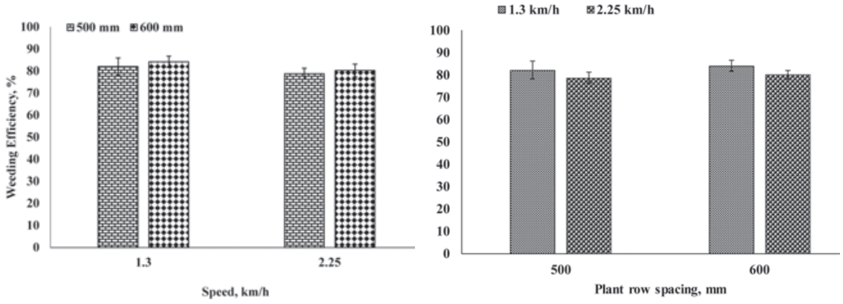
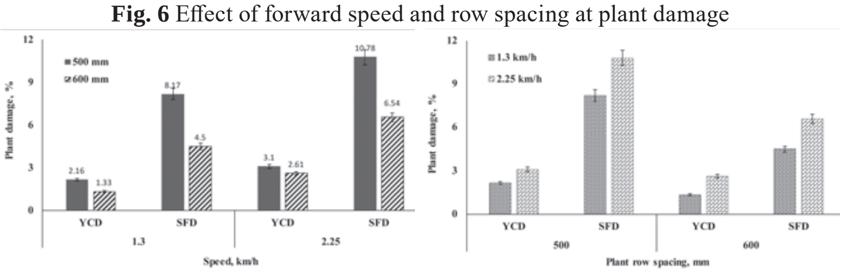


Fig. 6 Effect of forward speed and row spacing at plant damage



was able to uproot the weeds efficiently from the field up to a depth of 60 mm. The weeding efficiency was observed in the range of 78.8% to 84.2% at different operating parameters. Yield critical and superficial plant damage was found to be in the range of 2.16% to 3.1% and 8.17% to 10.78%, respectively at different operating parameters. The value of maximum draft and field efficiency of machine was found to be 965 N and 79.79% respectively.

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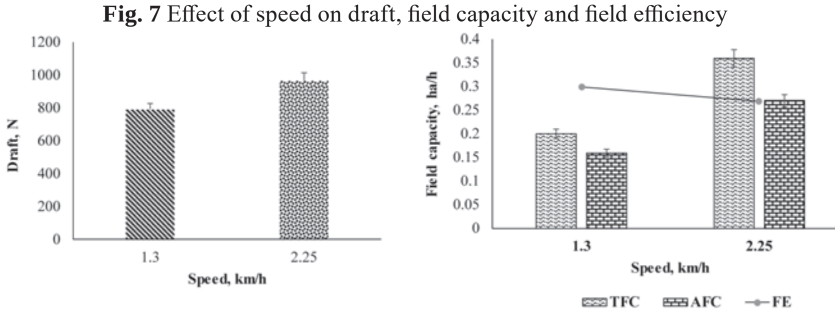
Fig. 7 Effect of speed on draft, field capacity and field efficiency



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A Multipurpose Tool Carrier for Homestead Agriculture in Kerala

by

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Abstract

Homesteads lack appropriate machinery that suits their diverse requirements. Homestead agriculture warranted an affordable and versatile powered multipurpose tool carrier capable of improving the efficiency of human power. The multipurpose tool carrier (MPTC) can be substituted as to avoid the requirement of different implements and power sources for different operations. Hence, a MPTC powered by the engine of a 1.5 kW back pack brush cutter which is commonly available in farming households was designed, developed and tested in the field. Main components of MPTC were support frame along with handle, transmission systems with gear reduction units which converted 9340 rpm of the engine to 226 rpm with necessary transmission shafts and transportation wheels. Tools developed as attachments to MPTC were rotary tiller/weeder for vegetable crops, paddy weeding attachment and surface pulverizer cum two-row vegetable weeder and horizontal auger for coconut basin listing. The multipurpose tool carrier with its different attachments was tested in fields with moisture contents ranging from 10 to 30%. From the field evaluation of rotary weeding attachment, it was found out that the depth of cut was 3-5 cm and the average weeding efficiency was 90.07%. The fuel consumption, field efficiency, average weeding efficiency and average plant damage in the case of paddy weeder were 0.675 l h^{-1}, 66.4%, 71.09% and 4.87%, respectively. Surface pulverizer cum two-row vegetable weeder attachment for row crop vegetables gave an average weeding efficiency of 80.27% with a fuel consumption of 1.64 l h^{-1} and a field capacity of 0.024 ha h^{1}. Coconut basin lister could make 14-25 shallow basins per hour based on the soil condition.

Keywords: brush cutter, multipurpose tool carrier, weeder, rotary tilling, basin lister weeding efficiency

Introduction

Agricultural systems can be divided into industrial agriculture and sustainable agriculture. Industrial agriculture focus on the production of crops which can be promoted for sale. In sustainable agriculture, practices are done to meet the desired needs of a small family often called homestead agriculture. The purpose of sustainable agriculture is to protect natural biodiversity, enhance crop production and increase the prosperity of a family through homestead agriculture. Kerala, a tropical state in South India, is an example of a region with a dynamic history of land-use change that has not been particularly well-renowned. In Kerala, agricultural practices in large fields were declining habitually due to the scarcity of land holdings and growing demand for houses. Kerala has got high population density and the size of small farm holdings in Kerala ranges from 0.02 to 1 ha (Nair and Sreedharan, 1986).

All these demanded for the practice of homesteads thereby calling for a revival of homestead agriculture in Kerala. As land scarcity is the major barrier for farmers, they are enforced to do cultivation in the available area. Homestead is defined as an operational farm unit in which a number of crops are grown with livestock, poultry or fish production mainly for the purpose of satisfying the farmer's basic needs (John, 2014). One of the most important causes for the decreasing rate of productivity in small farms including homesteads is the lack of suitable machinery that caters for this agricultural practice and suits the requirements of these small-scale farms. For this reason, many small farms are regarded as unproductive and ineffective. Since the common practice is mixed farming of the available area, the mechanization issues in homestead agriculture are much more complicated compared to commercial agriculture.

The present scenario in homestead agriculture warrants an affordable and versatile power operated multipurpose tool carrier. The multipurpose tool carrier is a scientific term used to indicate a multipurpose tool frame that provides the link between the implement and the power source (Bansal and Thierstein, 1982). As a multipurpose unit, tool carriers are designed to be used with a number of implements. The unit is conceived to work in a way similar to a multipurpose tractor which facilitates quick changing of implements on the toolbar according to the operational requirements.

The mechanization of homestead agriculture in Kerala is in its juvenile stage. Even though power tillers were expected to cater for the needs of small scale (Veerangouda et al., 2011; Ramya et al., 2016) and homestead farmers in Kerala seldom own power tillers (Prasad et al., 2016). The main reason is that farmers are not satisfied with the versatility and ease of operation, especially in undulating fields. Presently, engine operated brush cutters are probably the widely used powered aid in homestead agriculture. Among them, backpack engine operated brush cutters are comparatively cheaper and much versatile. The development of a multipurpose tool carrier powered by the engine of such a brush cutter was expected to avoid the requirement of different implements and power sources for different operations and hence offered much utility and cost saving over traditional implements (Tiwari et al., 2009). Such a machine was envisaged as farmer-friendly and women-friendly as it could easily be operated and handled. Hence the development of a multipurpose tool carrier for homestead agriculture, powered by an affordable engine was highly relevant in the present context.

Material and Methods

2.1 Design Consideration for the Multipurpose Tool Carrier

i. The total power requirement for different attachments of the multipurpose tool carrier should not exceed the power availability of a 1.5 kW (2 hp) back pack brush cutter engine
ii. Functional requirements of the multipurpose tool carrier should match with the available torque and available speed.
iii. The multipurpose tool carrier should match with the required farm operations envisaged in homestead agriculture.
iv. Selection of material for the fabrication should be based on market availability.
v. The tool carrier should be simple in construction which could be manufactured at low cost.
vi. Handle height and hand grip of the machine should be acceptable with respect to the recommended ergonomic standards.
vii. Easy adjustability of the tool carrier for different tools needed for different operations should be ensured.
viii. Safety and operator's comfort was also considered.
ix. Affordability of the machine by homestead farmers.

2.2 Development of Tool Carrier Frame

The multipurpose tool carrier is a technical term used to indicate a multipurpose tool frame that provides the link between different implements and a power source (Bansal and Thierstein, 1982). A basic frame along with a power source which could be fitted with different tools as per the requirement was the envisaged system (**Fig. 1**). Brush cutter engine speed was in the range of 9,000 rpm which is too high to operate any soil working attachment. As this high speed was not compatible with the required operations, a gear reduction unit was introduced which could convert the high engine speed to the required speed range. A suitable transmission shaft was designed for the purpose of transmitting power from the engine to the gear reduction unit.

Fig. 1 Conceptual design of the multipurpose tool frame

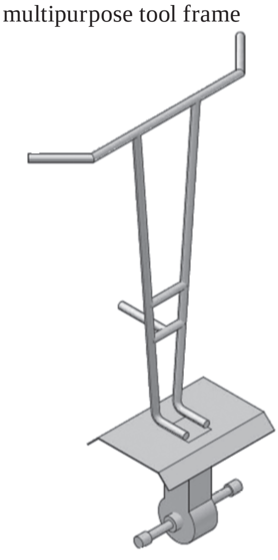


Fig. 2 Back pack type brush cutter

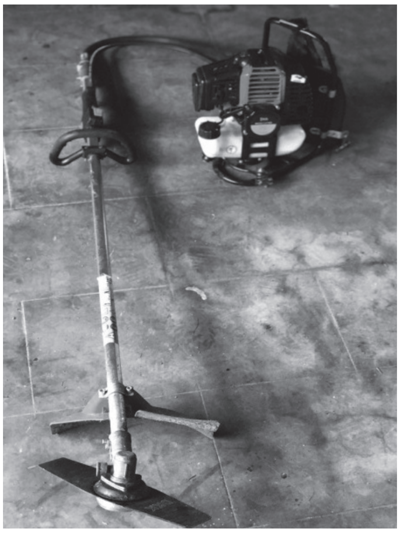
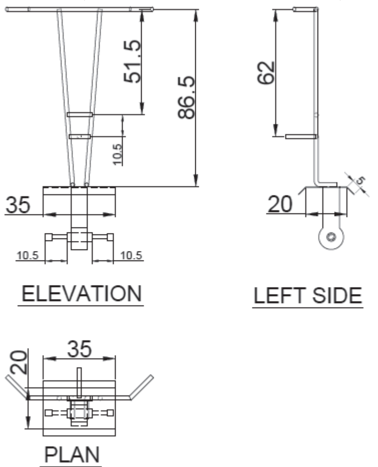


Fig. 3 Engine of back pack type brush cutter

Fig. 4 Basic frame of multipurpose tool carrier (All demensions are in mm)



2.2.1 Selection of Configuration for Supporting Frame with Handle

A suitable configuration of supporting frames with a handle for the purpose of attaching the prime mover and different tools was designed. The handle length and grip dimensions were designed in such a way to put the operator's comfort into consideration (Tiwari et al., 2009).

