



Design, development and performance evaluation of tractor-drawn raised-bed pulse-planter for precision sowing of pigeonpea (*Cajanus cajan*)

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ABSTRACT

In order to promote pulse productivity in India, our government has given prime emphasis on farm mechanization in pulse farming so as to enhance their acreage and productivity under pulses. In this direction, IARI-New Delhi has developed a tractor-drawn ‘single-row/double-row raised-bed pulse-planter for pigeonpea (SR/DR-RB-PP)’ during 2014–2019. This pulse-planter consisted of inclined plate metering mechanism, chassis, power transmission system, raised-bed maker, etc. For designing of the cells in the incline plate of metering mechanism of planter, the physical properties of pigeonpea (*Cajanus canja* (L) Millsp) seeds were studied thoroughly. Bulk density, true density, 100-seed weight and sphericity of the pigeonpea seed ‘Var. Pusa-992’ were computed as 0.804 ± 0.012 g/cc, 1.28 ± 0.016 g/cc, 8.52 ± 0.48 g and 0.81, respectively. Dimensions of chassis i.e. frame of planter were decided based on the mathematical calculations along with static simulation for stress analysis in ‘Creo-Simulation CAD 1.0 Designing Software’. Draft of developed pulse-planter was measured with 3-point dynamometer as 480 ± 75 kgf. Recommended sowing travel speed, field capacity and field efficiency of tractor-drawn ‘SR/DR-RB-PP pulse-planter’ was 1.5–2.0 km/h, 0.2 ha/h and 83.8%, respectively. SR/DR-RB-PP planter worked satisfactory during field test. Developed pulse-planter was field tested, refined and validated at ICAR-IARI-Agronomy Research Farm, New Delhi during 2017–2019 for consecutive 3-years in Randomized Block Design (RBD) replicated 4-times for its agronomic performance compared with manual sowing of pigeonpea. On an average, the variation in grain yield under raised-bed double-row manual-sowing (RB-DR-MS) and raised-bed double-row pulse-planter sowing (RB-DR-PPS) was 1.18% while in raised-bed single-row manual-sowing (RB-SR-MS) and raised-bed single-row pulse-planter sowing (RB-SR-PPS), it was 2.43%. Grain, stover and biological yield followed the trend of RB-DR-MS>RB-DR-PPS>RB-SR-MS>RB-SR-PPS>FB-DR-MS>FB-SR-MS, respectively. Overall, RB-DR-PPS and RB-DR-MS were equally best performers w.r.t. grain and stover yield in pigeonpea. Thus, ‘SR/DR-RB-PP pulse-planter’ holds great promises in mechanization of pigeonpea sowing both in single-row and double-row raised-beds for improving the pigeonpea acreage and productivity coupled with time-saving and drudgery reduction so as to enhance farm productivity and farm incomes.

Key words: Agronomic performance, Farm mechanization, Pulse-planter, Pigeonpea, Productivity, Raised-beds

India has distinction of having one third of global pulse acreage, ~25% of world’s production and 27% of total pulses’ consumption at global level (Choudhary *et al.* 2015; Varatharajan *et al.* 2018). India has annual pulse production of about 23 million tonnes (mt) from ~29.5 m ha area with average productivity of 779 kg ha⁻¹ (Varatharajan *et al.* 2019a). Pulses have higher protein content besides being good source of quality fibre, vitamins and minerals (Kumar

et al. 2017, 2018); besides being soil fertility restorers due to biological N-fixing ability owing to *Rhizobium* symbiosis (Choudhary *et al.* 2015). Pigeonpea [*Cajanus cajan* (L.) Millsp] is an important pulse crops in India grown on ~5.4 m ha area producing 4.8 mt grains with average productivity of 885 kg ha⁻¹ (Varatharajan *et al.* 2019b). It is 5th most prominent pulse crop in the world and 2nd most important crop after chickpea in India (Choudhary *et al.* 2015). Thus, pulses have great contribution in Indian agricultural economy and farmers’ well-being as well. However, still our average pulse productivity is far below the world averages’ where low farm mechanization is one of the important constraints for low yields (Pooniya *et al.* 2015; Varatharajan *et al.* 2019b).

