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Design and comparative performance of shapes of positive seed knocking devices for a vertical plate seed metering mechanism

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ABSTRACT

Three different shapes of positive seed knocking devices were introduced in a vertical plate type seed metering mechanism in order to improve performance of seed delivery system. A seed metering plate of 86 mm in diameter having equally spaced nine cells was designed for a selected pea variety and fabricated. Effect of concave, convex and straight edge positive seed knocking devices on performance of the vertical plate seed metering mechanism were evaluated under laboratory condition at 37.04, 44.45 and 51.86 rpm operating speeds using the pea seeds. There was occurrence of cells jammed with seeds in case of seed metering mechanism without seed knocking device whereas no incidence of jammed cell occurred with positive seed knocking device. Mean seed spacing closest to theoretical spacing for 30o (10.37 cm) and 40o (10.04 cm) left side angle of cell were observed both with convex edge positive seed knocking device. Lowest average missing index of 2.7% and highest uniformity of seed placement of 96.8% were observed with convex edge positive seed knocking device with seed metering plate having cell depth of 8.48 mm and 40o left side angle of cell.

1. Introduction

Sowing of seed is a very important and labour intensive farm operation for cultivation of field crops. Traditional method of sowing and planting is still practiced in many of the poorly mechanized fields in the country but these methods are known inefficient, involve huge drudgery and causes high losses of costly input. The present highly competitive agriculture needs application of improved tools and implements for carrying out various farm operations. To produce proper yield, one of the important farm operation is to sow the seeds in properly spaced rows so that plants get uniform nutrients, moisture and sunlight. In row planted crops, proper intercultural operations also can be performed with mechanical tools and implements (Godara *et al.*, 2015).

The row spacing, plant to plant spacing, and seed depth requirements depend on the crop and other local factors (Dhakad and Khedkar, 2014; Ramesh and Girishkumar, 2014). Broadcasting of seeds do not maintain uniform plantspacing and depth in the soil which hinders the growth and lower the produce. The area under multiple cropping as well as use of high yielding variety seeds are also increasing day by day to produce more from the same available area which in turn require application of improved tools and implements. Precision planters are usually designed to place a single seed in each hill at desired spacing and proper depth into the soil (Ryu and Kim, 1998; Navid *et al.*, 2012). Different types and sizes of

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sizes of advanced seed drills and planters for various crops are being implemented in agriculturally developed parts of the country. However, use of seed drills and planters is still negligible in marginal farms and in hilly areas particularly in north eastern states of the country. Moreover, larger size, high power operated sowing equipment suitable in plain areas are not suitable in the hills due to uneven topography and small size of land holdings. Mass flow type seed metering mechanism fitted in commercial sowing equipment such as seed drill and seed cum fertilizer drill operated by animal, power tiller and tractor meter high and non-uniform seed rate. They are not economical for costly seeds and also usually require thinning operation which further increases the cost of operation (Singh *et al.,* 2012). Metering device is an important and vital component in precision planters which effect the planter performance. It aims to pick seeds from the seed hopper and drop a single seed in each hill at required seed spacing. The roller type seed meters has many advantages such as simple structure, light weight, easy adjustment, capability for high speed planting and low cost, etc. (Navid *et al.,* 2012). With the use of planters, the seed germination efficiency could be increased and seed-rate reduced (Dixit *et al..* 2011).

Suitable design of seed metering mechanism is considered highly important to achieve proper performance of sowing implement (Khandai *et al.,* 2015). Variations to select or drop a single seed results in large or non-uniform spacing between the seeds. Singh *et al.*, (2017) designed and developed a single row manual/ bullock drawn multicrop planter using cell type seed metering roller having four different sizes of cell to suit line sowing of wheat, maize, soybean, lentil, pea, mustard, millet etc. in hilly areas. Ryu and Kim, 1998 and Ahmadi *et al.,* 2008 considered groove shape as the most important design parameter affecting seed dropping process from the groove of a seed metering mechanism. Hongxin *et al.*, 2015 developed four plate series of vertical disc seed.