Table 1 Details of brush cutter engine

Model	CG437(A)
Engine	Single cylinder two-stroke petrol engine
Displacement	31 cc
Engine Power	1.5 kW
Speed	9340 rpm
Weight	4.70 kg

2.2.2 Prime Mover

The multipurpose tool carrier was expected to be an affordable mechanical aid for homestead agriculture. In this case, the prime mover selected should be economical for farmers to afford (Takur et al., 2018). Hence it was decided to select a low cost back pack brush cutter as the basic unit (**Fig. 2**). The back pack brush cutter engine shown in **Fig. 3** was selected as the prime mover for the multipurpose tool carrier. The details of the selected brush cutter are given in **Table 1**.

2.3 Development of Different Attachments

The different operations considered necessary in the homestead agriculture were identified. Based on that and according to the power availability with multipurpose tool carrier, different attachments that would be compatible to the multipurpose tool carrier (MPTC) were identified. A suitable weeding attachment for weeding of vegetable garden was identified according to the soil condition and depth of operation required. A paddy weeding attachment, surface pulverizer cum two-row vegetable weeding attachment and coconut basin listing attachment were developed as an attachment to MPTC.

Results and Discussion

3.1 Basic Tool carrier frame with handle

The tool carrier frame was made up of 2.54 cm diameter GI pipe and a 5 mm thick MS plate as shown in the **Fig. 4**. The brush cutter engine was mounted on the tool frame. The length of the handle was 98 cm with a hand grip of 15 cm length. Along with the frame, another member was provided as an aid for attaching supporting tools viz. transporting

Fig. 5 Engine mounted multipurpose tool carrier frame fitted with gear reduction unit

Fig. 6 Power transmission gear box

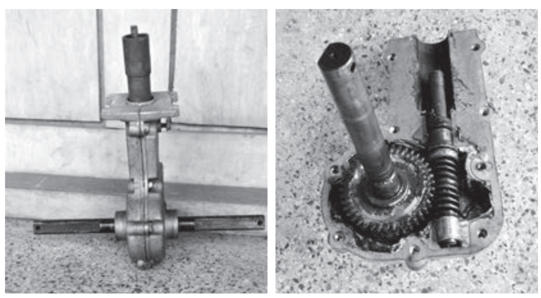


Fig. 7 Power transmission shaft with hollow casing

Fig. 8 Rigid shaft (All demensions are in mm)

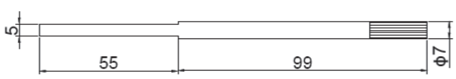
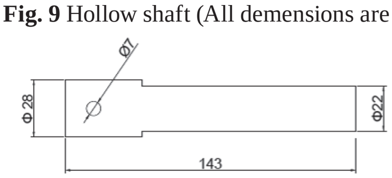


Fig. 9 Hollow shaft (All demensions are in mm)



wheels, depth adjusting attachment and float. This member was fabricated with a GI pipe of 2.5 cm diameter and 30 cm long. A view of the engine mounted multipurpose tool carrier frame fitted with gear reduction unit is shown in **Fig. 5**.

3.2 Gear Reduction Unit

A gear reduction unit was provided with a reduction ratio of 40:1. Two horizontal drive shafts on both sides of the gear reduction unit were provided where different tools could be attached according to the required operation. A gear reduction unit available in the market was used for the purpose and was fitted to the tool carrier. This is shown in **Fig. 6**.

3.3 Transmission Shaft

Power was transmitted through a rigid shaft (**Fig. 7**) of 14.5 cm length from brush cutter engine to gear reduction unit. One end of the shaft had a square cross-section of side 5 mm and the other end had a circular cross-section of diameter 7 mm. The rigid shaft (**Fig. 8**) was inserted into a hollow shaft whose dimensions are shown in **Fig. 9**.

3.4 Development of Different Attachments

Vegetable weeding attachment system (**Fig. 10**) consist of a rotary weeding assembly and transportation wheels fitted to the tool carrier frame. A compatible rotor assembly available in the market was selected. The weeding rotor consist of two sets of blades attached to the gear reduction unit. Each rotor had a diameter of 15 cm as shown in **Fig. 11**. Total width of the assembly was measured as 40 cm.

A paddy weeding attachment to enable wet land weeding as shown in **Fig. 12** was developed for the multipurpose tool carrier engine powered by the back pack brush cutter engine. The weeding attachment was developed based on the paddy row spacing of 30 cm.

For the purpose of weeding cum earthing up of row crop vegetables at early stages, a helical blade attachment was fabricated as shown in **Fig. 13**. This helical rotor was intended for two-row weeding with simultaneous soil displacement onto the base of the young plants. The rotor was designed in a helical shape so as to enable two-row weeding cum earthing up operation. It was made up of 2 mm thick GI sheet. Two circular discs of 20 cm diameter were cut from the GI sheet and it was then welded to a pipe of 2.5 cm diameter and 20 cm length. Eight rectangular sheets of width 4 cm and 20 cm length were drawn into helical shape as shown in **Fig. 14**. It was then inserted into the grooves made in the disc.

A horizontal auger system along with accessories was designed and fabricated as an attachment for multipurpose tool carrier for the purpose of coconut basin listing as shown in **Fig. 15**. Two horizontal

Fig. 10 Vegetable weeder attachment assembled with MPTC

Fig. 12 Paddy weeder fitted on MPTC

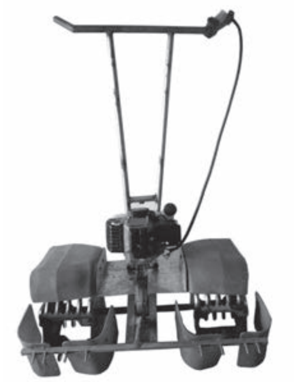


Fig. 13 Helical blade rotor attached to MPTC

Fig. 15 Horizontal auger attached to MPTC along with accessories

Fig. 11 Weeding rotor with gear reduction unit and transportation wheel

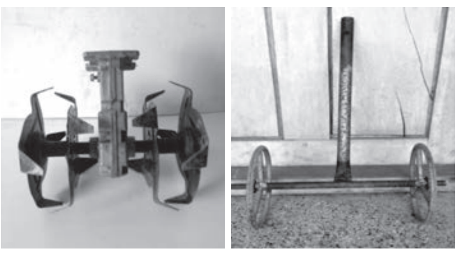


Fig. 14 Weeding rotor with gear reduction unit and transportation wheel (All demensions are in mm)

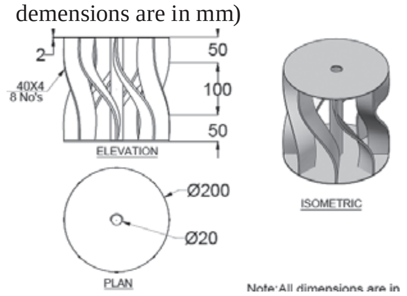


Fig. 16 Design of auger (All demensions are in mm)

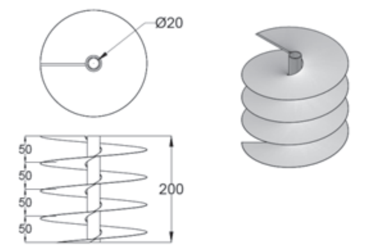


Table 2 Analysis of variance of depth operation with moisture content

Source of Variation	SS	df	MS	F	P-value
Depth	1.167	2	0.5833	2.33	0.153NS
Residuals	2.250	9	0.2500		
Total	3.417	11			

NS = Not significant at 5% level

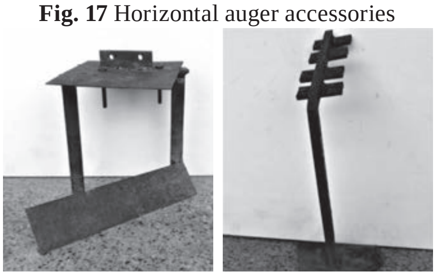
Table 3 Average weeding efficiency and speed of operation

Field	Moisture content, %	Speed of operation, km h^{-1}	Average weeding efficiency, %
F1	9.61	0.96	90.56
F2	14.9	0.75	88.72
F3	20.37	0.48	90.18

augers shown in **Fig. 16** were fabricated using a GI sheet of thickness 2 mm. The overall dimensions of the auger were 20 cm (length) × 20 cm (diameter) with a pitch of 5 cm. The two augers were attached to the MPTC in such a way that both the augers will throw the soil in the same direction.

Fig. 17 shows the accessories fitted to support coconut basin listing.

Fig. 17 Horizontal auger accessories



(a) (b)

(a) Shows the metallic plate for removing excess soil from the coconut basin and (b) Shows a wedge used to maintain the depth of basin listing.

3.5 Performance Evaluation of Multipurpose Tool Carrier with Different Attachments

The multipurpose tool carrier along with different attachments was tested in the field. Soil physical properties as well as machine performance indices were assessed during the test. Different tools attached to the MPTC were tested separately to find out their performance indices.

Fig. 18 Field testing of vegetable garden weeder

3.5.1 Performance Evaluation of the Vegetable Garden Weeder

The vegetable garden weeder was tested in three different fields (F1, F2 and F3) with corresponding moisture contents of 9.61%, 14.9% and 20.37%, respectively. This is shown in **Fig. 18**.

Presented in **Table 2** is the ANOVA results obtained for showing the effect of depth of operation on moisture content. It can be observed from **Table 2**, that depth of operation was not affected by the moisture content of the field.

Fig. 19 shows the variation of depth of operation with moisture content. Results of average weeding efficiency and speed of operation was determined using standard procedure as shown in **Table 3**.