The domestic pulse production had been often less than the estimated demand, i.e. 23–24 mt (Tiwari and Shivhare 2016). However, during this decade due attention has been paid by the Government of India to expand the pulses acreage and productivity through policy interventions,

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financial and structural infrastructure as well as technological interventions like crop improvement, crop diversification and pulse intensification, etc. Choudhary and Suri 2014a, 2014b; Pooniya *et al.* 2015). As a result, we are now going to achieve the food and nutritional security targets in pulses by the end of this decade (Pooniya *et al.* 2015; Varatharajan *et al.* 2019a, 2019b). However, the mechanization level of seeding and planting for all the field crops is ~29% which is further very meagre in pulse crops (Kapur *et al.* 2015; Choudhary and Suri 2018). That's why, our pulse productivity is still far below the developed nations probably due to low farm mechanization in pulses being one of the major constraints (Choudhary *et al.* 2015; Pooniya *et al.* 2015).

Since, *khari* pulses like pigeonpea are grown as rainfed crops in wet monsoon season in flat-beds (FB) where moisture stress in early establishment and post-flowering stages as well as water stagnation due to poor drainage in FBs during peak vegetative growth phase to post-flowering stage, are usual abiotic stress features (Choudhary *et al.* 2015; Varatharajan *et al.* 2019b). Higher weed infestation in flat-beds is again a worrisome issue compared to raised-bed (RB) system in pulses (Pooniya *et al.* 2015; Varatharajan *et al.* 2019a). Apart from better mechanisation, RB system leads to better water conservation (Jakhar *et al.* 2017; Kumar *et al.* 2018), excess water drainage, irrigation water saving by ~16–20% over FB/convention sowing practice in pulses (Pooniya *et al.* 2015) with higher crop and water productivity (Varatharajan *et al.* 2019c), besides better weed management (Varatharajan and Choudhary 2018; Rajpoot *et al.* 2016, 2019). The farm mechanization tools like pulse-planters may also be helpful in drudgery reduction and time saving besides higher precision in pigeonpea sowing (Choudhary *et al.* 2015; Pooniya *et al.* 2015; FAO 2019). Thus, for enhanced pulse productivity, there is a dire need of developing the pulse-planters specifically '*single-row/double-row raised-bed pulse-planters*' keeping in view their multiple benefits. Hence in this direction, IARI–New Delhi has developed a tractor-drawn '*single-row/double-row raised-bed pulse-planter for pigeonpea* (SR/DR-RB-PP)' during 2014–2019.

MATERIALS AND METHODS

For the development of '*single-row/double-row raised-bed pulse-planter*' during 2014–2019, first of all, a study on physical properties of pigeonpea seeds 'Pusa-992' was done while designing the cells in inclined plate of the metering mechanism. The detailed designing of seed metering mechanism, power transmission unit for seed metering mechanism, chassis or frame of planter to withstand all the forces during operation and transportation, furrow maker as well as raised-bed (RB) maker are discussed in this section hereunder:

Development of seed metering mechanism

Inclined plate metering mechanism is best metering system for planting the bold seeds like pigeonpea, maize, chickpea, groundnut, okra, etc. (Sahoo and Srivastava 2008).

Therefore, inclined plate metering mechanism was selected for developing the pulse-planter. For designing of the seed metering unit, the design of the cells in inclined plate was done, and then the number of cells and power transmission from ground wheel to metering plate was designed.

Cell design of inclined plate

For designing the cells in the plate, the engineering properties and germination rate of pigeonpea seeds were studied. The engineering properties of seeds such as shape, size, sphericity, true density and angle of repose (friction) of seeds play important role in designing the cells in inclined plate. Thus, the range of shapes/sizes of pigeonpea seeds and their engineering properties like grain length, width and thickness were determined. All these parameters were assessed for pigeonpea var. 'Pusa-992' seeds using standard procedures and formula as used by Kushwaha *et al.* (2019). Based on these properties of pigeonpea seeds, the corresponding dimensions of cell were decided for accommodating 2 seeds in each cell. The size of pigeonpea seeds was determined in terms of length, width and thickness of 100-seeds and their average value and standard deviation is shown in Table 1. Length, width and thickness were measured at three major axes with the help of digital vernier caliper having least count of 0.01 mm. Average germination rate of pigeonpea seeds is considered as 81.2% (Mishra *et al.* 2017). Equivalent diameter of seeds was determined as 4.7 mm. Therefore, circumference cut as 11.0 mm and depth of cut as 10 mm, were taken for accommodating the maximum two seeds per drop for designing the cell in inclined plate of the planter (Fig 1).