2. Theoretical Considerations

Plate type seed metering mechanism normally discharge the seeds mainly due gravity. Fall of a seed from the cells depends on angle of repose of seed and friction angle (Ryu and Kim, 1998). A seed in the cell begins to slide and fall, if the sliding angle exceeds the angle of repose of the seed. Preliminary testing of the developed seed metering mechanism, when tested under laboratory condition, occurrence of cells jammed with seed were observed and caused higher missing hills. Hence a positive seed knocking device was considered important to avoid missing of seeds caused due to occurrence of jammed cells by positively pushing the seeds out of the cells and to prevent the cell run repeatedly with jammed cells.

Working principles of the seed metering mechanism

The seed metering mechanism was designed such that each cell picks up a single seed from the seed hopper. Each cell rotate along with a seed and travels toward seed tube. In addition to gravity, the seeds are pushed out from the cell by a spring loaded knocking device and deliver in the seed tube. Since, all the seeds are released from the same exit point due to the action of the seed knocking device, the exit path of the seeds from the seed metering mechanism are assumed to be uniform thus improving the uniformity of seed spacing.

Design considerations of seed metering plate

Size of seed, shape and size of the cells, number of seeds to be placed per hill and, number of cells in a plate are most important design parameters for a precision seed metering mechanism (Ryu and Kim, 1998; Jayan and Kumar, 2004; Ahmadi *et al.,* 2008). Sphericity, true density and angle of repose of seeds also affect the flow characteristics of the seeds in a planter (Jayan and Kumar, 2004). The matching of size of the cells to the size of the seed highly affect the performance of the seed metering unit (Wankhade and Kotwal, 2014).

The size of cell should be in relation to the shape and size of the seeds for precision metering and to minimize seed damage. Maximum seed size in relation to shape and size of cell, exposure time of a cell to seed in repose of seed and friction angle (Ryu and the hopper and linear speed of the cell affect the cell filling performance of a seed metering mechanism (Kepner *et al.,* 1987). Increasing metering speed was found to decrease available time for seed to enter in the cell (Navid *et al.,* 2012) and also increased percentage of seed damage (Kepner *et al.,* 1987).

The seed delivery (left) side angle of the cell is an important design parameter for a seed metering plate as it affects seed holding capacity of the cell and time delay between consecutive seed dropping from the cell (Ryu and Kim, 1998). Cell diameter should be nearly 10% greater than the maximum size of seed and the cell depth should be nearly equal to the average seed diameter or thickness (Kepner *et al.,* 1987). Too large cell size or cell depth shorter than the length of seed result higher seed damage (Ryu and Kim, 1998).

3. Design of seed Metering Mechanism

Design of seed metering plate

The following major factors were considered in designing the metering mechanism of the pea planter:

- The metering plate should meter one seed per cell.
- Seed to seed spacing of 10 cm could be achieved (Yadav *et al.,* 2009).
- Maximum permissible peripheral velocity of the plate should be 16.5 m/min (Sharma and Mukesh, 2013).
- Maximum permissible speed of the rotor should be 60 rpm (Sharma and Mukesh, 2013).

The seed metering mechanism was designed for field pea (Rachna variety). Considering the maximum permissible speed of the seed metering feed shaft and maximum permissible velocity of plates, the diameter of the seed metering plate was 86 mm with nine numbers of cells around the periphery of the plates.

Cell Design

Some of the design parameters mentioned by Ryu and Kim (1998) were used in designing the cells of the metering plates and shown in figure 1. The depths of the cells (dC) under the study was 1.15 times the average length (8.48 mm) of the seeds. The left (seed delivery) side angle of cells (βL) was made inclined downward for improving the uniformity of seed released from the seed meter. Preliminary study of the performance of the seed metering plates were conducted for 20o, 30o and 40o left side angle of cell. However, the study was confined on 30o and 40o left side angle of cell due to poor performance of 20o left side angle of cell. The right side angle of each cell (βR) in the study was 0o for all the plates. The bottom radius of the cells (RC) were half of the depth the cells.

Positive seed knocking device

Three shapes of mechanical type positive seed knocking devices (PSK) were developed. The devices were fitted in the gap between a pair of seed metering plates with cells. The shapes of the devices were designed such that the knocking of the seed from a cell starts at the point where opening of each cell has just complete towards the outlet. The shapes of the concave edge, (b) convex edge and (c) straight edge as shown in figure 2. Total and effective length of the curves of all the three seed knocking devices were same for comparative evaluation of performance.