Fig. 20 shows the variation of average weeding efficiency with moisture content. It was found that there was no difference between the weeding efficiencies with respect to moisture content as shown in **Table 4** and thus moisture content variation did not influence the weeding efficiency of the vegetable weeder

Fig. 19 Variation of depth of operation with moisture content

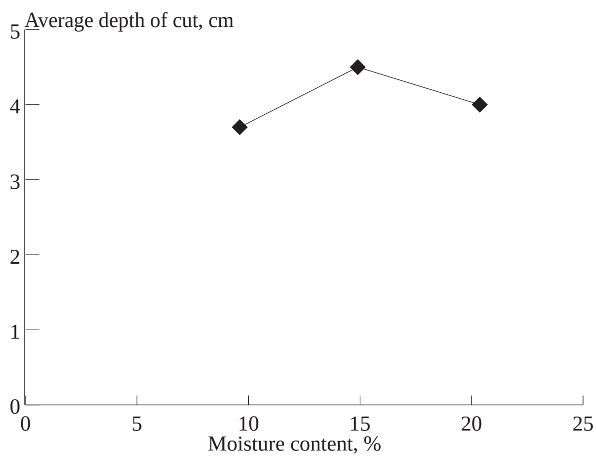
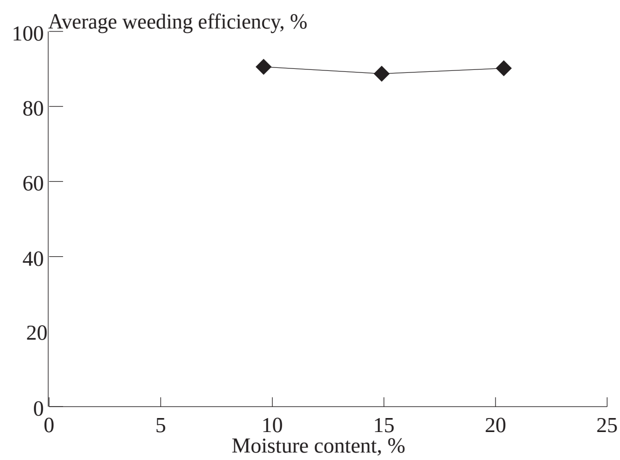


Fig. 20 Variation of Average weeding efficiency with moisture content



in the soil moisture range tested. Weeding efficiency of the weeder was not considerably influenced by the soil physical properties but the machine parameters were seen to. The weeding efficiency of 1.25 kW engine operated weeder developed by Devojee et al. (2018) was 87.9% which was lesser than the weeder attachment in this study.

The actual field capacity of the weeder observed in the fields with different moisture contents are given in **Table 5**. Maximum value of actual field capacity was found to be 0.012 ha h^{-1} which was applicable to fields F1 and F3. This value was found to be less than that of 0.023 ha h^{-1} meant for a maize power weeder which is operated by a 1.25 kW knapsack petrol engine developed by Devojee et al. (2018). It has 2 blades while that of 6 blades gave an actual field capacity of 0.029 ha h^{-1}. This was probably due to the higher speed of operation compared to the developed weeder in this study.

3.5.2 Performance Evaluation of Paddy Weeder

The actual field capacity of the paddy weeder was obtained as 0.0518 ha h^{-1}. Speed of operation was calculated as 0.936 km h^{-1} and the theoretical field capacity was calculated as 0.078 ha h^{-1}. Hence the field efficiency of the paddy weeder was observed to be 66.41%. Fuel consumption was observed to be 0.67 l h^{-1}.

3.5.3 Performance Evaluation of Surface Pulverizer Cum Two-row Vegetable Weeder

Two-row vegetable weeder was tested in a field having moisture content of 7.18% cultivated with chilli crop after 15 days of transplanting the seedlings. Weeding was done after 15 days of transplanting since the weeder was developed for early stage weeding. Occurrence of plant damage will be less as identified at early stage (Kamal and Oladipo, 2014). The plants were spaced 50 × 50 cm. Plant heights measured were within the range of 120-130 mm.

It was observed that when the weeder was operated at a speed of 1.31 km h^{-1}, the average weeding efficiency was obtained as 86.23%. A higher weeding efficiency of 95-97% was observed by Olukunle and Oguntunde (2006) for a garden weeder when operated at a speed range of 1.5-1.8 km h^{-1}.

The average field efficiency was found to be 76.92% which was lesser compared to the field efficiency of the early stage weeder developed by Olaoye et. al. (2012). This is probably due to higher actual filed capacity and theoretical filed capacity obtained for the developed weeder.

3.5.4 Performance Evaluation of Coconut Basin Lister

The coconut basin lister was tested in coconut fields at two different moisture contents viz. 15.38% and 21.15% as shown in **Fig. 21**. The performance indices of coconut basin lister at different moisture contents are shown in **Table 6**.

The coconut basin lister performed well in the field with 15.38% moisture content compared to the field with higher moisture content. As the moisture content increased the operational speed was found to decrease and thus the time taken in making shallow basin of 3 m diameter was higher. This might be due to the sticking nature of soil particles as moisture content increased and thus it seemed to interfere with the operation.

Table 5 Actual field capacity of vegetable weeder

Field	Actual field capacity, ha/h
F1	0.012
F2	0.006
F3	0.012

Conclusion

The development of a MPTC powered by the engine of a brush cutter which is commonly available in farming households was expected to avoid the requirement of different implements and power sources for different operations. Hence it offered much utility over traditional implements instead of procuring different kind of tools to accomplish these operations.

Fig. 21 Coconut basin lister in operation

Table 4 Analysis of variance of weeding efficiency with moisture content

Source of Variation	SS	Df	MS	F	P-value	F crit
Between weeding efficiency	7.487391	2	3.743695	0.131539	0.87839	4.25[NS]
Residuals	256.1448	9	28.46053			
Total	263.6322	11				

NS = Not significant at 5% level

Table 6 Performance indices of basin lister

Performance indices	Moisture content, %	
	15.38	21.15
Basin diameter, m	3	3
Time taken, min	2.1	4.06
Speed of operation, km h^{-1}	0.53	0.145
Fuel consumption, l h^{-1}	2.25	2.85
Volume of soil displaced, m^3 h^{-1}	31	6.264
Capacity, (basins/h)	25	14

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Development and Performance Evaluation of Maize (*Zea mays*) Sheller

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Abstract

Maize (*Zea mays*) belongs to a Gramineae family is one of the most common cereal grains and originated from Mexico and South America. Maize, also called corn. The developed maize sheller was consisted of motor, belt, pulley, hopper, cylinder, frame, rotor shaft and outer cover. The developed maize sheller was operated for three different speed and moisture content of 150, 200 and 250 rpm and 12, 14 and 16% (w.b) respectively. Keeping in view with highest shelling efficiency, minimum grain damage the parameter was optimized 150 rpm cylinder speed and 12% (w.b) moisture content of maize crop. The Shelling rate, shelling efficiency and grain damage of maize was 88.27 kg/h, 96.75%, 3.10% and 83.57 kg/h, 95.25%, 7.61% at optimized parameters at speed of 150 rpm and moisture content of 12% (w.b) respectively. The payback period was 1.13 years while the benefit-cost ratio was 1.01. The total manufacturing cost of maize sheller was Rs. 10235.

Introduction

Maize (*Zea mays*) belongs to a grass family (Gramineae) is one of the most common cereal grain and originated from Mexico and South America. Maize, also called corn, is believed to have originated in central Mexico 7000 years ago from a wild grass (Dula, 2019). The importance in human and animal diet it is called as queen of cereals and king of fodder. It is a versatile grain crop and commonly known as corn in America. The plant prefers light (sandy), medium (loamy), and heavy (clay) soils and requires well-drained soil. It cannot grow in the shade and also requires moist soils. Maize contains approximately 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100 g and is grown throughout the world (Dula, 2019).

There are different losses occur in maize sheller like gathering, threshing, separating and cleaning devices of the machine. Kernel loss and damage losses depend on machine design, adjustment and operation, field conditions, weather, and crop morphological, physical and mechanical properties (Sehgal and Brown, 1965; Byg et al., 1966). One of the most important crop factor influencing harvesting and post harvesting operations for maize is moisture content (Hunt, 1973). Shelling of maize achieved maximum 10% kernel loss due to high moisture content and also it means a 5% grain loss is approximately equivalent to a 25% loss of profit (Anazodo, 1980). Also, cob breakup is affected by cylinder speed, moisture content, cylinder concave clearance and maize variety (Wall & Norris, 1979).

Maize ranks third the most important cereal grain in the world after wheat and rice (Nwakaire et al., 2011). Also, it provides a basic raw material for the production of starch, oil and protein, alcoholic beverages, food sweeteners and, more recently, fuel nutrients for humans and animals. Maize accounts for 15-20 % of the total daily calories in the diets of people in more than 20 developing countries (Dauda, 2015).

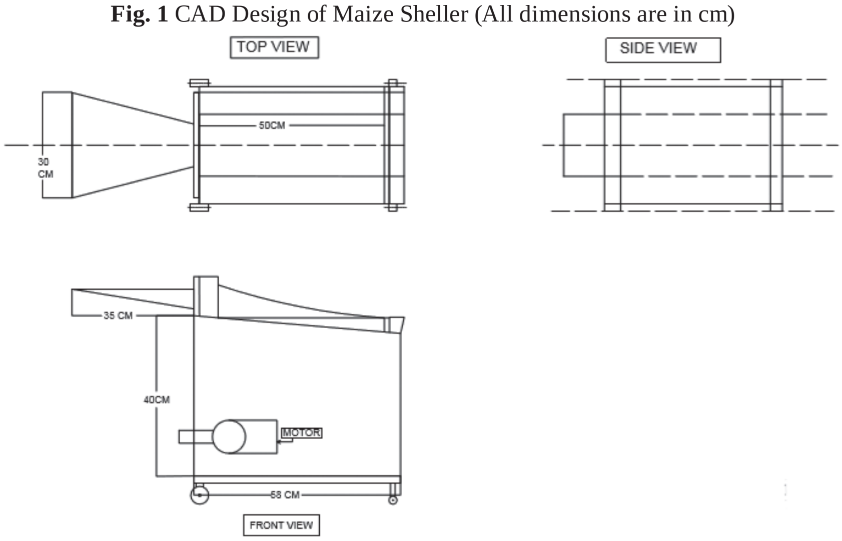
The period between planting and harvesting for maize depend upon the variety, but in general the crop physiologically mature in 7 to 8 weeks after flowering, at that time the kernel contains 35 to 40% moisture and has the maximum content of dry matter. Maize shelling is difficult at moisture content above 25%, with this moisture content, grain stripping efficiency is very poor with high operational energy and causing mechanical damage to the seed. A more efficient shelling is achieved when the grain has been suitably dry to 13 to 14% moisture content (Danilo, 1991) Shelling is the removal or separation of maize grain from the cob and it is an operation that follows the harvest. It can be carried out in the field or on the farm by hand or machines. The grain is obtained by shelling, friction or by shaking the products. The difficulty of the operation depends on the varieties grown, the moisture content and the degree of maturity of the crop.

Maize is shelled traditionally by hands. This is done in such a way that maize is rubbed against another until the grains are removed from the cob. Likewise, the grain can be detached from the cob with the use of pestle and mortal. But this traditional method of shelling is highly tedious, inefficient and time consuming with low productivity (FAO, 2005). However, the modern way of shelling is by the use of mechanical means, which can be driven by prime mover or tractor. This prime mover can either be diesel/petrol engine or electric motor. The efficiency and throughput of this machine depending on the type of machine, the skill of workers and organization of the work, yield can vary from 100 to 5,000 kg/h (FAO, 2005). The power requirement of such sheller is high and hence, the prime mover is very expensive. Hence, a pedal operated maize sheller is simple in design, affordable and suitable for small and marginal farmers and will meet the need of the farmers for growing maize. Keeping in view the above facts, the present study has been has been undertaken by following objectives.