Design of number of cells in the metering plate

Theoretical calculation for deciding the number of cells in inclined plate is discussed in this sub-section. While designing the number of cells in the plate, the plant to plant spacing, speed reduction from ground wheel to plate and diameter of ground wheel was taken. Speed of inclined plate was less than the speed of ground wheel for smooth seed dropping and without missing the seeds from seed box to furrow opener. Therefore, speed reduction from

Table 1 Engineering properties of pigeonpea 'var. Pusa-992'

Measured parameters	Values
Equivalent diameter (mm)	4.69
Sphericity (mm)	0.81
Average length (mm)	5.82 ± 0.48
Average width (mm)	4.72 ± 0.42
Average thickness (mm)	3.77 ± 0.38
Moisture (db) (%)	10.2%
Weight of 100 seeds (g)	8.52±0.48
Angle of repose (°)	32.22±2.7
Bulk density (g/cc)	0.804±0.012
True density (g/cc)	1.28±0.016

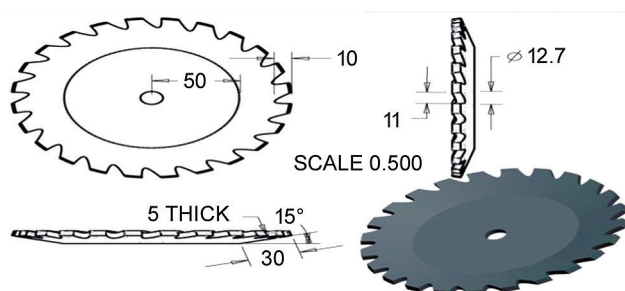


Fig 1 CAD drawing of inclined plate (in mm)

ground wheel to inclined plate of metering mechanism was selected at three stages from 14 to 15 teeth sprocket, 15 to 32 teeth sprocket and bevel gear arrangement as 10 to 16 teeth (Equation 1).

The agronomic recommendation for plant to plant spacing in pigeonpea was taken as 20 and 40 cm for single-row and double-row pigeonpea sowing in raised-beds, respectively (Let's say $S = 20$ cm), so as to maintain optimum plant population/ha. It is assumed that N_g is number of revolutions of ground wheel travelled for a distance of S cm ($S =$ plant to plant spacing). N_p is number of revolutions of inclined plate for dropping one seed. D_g ($D_g = 44$ cm) is diameter of ground wheel. Power transmission from ground wheel to inclined plate is given in Fig 2. The speed ratio of ground wheel to inclined plate is defined as:

$$\text{Speed ratio} = \frac{\text{Rpm of ground wheel } (N_g)}{\text{Rpm of plate } (N_p)} = \frac{\text{Product of no. of teeth on Driven}}{\text{Product of no. of teeth on Driving}}$$

$$= \frac{14 \times 32 \times 32 \times 16}{14 \times 15 \times 32 \times 10} = 3.413 \quad (1)$$

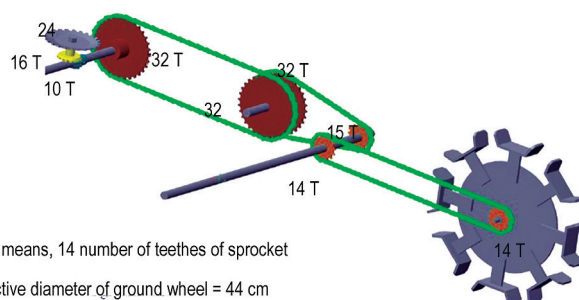
Let's n is the number of cells in inclined plate, hence one revolution of plate will drop the n number of seeds.