Seed metering mechanism with positive seed knocking device

The seed metering mechanism consisted of a pair of metering plates with a gap of 1.5 mm in between them. The plates with cells were closed from both sides with other plates without cell. One side of the plate without cell was extended with a bushing unit. The seed metering feed shaft passes through all the components of the seed metering mechanism and fastened with the bushing unit. Figure 3 shows a seed metering mechanism with convex edge positive seed knocking device.

Evaluation of the seed metering mechanism

The developed seed metering mechanism along with a seed hopper were fitted on a grease belt testing unit. Performance of the seed metering mechanism having plate with 30o and 40o cell left side angles and using the three shapes of the positive seed knocking devices (concave, convex and straight edge) were evaluated at three speeds of operation relative to 2.0, 2.4 and 2.8 km/h forward travel speed of a planter. Five replications were conducted for each experiment. In each replication, 40 seed spacing and broken seeds delivered from the seed metering unit were recorded. Different seed metering plates and experimental variables studied are shown in Table-1.

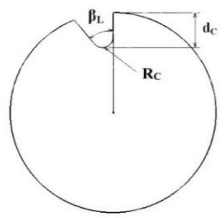

Fig. 1. Cell design parameters

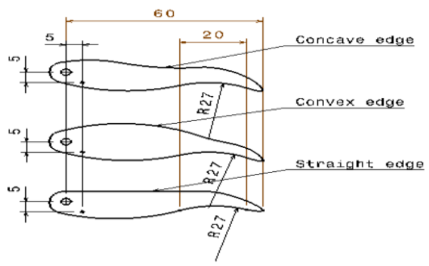

Fig. 2. Shapes of positive seed nocking

Table-1. Experimental variable

Plate series	Left side angle of cell, °	Shape of PSK
$P30_{CC}$	30	Concave edge
$P30_{CV}$	30	Convex edge
$P30_{ST}$	30	Straight edge
$P40_{CC}$	40	Concave edge
$P40_{CV}$	40	Convex edge
$P40_{ST}$	40	Straight edge

4. Performance indices

Uniformity of seed spacing of the seed metering mechanism and the three seed knocking devices were evaluated. Missing index, multiple index, uniformity of seed placement and damaged seeds were also analysed. The results were analysed using IBM statistical software SPSS 20.

The percentage multiple index and missing index of the seeds dropped on the grease belt were calculated by the following equations (Korucu and Arslan, 2009; Singh *et al.,* 2012):

$$I_{miss} = \frac{n_1}{N} \times 100$$

$$I_{mult} = \frac{n_2}{N} \times 100$$

where,

I_{miss} = missing index, %

I_{mult} = multiple index, %

N = total number of spaces

n_1 = number of spaces > 1.5 times the theory space

n_2 = number of spaces $\leq$ 0.5 times the theory space

Uniformity of seed placement (I_q) is the percentage of spacing of the seeds not less than 0.5 times but not greater 1.5 times the theory spacing. The uniformity of seed placement was calculated by the equation (Korucu and Arslan 2009; Bakhtiari and Ahmad 2017):

$$0.5x_s \leq I_q \leq 1.5x_s$$

Or

$$I_q = 100 - (I_{miss} + I_{mult})$$

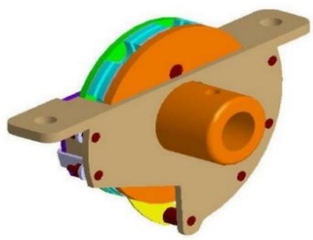

Fig. 3. Seed metering mechanism with positive seed knocking device

Percentage seed broken was calculated as the ratio of the observed weight of the damaged seeds to the theoretical weight of the total seeds recorded in the same length

5. Results and Discussions

Preliminary study showed occurrence of cells jammed with seeds in case of the seed metering mechanism without seed knocking device.