The major steps involved in the processing of maize are harvesting, drying, dehusking, shelling, storing, and milling. For the rural farmers to maximize profit from their maize, appropriate technology that suites their needs must be used. The processing of agricultural products like maize into quality forms not only prolongs the useful life of these products, but increases the net profit farmers make from mechanization technologies of such products. One of the most important processing operations done to bring out the quality of maize is shelling or threshing of maize. For maize one of its postharvest challenges is shelling (Kaul and Egbo, 1985) reported that maize harvested are traditionally shelled by hand or by beating sacks stuffed with maize cobs with wooden flails. These traditional methods of shelling maize are time wasting, hazardous and associated with lots of drudgery (Oriaku et al., 2014).

Thus, there is a need for smallholder farmers to design, develop, and introduce appropriate maize shellers that reduce postharvest loss, decreases labor and time productivity and reduces drudgery. Hence, this research project focuses on modifying the design and development of maize sheller to improve performance, and evaluating the sheller with farmers for further promotion and modification activities.

Fig. 1 CAD Design of Maize Sheller (All dimensions are in cm)



Material and Methods

Following are some considerations for development of motor operated maize sheller:

1. It should be portable and affordable for small scale farmers.
2. Machine should be easily operated by labor.
3. Local material should be easily available.
4. It should be simple and maintenance free when necessary.

3.1 Location of Experiment

The Design and development of maize Sheller was developed at the workshop of Department of Farm Machinery and Power Engineering, Aditya College of Agriculture Engineering and Technology, Beed and performance evaluation in field of college of Agricultural engineering and Technology, Beed, under university of Vasantrao Naik Marathwada Krishi Vidyapeeth Parbhani.

3.1.1 Moisture Content

The moisture content of grain should be reduced to 16% or less. It is therefore important to measure the moisture content before shelling in order to avoid damage to the grains.

3.2. Principles of Shelling

The shelling is accomplished by the shearing by the rotating pegs mounted on the cylinder, which force out the grains from the maize cobs holding them. Different grain crops and different varieties of the same grain crop have varying characteristics, which require different speeds of the cylinder for achieving the best result of shelling, therefore adjustment of cylinder speed and proper feeding of cobs is essential.

Table 1 Components of maize sheller

Sr. No	Components	Material	Dimension
1	Frame (L × W × H), cm	Mild Steel	58 × 50 × 62
2	Hopper (L × W × H), cm	Mild Steel	35 × 30 ×40
3	Cylinder (d × L), cm	I.S steel	6.5 × 28
4	Rotor shaft (L × d), cm	Mild Steel	30 × 5
5	Outlet cover, d cm	Metal Sheet	18

3.3 Design Considerations

3.3.1 Frame

The frame was made up of mild steel. The overall dimensions of frame were 580 mm length, 550 mm width and 410 mm height. The whole sheller was fixed to this framework. The frame had of bottom set, motor, stand, etc.

3.3.2 Hopper

The hopper was fabricated in trapezoidal shape, using mild steel sheet of 18-gauge thickness and had dimensions of 360 mm length, 200 mm width and 100 mm height.

3.3.3 Cylinder

It was made up of I.S steel of 98 mm diameter. The cylinder length was 580 mm, having beaters which rotated along the cylinder and separated grains from the cobs. However, cylinders with beaters are easy for manufacturing and are economical.

3.3.4 Outer Cover

It was made up of M.S. sheet and was bended to semi-circular shape of diameter 580 mm and was rigidly fixed to give protection to the cylinder and avoid grains spilling out. It had the provision for attaching to a hopper. A flange was attached to it along the length to facilitate cleaning of inner cylinder.

3.3.5 Rotor Shaft

It was one of the key components of the machine; other parts flats of cylinders and bearings were mounted on the shaft. The standard size and length of the shaft were selected based on the shaft design. The pulley was attached to give drive to shaft from motor.

3.3.6 Outlet

The outlet for separated grains was made at the bottom of the shelling cylinder. It was made up of metal sheet to collect grains without shattering outside.

3.4 Design Details

The schematic diagram of machine and the important machine parts are described below:

3.4.1 Diameter of Rotor Shaft

The shaft was a rotating member having circular cross section, to which transmitting elements such as pulleys, belt and rolling element bearings, are mounted. The material used for shaft was high carbon steel of grade 40C8, ultimate tensile strength of 560-670 M Pa and yield strength of 320 M Pa.

3.5 Shaft Design

The shaft design primarily consists of the determination of the optimum shaft diameter to ensure sufficient strength and rigidity, when the shaft was transmitting power under various operating as well as loading conditions. Standard size shaft of 15 mm diameter and 600 mm length was selected keeping a factor of safety of about 4, which was the result of studies conducted before the actual experimentation.

3.5.1 Power Requirement

As the torque transmitted by the shaft was known, the horsepower was calculated by (Khurmi, 2005):

Power, hp = $2\pi NT / 4500$

Where,

N = speed (rpm) = 750 rpm

T = torque (kg m) = 27.55 kg-m

P = power, kw

Power = $(2\Pi \times 750 \times 27.55) / (60 \times 1000)$

Power = 2.164 kW

Therefore, actual horsepower required was 2.164 kW.

3.5.2 Diameter of pulley shaft

The diameter of pulley shaft was obtained from the velocity relationship by (Khurmi, 2005).

$N_1 D_2 = N_2 D_2$

Where,

N_1 = speed of motor pulley = 750 rpm (measured value)

N_2 = speed of motor shaft = 300 rpm

D_1 = diameter of motor pulley = 40 mm

D_2 = diameter of rotor pulley (mm)

Therefore, from equation,

$750 \times 40 = 300 \times D_2$

$D_2 = 100$ mm

Therefore, dimeter of motor pulley of 100 mm was selected.

3.5.3 Length of Belt

Here, the belt was considered as an open drive. This type of belt drive was employed when the two parallel shafts have to rotate in the same direction. The length of belt was obtained by using the formula is given by (Khurmi, 2005)

$L = 2C + 2\pi(d_1 + d_2) + [(d_1 + d_2)^2 / 4C]$

Where,

C = length of central distance (mm)

d_1 = diameter of large size pulley (mm)

d_2 = diameter of small size pulley (mm)

Therefore, Length of belt

Fig. 2 Developed maize sheller

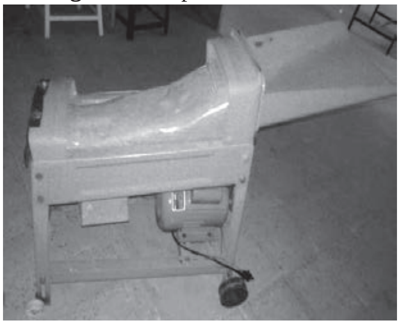


Table 2 Physical characteristics of maize

Sr. No	No. of observation		Maximum	Minimum	Average
1	Length of maize (mm)		227	189.4	211.11
2	Diameter of maize (mm)	Major	54.2	42.2	45.2
		Intermediate	41.2	34.5	34.85
		Minor	34.5	22.5	26.5
3	Diameter of core (cob after shelling) (mm)	Major	48	36.5	43.45
		Intermediate	40.42	21.51	32.97
		Minor	30.40	22.70	27.55
4	Weight of cob with husk (g)		420	252	331.27
5	Weight of husk (g)		74	36	52.36
6	Weight of dehusked cob (g)		346	216	280.21
7	Weight of core (cob after shelling) (g)		122	88	107.23
8	Weight of shelled kernels (g)		192	122	159.25
9	Weight of unshelled kernels (g)		32	6	21.36

$L = 2 \times 250 + [(\pi(100 + 40) / 2] + [(100 - 40)^2] / 4C$

$L = 723.54$ mm.

A standard belt length 720 mm was selected for power transmission from motor to cylinder pulley.

3.5.4 Horsepower Required

The calculated horsepower of the machine was 2.164 kW, The 3D design of maize sheller (Figure 1). The recommended horsepower of machine was calculated by using the formula:

Horsepower Required, hp = (Actual hp) / (Motor efficiency × Belt efficiency)

The horsepower of machine was 1 hp.

3.6 Physical Properties of Maize

3.5.1 Size

To determine the average size of the maize a sample of 120 cobs was randomly picked and their major dimensions namely, cob length, cob width, cob diameter and grain diameter were measured using a measuring tape.

3.6.2 Weight

To determine the average weight of the maize a sample of 120 cobs was randomly picked and their weight was recorded and also cobs without seed weight was also measured using a weighing balance.

3.6.3 Shape

The shapes of maize were determined through visual observations and by comparing with the standard shapes.

3.7 Performance Test

The following performance parameters were determined.

3.7.1 Shelling Rate

The shelling rate of developed maize sheller was calculated by following equation, (Bello et al., 2019).

Shelling rate, kg/h = (Mass of shelled grain × 3600) / (Time taken)

3.7.2 Shelling Eficiency

The shelling efficiency of developed maize sheller was calculated by following equation, (Bello et al., 2019).

Shelling efficiency, % = (Mass of shelled grain) / (Total mass of grain (Shelled + Unshelled)

3.7.3 Grain damage

The Grain damage of developed maize sheller was calculated by following equation, (Bello et al., 2019).

Grain damage, % = (Mass of damage grain) / (Mass of shelled grain)

3.8 Materials

The materials used for the development and fabrication of shelling machine (**Table 1**). The developed maize sheller (**Fig. 2**).

Results and Discussion

4.1 Physical Characteristics of Maize Cob

Physical characteristics such as length and diameter of maize cobs was measured. The maximum and minimum length of maize cob ranged from 227 to 189.4 mm respectively. The average length of maize cob was found as 211.11 mm. The average diameter of maize cobs at three point's viz., major, intermediate and minor were observed as 45.2, 34.85 and 26.5 mm respectively. These average values for core (cob after shelling) were observed as 43.45, 32.97 and 27.55 mm. The Weight of cob with husk, Weight of husk, Weight of dehusked cob, Weight of dehusked cob, Weight of shelled kernels, Weight of unshelled kernels was 331.27 g, 52.36 g, 280.21 g, 107.23 g, 159.25 g, 21.36 g respectively (**Table 2**).