$$\text{For dropping one seed, plate was revolved as } N_p = 1/n \quad (2)$$

Again distance travelled in one revolution of ground wheel is $\pi \times D_g = \pi \times 44$ cm. Hence, the number of revolutions made by ground wheel for S cm plant to plant spacing was:

$$N_g = S / (\pi \times 44) = 20 / (\pi \times 44) \quad (3)$$

Dividing equation (3) by (2) and substituting N_g/N_p



14 T means, 14 number of teeth of sprocket

Effective diameter of ground wheel = 44 cm

Fig 2 Power train of seed metering mechanism

value from Equation (1) will give the speed ratio:

$$\frac{N_g}{N_p} = \frac{20}{\pi \times 44} \times \frac{n}{1} = 3.413$$

Therefore, $n = 24$ for sowing of pigeonpea seeds in single-rows for maintaining 20 cm plant to plant spacing in raised-beds; the number of cells in inclined plate was 24. Similarly, $n = 12$ for sowing of pigeonpea seeds in double-rows for maintaining 40 cm plant to plant spacing in raised-beds; another inclined plate was fabricated with 12 cells.

Development of raised-bed maker

In general, the agronomic recommendation for row to row spacing for pigeonpea sowing is 450-700 mm (Kaur and Saini 2018). Therefore, the row to row spacing for single-row sowing in one raised-bed (RB) was kept as 700 mm (Fig 3). Single-row and double-row sowing provision in the RB were given in the developed planter. In double-row sowing in one RB, row to row spacing was kept as 500 mm. On the raised-bed top, the row to row spacing of 200 mm was maintained in double-rows, therefore, top width of raised-bed was taken as 300 mm. Finally, under single-row raised-beds the row to row spacing was 70 cm while plant to plant spacing of 20 cm was maintained within single-rows. In double-row raised-beds, the paired-row spacing was 20 cm while adjacent-row to row spacing was 50 cm with average plant to plant spacing of 40 cm both in paired-rows and adjacent-rows. For proper drainage of water vis-a-vis for proper aeration of pigeonpea roots (depth of root zone), height of raised-bed was maintained as 250 mm. The 700 mm width of bed was finally kept for fabricating the raised-bed planter in the Division of Agricultural Engineering, IARI-New Delhi. Dimensions and isometric view of CAD designing of raised-bed maker is given in Fig 3.