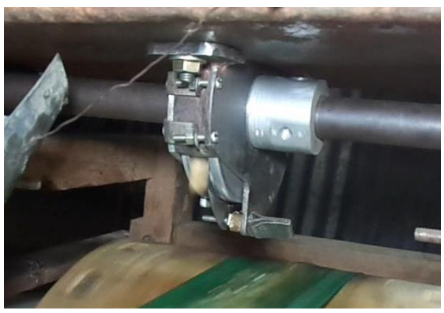

Fig. 4. Seed knocked out of cell by positive seed knocking device

Some of the jammed cells were observed rotating continuously leading to periodic missing hills. The occurrence of the jammed cells might be due to entry of more than one number of smaller size seeds and stuck up in the cell. Presence of positive seed knocking device in the seed metering unit pushed out the seeds from each cell (Fig. 4) and completely eliminated occurrence of cells jammed with seed.

Seed spacing

Distribution of 80 seed spacing for 8.48 mm depth and 40^o left side angle of cell with convex edge PSK at three different speeds of seed metering feed shaft is shown in figure 5.

The effect of the three shapes of PSK on mean seed spacing is shown in figure 6. Comparing the three shapes of PSK, the mean seed spacing of 10.21 cm with convex edge PSK was lowest and closest to the theoretical spacing of 10 cm. The mean seed spacing with concave and straight edge PSK were 10.45 cm and 10.48 cm respectively. Figure 6 shows lower and closer mean seed spacing to theory spacing in case of 40^o as compared to that of 30^o cell left side angle for all types of PSK. The average mean seed spacing for 40^o was 10.27 cm as compared to 10.48 cm for 30^o and were found significantly different (p = 0.01).

The mean seed spacing for the seed metering mechanism with PSK increased with increase in speed of operation and found significantly different at 5% level of significance. The effect of speed of operation for the three different shapes of PSK is presented in figure 7. The mean spacing (combined left side angle of cell) at 37.04, 44.45 and 51.86 rpm were 10.27, 10.49 and 10.58 cm respectively for concave edge PSK; and 10.31, 10.52 and 10.61 cm respectively for straight edge PSK. The mean spacing with convex edge PSK at 37.04, 44.45 and 51.86 rpm were 10.15, 10.20 and 10.26 cm respectively and were found closet to the theoretical spacing as compared to that of concave and straight edge PSK. Statistical analysis indicated significant difference between mean seed spacing at 37.04 rpm and 51.86 rpm (p=0.02) however no significant difference were observed between 37.04 rpm and 44.45 rpm as well as between 44.45 rpm and 51.86 rpm.

The mean seed spacing for the three PSK for cell left side angle of 30o at the three speeds varied from 10.31 cm with concave edge PSK to 10.70 cm with straight edge PSK. The mean spacing for the three PSK for cell left side angle of 40o at the three speeds varied from 9.95 cm with convex edge PSK to 10.55 cm with concave edge PSK. Convex edge PSK performed best in terms of mean seed spacing closest to theoretical seed spacing both for 30o (10.37 cm) and 40o (10.04 cm) left side angle of cell.

Multiple index (Imult)

The average multiple index for the seed metering mechanism with the three types of PSK varied from nil for P30CV to 1.2% in case of P30CC. No relationship for the shapes of the PSK with left side angle of cell and speed of operation were observed. This may be due to entry of more than one seed into a cell occur only when the cell encounter smaller size seeds and no regular trend occurred.

Missing index (Imiss)

The seed missing index for the three shapes of PSK for 30o and 40o left side angle of cell at the three different speeds varied from 2.0% to 8.0%. The seed missing index were observed increased with increase in speed of operation (Fig. 8). The average missing index of 2.7% was found in case of P40CV whereas highest missing index of 6.7% was observed in case of P30CC. Missing index for all the three PSK at cell left side angle of 40o were lower than that of 30o. Lower seed missing index in case of 40o left side angle of cell might be due to better and uniform entry of seeds into the cells as compared to the cells with left side angle of 30o. Lower angle and smaller opening of cells might have caused higher chance of missing of seeds entering into the cells in case of 30o cell left side angle.