4.2 Effect of Cylinder Speed

The Shelling rate, shelling efficiency and Grain damage of maize was 88.27, 88.74 and 90.92 kg/h, 96.75, 91.25 and 89% and 3.10, 3,84 and 4.04% for speed of 150, 200 and 250 rpm respectively. When cyl-

Table 3 Effect of speed of performance parameters of developed maize sheller

Sr. No	Cylinder Speed (rpm)	Mass of feed (kg)	Mass of shelled grain (kg)	Mass of unshelled grain (kg)	Mass of damage grain (kg)	Time taken (s)	Shelling rate (kg/h)	Shelling efficiency (%)	Grain Damage (%)
1	150	20	19.35	0.65	0.60	788.9	88.27	96.75	3.10
2	200	20	18.25	0.75	0.70	740.3	88.74	91.25	3.84
3	300	20	17.80	0.80	0.80	707.9	90.92	89	4.04

inder speed increases shelling rate and grain damage also increases but shelling efficiency decreases (**Table 3**). At a speed of 150 rpm the shelling rate was high but keeping in view of minimum shelling efficiency and grain damage the speed of 150 was optimized the best speed for operation of developed maize sheller. The higher shelling efficiencies were observed at 350 rpm rotor speed but damage was little higher at 350 rpm speed (Naveenkumar and Rajshekarappa, 2012). The maize cobs before and after shelling (**Fig. 3**).

4.3 Effect of Moisture Content

The Shelling rate, shelling efficiency and Grain damage of maize was 83.57, 67.81 and 63.84 kg/h, 95.25, 85.75 and 84.75% and 7.61, 10.95 and 13.24% for moisture content of 12, 14 and 16% (w.b) respectively, at optimized speed of 150 rpm. When moisture content increases the shelling rate and shelling efficiency decreases but grain damage increases (**Table 4**). At a moisture content of 12 % the shelling rate, shelling efficiency and grain damage was high. So, 12 % moisture content was considered as an optimized parameters for best shelling of developed maize sheller. The shelling efficiency of maize was 98.51 % found significantly higher when maize of 13 percent moisture content (Naveenkumar and Rajshekarappa, 2012). A more efficient shelling is achieved when the grain has been suitably dry to 13 to 14% moisture content (Danilo, 1991). The shelling rate was greatest at a moisture content of 10% and lowest at 17% (Nsubuga et al., 2020). (Nsubuga et al., 2020) reported that the optimum moisture content for shelling of maize crop was 13 %.

Conclusion

A motor operated maize sheller good option for the small farmer and also the developed maize sheller is reliable and satisfactory for the selected variety of maize. The developed maize sheller operated at three speed 150, 200 and 250 rpm and three moisture content 12, 14 and 16% (w.b). The maximum shelling rate, shelling efficiency and lower grain damage was observed at 150 rpm cylinder speed and 12% (w.b) moisture content. With the increase in moisture content shelling rate and shelling efficiency decreased and grain damage increased. With increase in cylinder speed shelling rate, and grain damage increased and shelling efficiency decreases. Keeping in view the maximum efficiency and minimum damage the cylinder speed of 150 rpm and moisture content of 12% (w.b) was considered the optimized variables. The payback period was 1.13 years while the benefit-cost ratio was 1.01.

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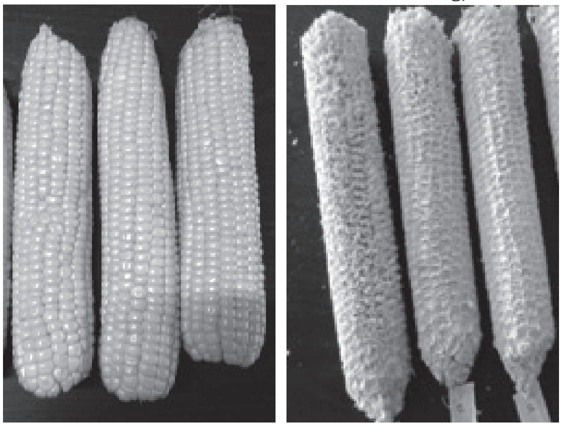

Fig. 3a Maize (before shelling) **Fig. 3b** Maize (cob after shelling)

Table 4 Effect of moisture content of performance parameters of developed maize sheller

Sr. No	Moisture Content (%)	Mass of feed (kg)	Mass of shelled grain (kg)	Mass of unshelled grain (kg)	Mass of damage grain (kg)	Time taken (s)	Shelling rate (kg/h)	Shelling efficiency (%)	Grain Damage (%)
1	12	20	19.05	1.10	1.45	820.6	83.57	95.25	7.61
2	14	20	17.15	1.25	1.80	910.4	67.81	85.75	10.95
3	16	20	16.95	1.45	2.25	955.8	63.84	84.75	13.24

Characterization of Paddy Straw Varieties of Punjab for Biogas Production

by

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Abstract

There are eight recommended varieties of paddy given in Package of Practices of Punjab Agricultural University, Ludhiana. These are PR-121, PR-124, PR-114, PR-122, PR-126, PR-118, PR-111 and PR-123. There are other varieties which are also being grown prominently in 5 agro climatic zones of Punjab. Huge quantity of straw generated from these varieties may be used for various applications depending upon the composition of straw. Proximate, chemical and elemental composition of paddy straw of different paddy varieties, along with biogas production potential of each paddy straw varieties during summer as well as winter, for varietal differentiation of prominent paddy varieties grown in Punjab has been studied. The study was helpful in determining the suitability of a particular variety for different applications like biogas production, ethanol production or thermal applications. The proximate and chemical composition of these varieties suggested a wide variation in different varieties. Biogas production varied from 54-205 litres/kg paddy straw. Cellulose varied from 31.2-39.2%, Hemicellulose from 14.1-30.2%, lignin from 4.6-12.7% and silica from 5.2-14.3%.Variation was also observed in the same variety taken from different agro climatic zones.

Keywords: Paddy straw, Biogas Production, Proximate, Burning, Hemi-cellulose

Introduction

Globally, India is the 2nd largest producer and consumer of rice after China and producing 21% of the world's total rice production. Rice is highly nutritional staple food which gives instantaneous potency and considered as an important crop in India after wheat and some other cereals, which covering 1/4th gross sown area and provided food to 1/2^{lf} of India's population (Mondal, 2004). Paddy comes under the major crop of Punjab and has an important status in its cultivation (Ravichandran et al., 2019). There are several varieties of rice sowing about 2.6 million ha area of Punjab like PR116, PR 118, (non-aromatic), Basmati 370, Pusa Basmati 2, Pusa Sugandh 2 & 3 (aromatic rice), PR126, and hybrids Pusa RH 10 etc.

Punjab's roles approx 26.69% rice to the central pool (Anonymous, 2020). Out of the total cultivated area of paddy, more than 85% is reaped by combine harvesters in the state. Growing of high production varieties of the paddy has resulted in yielding of immense quantities of its residues. There is no problem of managing paddy straw due to manually harvested method as it can be easily collected and is used as animal feed. But during harvesting period of paddy through the combine harvesters, it left 2-8 t/ha straw in the form of standing stubbles of 30-45 cm height and loose straw of 35-60 cm length. In India, merely Punjab produces approximately 21 million tons of paddy residues every year (Anonymous, 2020), out of which about 85-90% (Approx. 18.5 million tons) of its burnt in-situ (Mukharjee, 2016).

Usually, it is considered by most farmers that burning is the ordinary and much convenient method of paddy stubble management because it impedes in tillage and seeding practices for the next crop sowing, but other hand, it is badly leads to lowered air quality and living being's respiratory ailments in intensive paddy cultivated areas. On firing of one ton of paddy residue, liberate 1,515 kg carbon di-oxide, 92 kg carbon mono-oxide, 3.83 kg nitrous oxide, 0.4 kg sulphur dioxide, 2.7 kg methane, and 15.7 kg non-methane volatile organic compounds. Approximately 5.5 kg Nitrogen, 2.3 kg Phosphorus pentoxide, 25 kg Potassium oxide, 1.2 kg S, 50-70% of micronutrients absorbed by rice and 400 kg of Carbon is found in one ton of paddy straw. The burning practices are also resulted substantial loss of essential nutrients of plant (specifically Nitrogen and Sulphur) and organic carbon content (Anonymous, 2020).

In contemplation of the serious trouble of the burning of straw residues, there is a need of sincere efforts to conduct efficient utilization of immense yielded quantity of rice residues in the state in form of biogas production for conserving soil, living being's health, and increasing farmer's profits (Anonymous, 2020).

Biogas is one of the essential products of the anaerobic digestion of biomass and is considered an alternate green energy's resource which is found in form of mixture of various gases like methane, carbon di-oxide, oxygen, nitrogen, hydrogen sulphide and its composition depends on distinct biomass verities and anaerobic digestion process conditions such as temperature, pH, and retention time. Methane (CH_4) is the most important component of biogas because it has the highest energy density among the biogas components. Therefore, the high methane content of biogas is desired (Ngan et al., 2019).

Biogas has become new energy alternative fossil fuels. Lignocellulosics, being inexpensive and renewable resource, can be conveniently used as a feedstock for biogas generation. Paddy straw is retained copious content of lignocellulose which is rich in organic matter like cellulose, hemi-cellulose and lignin i.e. usually disposed of by firing in-situ which leads to causing environmental pollution whilst it can be used for biofuel generation (Kaur et al., 2016).

Material and Methods

Collection of the Data of Rice Production and Paddy Straw

The survey report regarding rice production and its straw was collected from the Department of Economics and Sociology, PAU Ludhiana. Prominent varieties of paddy grown in 5 agro climatic zones (ACZ) of Punjab are PR-121, PR-124, PR-114, PR-122, PR-126, PR-118, PR-111, PR-123 and PUSA-44. Straw from various varieties of paddy were received during (October-November) harvesting season and analysed under distinguished agro climatic zones. Agro climatic zones of Punjab are represented in **Table 1** and **Fig. 1**, each divided into various Krishi Vigyan Kendra (KVK) and Regional Research Stations.

Table 1 Agro climatic zones of Punjab

Zone series	KVKs & RRSs
ACZ-1	Pathankot, Hoshiarpur, Rupnagar, Ballowal Saunkhari
ACZ-2	Gurdaspur, Kapurthala, SBS Nagar, Fatehgarh Sahib, SAS Nagar
ACZ-3	Amritsar, Taran Tarn, Nurrmahal, Samrala, Ferozepur
ACZ-4	Faridkot, Moga, Barnala, Sangrur, Patiala, Shri Muktsar Sahib, Bathinda, Mansa
ACZ-5	Shri Muktsar Sahib (Abohar side)

Paddy Straw Varieties Characteristics Analysis

Characteristics of different paddy straw varieties were analysed before using testing for biogas production. Proximate, elemental and chemical analysis has been conducted on different paddy varieties which are discussed as follows.

Proximate Analysis

Moisture Content

The moisture content of the rice straw before and after sampling was determined by using ASAE [16] standard S 352.2 involving the use of oven drying methods. The initial weight of the sample was determined (W_1) and placed in an oven set at 103 °C for 24 hours. The samples removed and cooled it, reweighed (W_2). Moisture content of the samples calculated from the following expression on the basis of condition:

$$MC\ (\%) = [(W_1 - W_2) / W_1] \times 100$$

Where,

W_1 = Weight of sample before drying, (gram)

W_2 = Weight of sample on dried, (gram)

Gross Calorific Value (GCV)

The amount of heat liberated by burning known weight of samples in oxygen rich enclosure of constant volume were determined using MAC oxygen bomb calorimeter. The ASTM-711 standard procedure has been used along with all precau-

Fig. 1 Agro-climatic zones of Punjab

1. Nothern Plain, Dry subhumid, Growing period 120-160 days
2. Nothern Plain, Semiarid, Growing period 90-120 days
3. Western HImalyas, Subhumid (dry subhumid/moist subhumid), Growing period 180-210 days
4. Western Plain, Arid, Growing period 60-90 days
5. Western Plain, Arid, Growing period < 60 days

tions. For the computation work following equation has been used.

$Q_g = [(T_r \times W - e_1 - e_2) \times 1000] / g$

Where,

Q_g = Gross heat of combustion, MJ/kg

T_r = Corrected temperature rise, °C, and $T_r = T_f - T_i$

T_f = Final equilibrium temperature, °C

T_i = Temperature when charge was fired, °C

W = Energy equivalent of calorimeter, MJ/°C

e_1, e_2 = Corrections for heat of combustion of fuse wire and rolling paper used, MJ

g = Weight of sample, (gram)

Ash Content

Ash content determined by the oven dried sample in the crucible without its lid in a MAC MSW-253 high temperature muffle furnace at 600 °C for 2 hours according to the standard ASTM D 1102-84. It is calculated by following formula:

Ash (%) = $(W_1 / W_2) \times 100$

Where,

W_1 = Weight of ahs, (gram)

W_2 = Weight of oven dry sample, (gram)

Volatile Matter (VM)

VM plays a key role in thermal conversion since high amounts lead to more combustible gases during combustion. Volatile matter represents the availability of organic component into the combustible biomass that expelled from the biomass when exposed to 950°C for 7 min in an oxygen-free environment that directly correlates with burning property (Maguyon and Capareda 2013). It was calculated according to the standard ASTM 1982.

VM (%) = $(W_1 / W_2) \times 100$

Where,

W_1 = Weight of sample with lid prior to muffle furnace, (gram)

W_2 = weight of sample with lid after outing muffle furnace, (gram)

Determination of Fixed Carbon (FC) Content

It defines to the carbon left after the volatiles are expelled off. FC fraction in the residual biomass usually increases as volatiles are released during thermal degradation (Gummert, et al, 2020 and Maguyon and Capareda 2013). The oven dried samples were heated in muffle furnace at 915°C for 7 minutes in a covered tarred silica crucibles as per ASTM standard (ASTM-1982). FC was computed by following expression:

FC (%) = 100 − (VM + Ash) %

Determination of Total Solids (TS)

The weight of empty oven dried crucible was tare and 2 g sample (untreated/pre-treated paddy straw) was weighed. The crucible containing sample was placed in hot air oven at 105/7°C according to ASTM E1756-01 standard. The crucible containing sample was cooled in a desiccators and weighed. Total solid (TS) of the sample was determined as follow:

TS (%) = $[(W_2 - W_0) / (W_1 - W_0)] \times 100$

Where,

W_0 = Weight of oven dried empty silica crucible, (gram)

W_1 = Weight of fresh sample and crucible, (gram)

W_2 = Weight of oven dried sample and crucible, (gram)

a) Determination of Volatile Solids (VS)

ASTM 1982, Volatile solids were obtained by subtracting the ash content from 100.

VS (%) = 100 − Ash (%)

b) Determination of Total Organic Carbon (TOC)

Total organic carbon was obtained by dividing the VS (%) by a factor of 1.8

TOC (%) = VS (%) / 1.8

Elemental Analysis

Euro-Vector EA-3000 elemental analyser was used for determination of elemental Nitrogen (N), and Carbon (C) content. Specified pre-filled reactor samplers of CHNS-category were used for estimation N and C in straws of different paddy varieties in per cent.

Chemical Analysis

The AOAC (2000) standard methods have been used to analyse, cellulose, Hemi-cellulose, Lignin and Silica content of various varieties of paddy straw.

a) Determination of Hemi-cellulose

i. Determination of Neutral Detergent Fibre (NDF)

50 ml of neutral detergent solution was added into 0.5 g dried and ground paddy straw sample. The mixture was heated to boil on a hot plate and refluxed for 60 min. The liquid content was filtered through sintered glass crucible (G-1) mounted on suction flask. The vacuum was allowed from a suction pump. The washing with hot distilled water was repeated till the foam stops coming into the flask. The vacuum was removed and the residue was washed twice with acetone. The crucible was kept at 100°C in hot air oven for overnight. The crucible was weighed after cooling in desiccators and NDF was calculated by

NDF (%) = $[(W_1 - W_0) / S] \times 100$

Where,

W_0 = Weight of oven dried crucible, (gram)

W_1 = Weight of oven dried sample and crucible, (gram)

S = Initial weight of sample (dried, ground paddy straw), (gram)

ii. Determination of Acid Detergent Fibre (ADF)

Similar procedure was fallow as mention above while using acid detergent solution and calculated by

ADF (%) = $[(W_1 - W_0) / S] \times 100$

Hemicellulose (%) = NDF (%) − ADF (%)

b) Determination of Cellulose (Cel.), Lignin (Li) and Silica (Si)

i. Determination of Acid Detergent lignin (ADL)

The acid detergent fiber (ADF) residue was covered with cold solution of 72 % H_2SO_4 (w/w). The crucible was filled about half way with the acid and stirred. After 3 hours, suction was applied to wash the contents of the crucible with hot distilled water until the washings were acid free to pH paper. The crucible was heated at 100°C in hot air oven. Dried sample was cooled and weighed.

ii. Determination of Cellulose

The cellulose content of the sample was calculated by the following formula:

Cellulose (%) = $[(W_1 - W_2) / S] \times 100$

Where,

W_2 = Weight of 72% H_2SO_4 treated sample and silica crucible, (gram)

iii. Determination of Lignin

The crucible containing 72% H_2SO_4 treated sample was ignited at 600°C in muffle furnace for 3 h (or until carbon-free). The crucible while still hot was placed in oven at 100°C for 1 h after removing it from furnace. The crucible was cooled in desiccator and weighed. Lignin was determined as given below:

Lignin (%) = $[W_3 - W_2) / S] \times 100$

Where,

W_3 = Weight of furnace burnt sample and crucible, (gram)

iv. Determination of Silica

Three-four drops of hydrobromic acid was added into the crucible containing ignited (burnt) sample. After about 30 min, the crucible was washed with distilled water 2-3 times. The crucible was then dried in oven at 100°C. Dried sample was cooled and weighed.

Silica (%) = $[(W_4 - W_0) / S] \times 100$

Where,

W_4 = Weight of hydrobromic acid treated sample and crucible, (gram)

Correlation Analysis of Biogas Production

The presence of various kinds of organic and inorganic elements in paddy straw influenced the formation of biogas inside the digestion chamber. Distinct varieties of paddy straw collected from separates agro-climatic zones of Punjab were used for biogas production in lab scale digester of 2 litre capacity. Cattle dung 10% and bio-digested slurry (20%) were used as inducer and inoculum respectively. Daily biogas production was measured for a period of 3 months by water displacement method and data was analysed for correlation with different proximate and chemical constituents. Correlation coeffiienct value always vary between −1 to +1 i.e. defines the perfectaly negative and positive relationship with dependend variable.

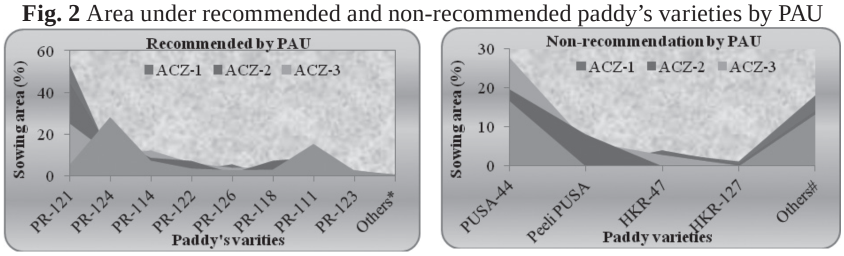
Results and Discussion

Paddy Varieties Sowed Areas in Punjab

Straw from various varieties of paddy (PR-121, PR-124, PR-114, PR-122, PR-126, PR-118, PR-111, PR-123, PUSA-44, HKR-47, Peeli PUSA and HKR-127 were received and analysed under distinguished agro climatic zones. The following **Fig. 2** shows the sown percentage area of recommended and non-recommended varieties of paddy by Punjab's KVKs and RRSs. The maximum percentage areas were cultivated by PR-121 among the all ACZs followed by PR-124 similarly maximum sowing percentage area covered by ACZ-1 among the all ACZs by various varieties of paddy crop respectively. Under the non-recommended varieties, PUSA-44 variety cultivated in maximum areas under the all ACZs followed by others# similarly ACZ-3 maximally farmed by different non recommended paddy varieties.

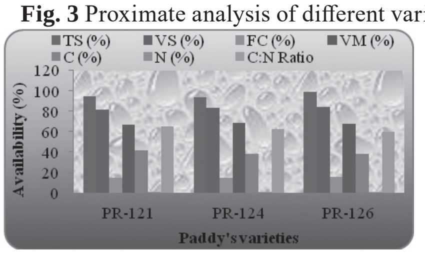
Fig. 2a shows that the maximum accumulative percentage sown areas was found by ACZ-1 with 74.79% followed by ACZ-2, 3, 4 & 5 respec-

Fig. 2 Area under recommended and non-recommended paddy's varieties by PAU

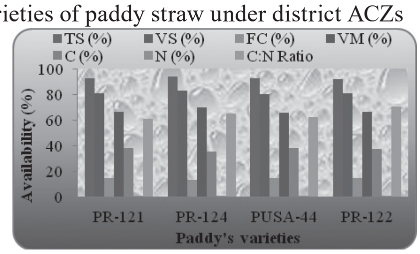


(a) (b)

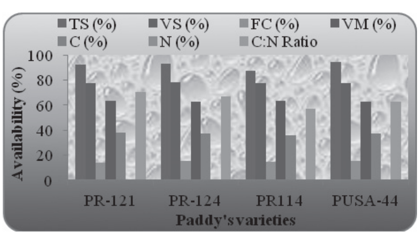
Fig. 3 Proximate analysis of different varieties of paddy straw under district ACZs



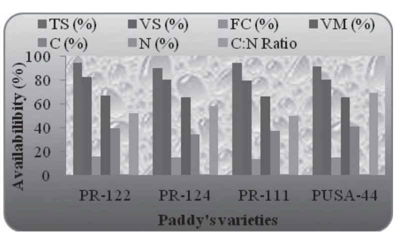
(a) ACZ-1



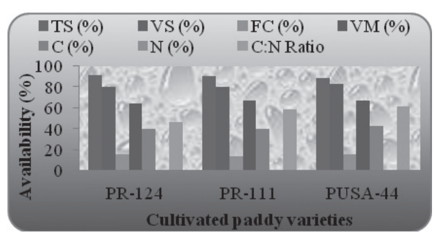
(b) ACZ-2



(c) ACZ-3



(d) ACZ-4



(e) ACZ-5

tively by distinct variety of paddy and highly averaged sowing variety of paddy was PR-121 (26.30%) followed by PR-124 respectively. Similarly **Fig. 2b** shows that HKR-127 grown in minimum cultivated area under various ACZs whereas ACZ-3 was cultivated maximum percentage areas by distinct paddy varieties.