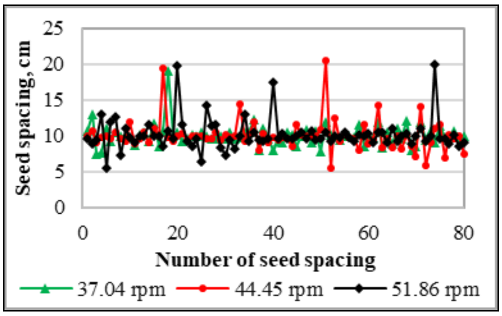

Fig. 5. Distribution of 80 seed spacing with convex edge PSK and 40^o left side angle of cell

Uniformity of seed placement (I_q)

Uniformity of seed placement due to the effect of the three shapes of PSK varied with variation of multiple and missing index. The effect of the three shapes of PSK on I_q at different speeds and left side angle of cell is shown in figure 9. In majority of experiments, decrease in uniformity of seed placement was observed with increase in speed of operation. The average uniformity of seed placement varied from 92.2% for $P30_{CC}$ to 96.8% for $P40_{CV}$. Lowest and highest uniformity of seed placement recorded at different speeds were 91.0% for $P30_{CC}$ at 51.86 rpm and 97.5% for $P40_{CV}$ at 44.45 rpm respectively. Higher uniformity of seed placement in case of $P40_{CV}$ shows better uniformity of distribution of seeds of the designed seed metering plate.

Percentage seed broken

The average percentage of broken seeds due to the effect of the three shapes of the PSK varied from 2.2% to 2.8%. Lowest percentage broken seeds of 2.2% was observed in case of $P40_{CC}$ and $P40_{ST}$. The percentage broken seed was observed highest in case of $P30_{ST}$.

6. Conclusion

- Compared to concave and straight edge, convex edge positive seed knocking device performed better in terms of mean seed spacing closer to the theoretical spacing for both 30o and 40o left side angle of cell.
- Missing index for all the three PSKs with cell left side angle of 40o were lower than that of 30o. Minimum average missing index of 2.7% was observed in case of P40CV.
- Mean seed spacing and missing index increased with increase in speed of operation.

Presence of positive seed knocking device in a vertical plate type seed metering mechanism could eliminate occurrence of jammed cells, lowered missing index and improved the uniformity of seed spacing.

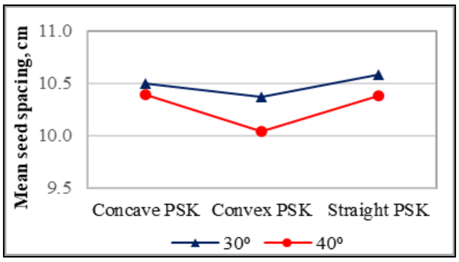

Fig. 6. Effect of PSK on mean seed spacing at cell left side angle 30º and 40º

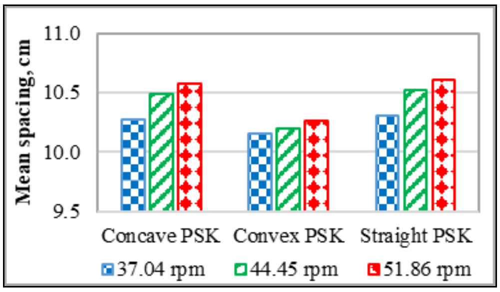

Fig. 7. Effect of PSK on mean seed spacing at three speeds

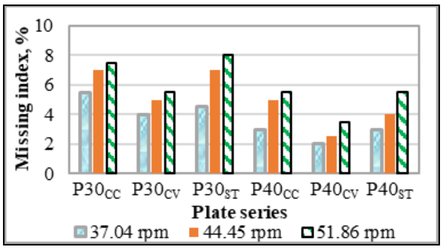

Fig.8. Variation of missing index with different PSK at different speeds

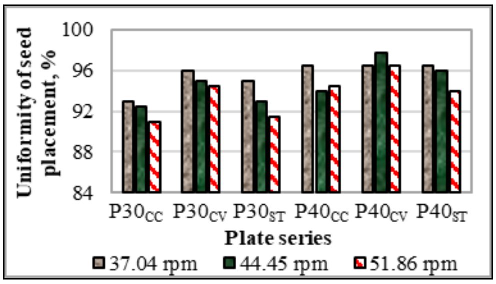

Fig. 9. Variation of uniformity of seed placement with different PSK at three speeds

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