Thermal Properties

Proximate Analysis of Paddy Straw

This analysis exposes the behavior of the feeding materials when it is heated (that defines how much driven off as gas or vapors and how much lefts as fixed carbon) (Maguyon and Capareda, 2013).

Fig. 3 represents proximate analysis of different varieties of paddy straw (PS) from five zones (ACZs) of Punjab. The percentage of TS, VS and FC content in all ACZs cultivated paddy varieties were varied from 87.22-98.55%, 77.8-84% and 13.5-16.1% respectively and paddy varieties PR-126 was found in higher percentage under ACZ-1 similarly its minimum percentage was found in paddy varieties PR-114 and PR-111 under ACZ-3 & 4 respectively. The percentage of volatile matter and C:N ratio were found in the range of 63.3%-67.9% and 54.12-65.55% respectively under distinct cultivated verities of paddy crop in various ACZs while PR-126 and PR-121 yielded in high percentage of both elements under ACZ-1 & ACZ-2 respectively similarly PR-114 and PR-111 produced minimum percentage of its both under ACZ-3 & ACZ-4. Generally, PS is characterized by high volatiles or VM, which is on par to the biomass of other byproducts. In bioenergy usage, mainly in ignition, a high VM has advantages, such as easier combustion; but it also tends to a fastest and more uncontrolled combustion (Liu et al, 2011). The percentage of C and N content varied from 35.9-39.63% and 0.603-0.71% respectively as shown in **Fig. 3** under all ACZs that all cultivated by distinct varieties of paddy crop. The higher percentage of N and C were found in PUSA-44 and PR-111 respectively under ACZ-5 & ACZ-4 respectively whereas the minimum percentage of N and C were found in PR-114 and PR-121 under ACZ-3 & ACZ-2.

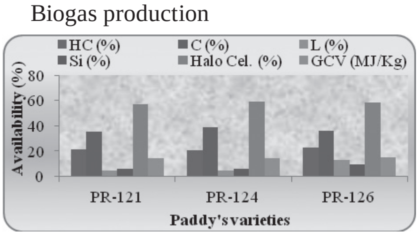
Chemical Analysis and Calorific Values

A chemical composition defines the nutritional quality of rice straw, which is played a key role in anaerobic digestion (Gummert et al., 2020). Usually, the chemical Analysis of the biomass is used to evaluate the thermal degradation and important in recognizing a material's suitability for thermal conversion (Capareda, 2014). Graphical representations of chemical analysis of paddy straw varieties are shown in **Fig. 4** and its findings depicts that the variation of paddy straw varieties in terms of cellulose, hemicelluloses, lignin and silica content along with its percentage availability. During analysis a wide variation among various constituents have been observed between Silica (S), Lignin (L), Cellulose (C) hemi cellulose (H Cel.), holo cellulose (Holo cel.) and Grass calorific value (GCV) content 6.9-10.85%, 4.7-13%, 33.35-36.1%, 17.6-23.95%, 53.2-59.3% and 13.58-14.85 MJ/kg respectively. The minimum availability of S, C, L, HC, Holo Cel., and GCV were occurred in PR-121 and PR-114 resp. varieties of paddy straw under ACZ-2 & 3 respectively but the higher availability of C, L, GCV, H Cel, Holo Cel., and S were found in PR-126, PR-122 and PR-111 under ACZ-1 & 4 respectively. However, the GCV of paddy straw is just 1/3rd of that of Kerosene, which has a GCV of 46.2 MJ/kg. A GCV is an important constituent that shows the energy value of paddy straw, if to be used for bioenergy (Gummert et al., 2020).

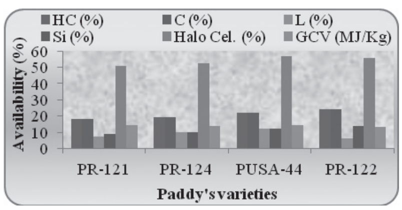
Biogas Production

Samples of all harvested paddy straw varieties from distinct ACZs were used for biogas production. The production of biogas was measured on daily period basis by water shifting method for a period of 3 months. From the **Fig. 5** clearly represents that the ACZ-4 was the leading zone for the biogas produc-

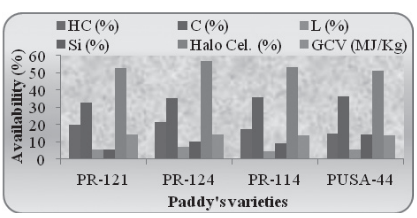
Fig. 4 Chemical analysis of different paddy straw varieties under distinct ACZs Biogas production



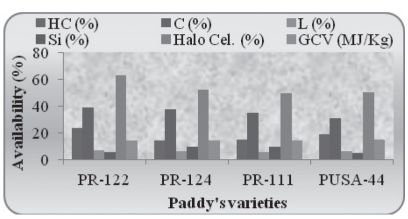
(a) ACZ-1



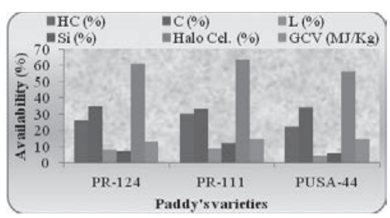
(b) ACZ-2



(c) ACZ-3



(d) ACZ-4



(e) ACZ-5

tion under trail of various kinds of paddy straw varieties followed by ACZ-2 & ACZ-1 respectively and in comparison of biogas production, findings revealed that it was achieved too high due to presence of VS followed by TS and PS content respectively.

Findings from **Fig. 6** depicts that maximum biogas production on the basis of PS, TS and VS were obtain in paddy straw variety PR-122 under ACZ-4, 204.93, 217.32 & 264.7 l/kg followed by PR-121 and PR-124 under ACZ-2 & 4 respectively. Similarly the minimal was found by PR-114, 53.75, 61.63 & 79.21 l/kg under ACZ-3.

But in case of individual ACZs of trailed distinct paddy straw varieties for biogas production due to presence of PS, TS and TS, **Fig. 7** findings depict that PR-124 was most effective under ACZ-1 & ACZ-3 followed by PR-121 and PUSA-44 respectively and PR-121, PR-122 and PUSA-44 were highly productive varieties under ACZ-2, ACZ-4 & ACZ-5 respectively.

Biogas Correlation Analysis with Various Existing Elements

Availablity of certain amount of existing elements in biogas digestion chamber domenstrates the effectiveness characteristics of biogas production. There are various kinds of correlated elements mentioned below **Table 2** with their coefficinet values.

From the above table correlation coefficient values of proximate analysis express that the biogas production is not significantly related with TS and VS concentration as biogas production as indicated by r = 0.36 & 0.32 respectively. FC is least negatively correlated with the biogas formation, which define slight effect. Generally, PS is characterized by high volatiles or VM, which is on par to the paddy straw of other by-products (Liu et al., 2011), its correlation value (r = 0.54) represents the moderate positively correlate with biogas production, which designated positive influence on gas formation during anaerobic digestion.

The presence of carbon in biogas defines the rising of gas formation due to accumulation of hereditary bacteria. The presence of carbon content in trailed paddy verities under distinct ACZs shows a moderate significant correlation (r = 0.43), which express that on increasing its percentage content in straw drawn an ample positive role in carbon dioxide formation and reduce pH value (Dioha et al., 2013).

N is an essential paddy straws constituents which of high value promote the production of gas that could increase the pH of anaerobic digestion slurry (Method of Soil Analysis 1979 and Dioha et al, 2013). The correlation value (r = 0.08) of N, unfold the least positive co-relationship with biogas formation, which define a non-significant effect.

Fig. 5 Biogas production under distinct agro climatic zones (ACZs)

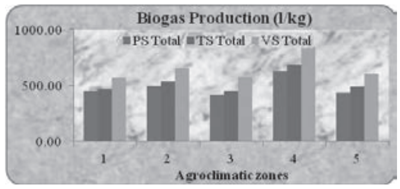
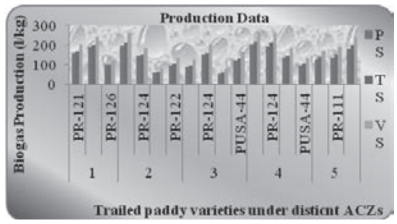
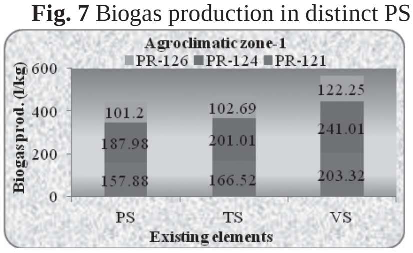


Fig.6 Graphical representation of biogas production under differnet ACZs in the presence of PS, TS and VS into various kind of paddy starw varieties

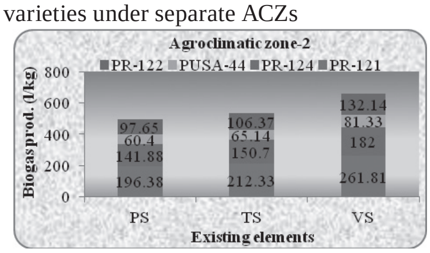


A positive correlation between Biogas and C: N ratio (r = 0.29) clearly indicates that biogas production increases with increase in C: N ratio. The C:N ratio is a critical factor in the anaerobic digestion process, which shows the good quality of biogas which is measured by the growth of the community of bacteria in the digestion chamber. If its value higher than optimise range (20-30), the rate of decomposition decreases whereas due to low range, the accumulation of ammonia can occur, which can enhanced the activity of bacteria and rapid decom-

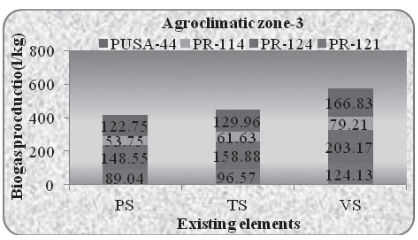
Fig. 7 Biogas production in distinct PS varieties under separate ACZs



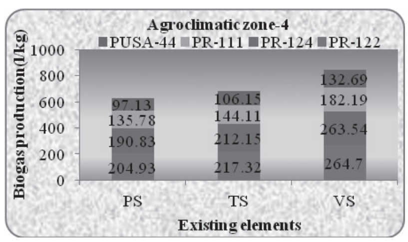
(a) ACZ-1



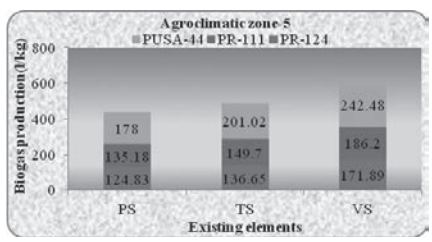
(b) ACZ-2



(c) ACZ-3



(d) ACZ-4



(e) ACZ-5

Table 2 Correlation coefficient values (r) for biogas formation

Sr. No.	Proximate Constituents		Sr. No.	Metal Composition	
	Parameters	Coefficient value		Parameters	Coefficient value
1	TS	0.36	1	As	0.669
2	VS	0.32	2	B	0.358
3	FC	-0.22	3	Ca	-0.377
4	VM	0.55	4	Cd	0.196
5	C	0.43	5	Cr	0.219
6	N	0.08	6	Cu	0.428
7	C/N ratio	0.29	7	Fe	-0.268
	Chemical Composition		8	Mg	-0.0016
8	Cel.	-0.25	9	Mn	-0.02
9	H Cel.	0.54	10	Ni	0.537
10	(Holo Cel.)	0.37	11	P	0.472
11	L	-0.008	12	Pb	0.144
12	Si	-0.22	13	S	0.528
13	GCV	-0.36	14	Zn	-0.286

position that farmed high quality biogas (Ngan et al., 2020; Bardiya and Gaur, 1997; Bird et al., 2001 and Chivenge et al., 2020).

Cel; L and H Cel., are the hereditary constituents of lignocellulosic biomass, whose interactions form a high resistant and recalcitrant lignocellulosic structures (Fu et al., 2018). The correlation coefficient values of Cel. and L ($r = -0.25$ and -0.008) respectively revealed that a revoked and trivial negative impact on production of biogas while H Cel. ($r = 0.54$) play a significant role and its higher percentage availability enhance the formation of biogas of trailed paddy straw varieties. As far as correlation think of holo cel., the coefficient values ($r = 0.37$) unfold that with the reduction in holo cel. content in different varieties, biogas production also decreased. In case of Si content, $r = -0.22$ showed a lighter negative correlation with the biogas generation which recognised that with the increasing value of Si content, has found drastic reduction in biogas generation.

Similarly the correlation of metallic elements or micro elements are also introduced in **Table 2** and findings culminate that As, Ni and S have very strong and moderate positively correlated (respectively) with biogas production followed by P and Cu; and expect these all remaining are slight negatively correlate and some were play a non-significant role in biogas production in trailed paddy varieties under distinct ACZs. The present investigations are reveals that the occurrence of some heavy metals in the digestion chamber reduced the efficiency of the AD process. (Mansour et al., 2014).

In the view of searching most efficient and successful variety of paddy straw for biogas production in Punjab region, following **Fig. 8** illuminate that under the presence of tremendous metallic contents PR-124 was the high biogas yielding straw variety followed by PR-122 and PR-121 respectively.

Seasonal Temperature Influence in Biogas Formation

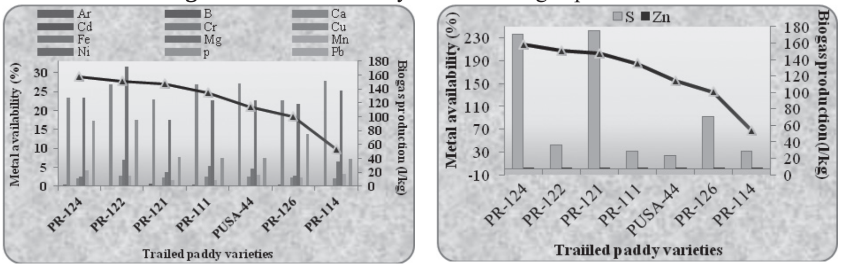
Lignocellulosic biomass having huge cel. and hemi cel. are too good for bio-conversion technique i.e. AD and biomass fermentation. The high amount of lignin results in resistance to enzymatic degradation. Temperature when enhance, leads to increased formation of biogas. Optimum production of biogas is varies from 30-40 °C (Lianhua et al., 2010). A significant variation was observed in biogas generation over the trailed period. This variation may be due to the fluctuation in digester and atmospheric temperature. The temperature influence the rate of digestion due to the direct contact of digester walls with the atmosphere, which siphon or driven off heat depending on the temperature fluctuations between the digester and its immediate environment (Kaur et al., 2016).

But at a temperature extent of 40-50 °C, biogas production will becomes slow because this temperature extent is not appropriate with bacteria activities. However, on par to 60 °C temperature, biogas formation reduced but completely cessasete at 65 °C or it’s higher (Chandra et al., 2012). Results from **Table 3** showed that biogas production in different varieties varies from 55 l/kg PS to 217 l/kg PS and 45-192 (l/kg) with minimum value in PR-114 and maximum in PR-122 during summer months and winter season respectively. Although, a reduction of 12-45% have been observed in trailed paddy straw varieties during winter months.

It means that the seasonal variability possess the rate of heat attain or driven off from the digester which then strike the microbial activities in the digester.

Thus, the investigation reveals that a definite extent of temperature is a very important variable for ef-

Fig. 8 Influence of heavy metal on biogas production



(a) (b)

ficient AD of rice straw.

Conclusion

The proximate, chemical and elemental composition of all paddy straw varieties showed wide variation in various constituents. The total solid content varied from 87.22-98.55%, volatile solids from 77.8-84% while fixed carbon from 13.5-16.1%. Volatile matter was found to be in the range of 63.3-67.9%, carbon content varied from 35.9-39.63%. The C: N ratio varied from 54.12-65.55. Cellulose content varied from 33.55-36.1%, Hemicellulose from 17.6-23.95%, Holo cellulose occurred from 53.2-59.3%, lignin from 4.7 -13.0% and silica from 6.9-10.85%. The average biogas production varied from 53.75-158.814 l/kg paddy straw. Variation was also observed in the same variety taken from different agro climatic zones. PR122, PR124, PR121, and PUSA-44 were found to be the most suitable varieties for biogas production. Varieties having high holocellulose content and volatile solids are more suitable for biogas production. C: N ratio of the paddy straw affects biogas production significantly as the varieties with low C: N ratio showed higher biogas production as compared to variety with High C: N ratio. Presence of lignin and silica complex hampers biogas production in various varieties as shown by negative correlation coefficient. Proximate, chemical and elemental compositions of paddy straw significantly influence biogas production.

The study helped in determining the suitability of a particular variety of paddy straw for different applications like biogas production, ethanol production or thermal applications.

Table 3 Comparative biogas production of paddy straw varieties during summer and winter months

Variety Name	Biogas (l/kg PS) Summer months	Biogas (l/kg PS) Winter Months	% reduction
PR-122	217	192	12
PR-121	173.7	148.7	14
PR-124	155.65	130.65	16
PR-111	153.2	128.2	16
PUSA-44	124.5	99.5	20
PR-126	119.5	94.5	21
PR-114	55	30.0	45

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■■


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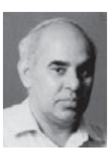
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Manbahadur Gurung	Bhutan	1972	2006
Merle L. Esmay	U. S. A.	1972	1990
Giuseppe Pellizzi	Italy	1973	2012
Mohamed A. Bedri	Sudan	1973	1987
Shahansha-Uddin Choudhury	Bangladesh	1973	1991
T. B. Muckle	U. K.	1973	1978
Chang Joo Chung	Korea	1975	2014
T. Touggaard Pedersen	Denmark	1975	1990
Bilash Kanti Bala	Bangladesh	1976	1982
George B. Hanna	Egypt	1976	1988
Jun Sakai	Japan	1976	2015
Siswadhi Soepardjo	Indonesia	1976	1985
Tieng-Song Peng Taiwan	Taiwan	1976	2015
Mohammad Ilyas	Pakistan	1977	1981
Amala Prasad Sharma	Fiji	1978	1981
Arumugam Kandiah	Ethiopia	1978	1989
Bherulal T. Devrajani	Pakistan	1978	2004
John Kilgour	U.K.	1978	2014
Satish Chandra	Fiji	1979	1990
Jitendra P. Mittal	Nigeria	1980	1993
Naresh Chandra Saxena	India	1980	1988
Paris Andereou	Lebanon	1980	1984
Wang Wanjun	China	1981	2012
Allah Ditta Chaudhry	Pakistan	1981	2015
Allan L. Phillips	U. S. A.	1981	2004
Julien G. Van Lancker	Brundi	1981	1989
Suppiah Kathirkamathamby	Sri Lanka	1981	1991
Armed Hossain Mirdha	Mexico	1982	1991
A. A. Valenzuela	Chile	1982	2013

Name	Nationality	Inaugural year	Retired year
David Boakye Ampratwum	Ghana	1982	2011
Kshirode Chandra Roy	Bangladesh	1982	1985
M. H. Abdel Aziz	Saudi Arabia	1982	1991
Krishna Prakash Srivastava	Ethiopia	1983	1989
Muhammad Siddique Chaudhry	U. S. A.	1983	1991
Wimala Tissa Weerakoon	Zambia	1983	1985
Harry D. Henderson	Lebanon	1984	1985
Mohammad Afzal	Pakistan	1984	1994
A. P. Kaloyanov	Bulgaria	1985	2013
Soedjatmiko	Indonesia	1986	2014
Aalbert Anne Wanders	Netherlands	1988	2007
Ali Mahmoud El Hossary	Egypt	1988	2010
Chanchai Rojanasaroj	Thailand	1988	2011
Edward A. Baryeh	Zimbabwe	1988	2014
T. P. Ojha	India	1988	2015
Eltag S. Eldin Mahmoud	Sudan	1990	2011
Henrik Have	Denmark	1990	2009
Graeme Ross Quick	Australia	1995	2015
Rafiq ur Rehman	Pakistan	1995	2015
Abdulsamad Abdulmalik Hazza'a	Yemen	1999	2014
Yunus Pinar	Turkey	1983	2016
William J. Chancellor	U.S.A	1972	2017
Kunihiro Tokida	Japan	2016	2017
Shujun Li	China	2012	2018
S. F. (Sen-Fuh) Chang	Taiwan	1987	2018
Jan Pawlak	Poland	2002	2019
Oleg S. Marchenko	Russia	2003	2019
W. B. Hoogmoed	Netherlands	2007	2019
Sitaram Dagdupant Kulkarni	India	2017	2020
Shah M. Farouk	Bangladesh	1982	2021
S. R. Verma	India	1982	2021
Chetem Wangchen	Bhutan	2006	2022
Israel Kofi Djokoto	Ghana	1987	2022

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