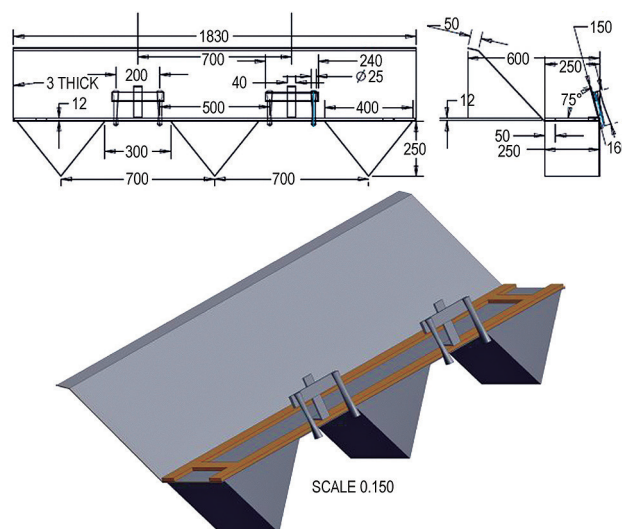


Fig 3 Dimensions & isometric view of CAD designing of raised-bed maker

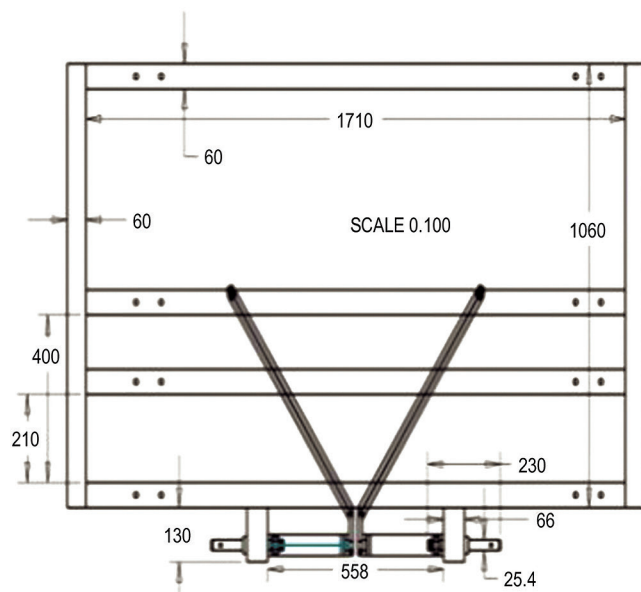


Fig 4 Dimensions of fabricated frame of pulse-planter

Design of chassis

Draft requirement of furrow opener as per Singh *et al.* (2018) for IISR-Lucknow deep furrow opener is specific, as draft multiplying with furrow opener correctional area, where specific draft was 0.06 N/mm^2 . Correctional area for each designed furrow opener was $\frac{1}{2} \times 250 \times 400 = 3000 \text{ mm}^2$. The planter was developed for making two furrows/bed. Thus, three tine was required for making two bed in one pass. The draft requirement experience by the chassis of planter = $(0.06 \times 3000 \times 2) / 9.81 = 612 \text{ kgf}$. Therefore, total draft exerted by each tine of planter is 204 kgf. The CAD drawing in the 'Creo-Parametric 1.0 Designing Software' with dimensions of fabricated frame of planter is shown in Fig 4. The CAD drawing of metering unit and isometric view of computer aided design of pulse-planter is shown in Fig 5.

For optimizing the dimensions of tool-bar of chassis, the draft of 204 kgf was applied on the each furrow opener in the 'Creo-Simulation 1.0 Software' (Fig 4). Maximum von-stresses in different parts of chassis are shown in Fig 8. Maximum von-stress in tool-bar (Part 1) of 1800 mm length is 11.5 MPa (Fig 8a)]. Maximum von-stress in tool-bar of 600 mm length (Parts 2) of chassis is 28 MPa [Fig 8(b)].

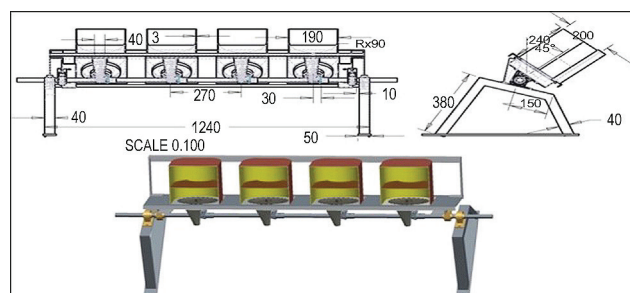


Fig 5 CAD drawing of metering unit of pulse-planter



Maximum von-stress in tool-bar of 400 mm (Parts 3), i.e. tine of chassis is 28 MPa [Fig 8(c)].

In developed SR/DR-RB-PP planter, the seed metering unit consisted of 4 hoppers with one hopper for each individual furrow-opener. Inclined plate metering mechanism of 24-cells with seed tube was attached to each hopper (Fig 5). It consisted of seed tubes, inclined plate, power transmission unit, three point linkage, bearing, furrow-opener ground wheel etc (Fig 6).

Agronomic practices for pigeonpea seed sowing

For pigeonpea 'Var. Pusa-992' sowing, the recommended sowing time is 20th May to mid June with pre-sowing irrigation maintaining row to row spacing of 60–70 cm (70 cm) with average plant to plant spacing of 15–20 cm in single-rows (Kumar *et al.* 2019; Varatharajan *et al.* 2019a, 2019c). The seed @ 12–15 kg/ha is sufficient. Recommended travel speed of tractor with planter is 1.5–2.0 km/h for planting of seeds. Density of pigeonpea seeds and weight of 100-seeds was 804 kg/m^3 , 8.52 g, respectively (Table 1).

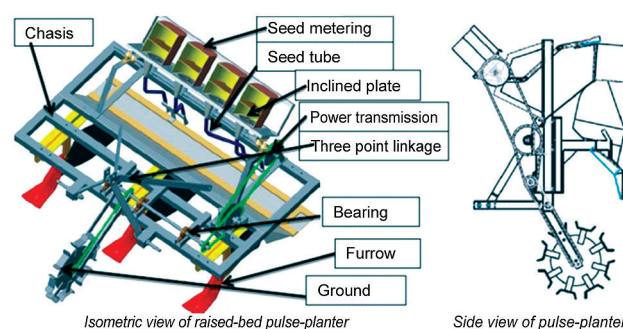


Fig 6 Isometric view of computer aided design of pulse-planter

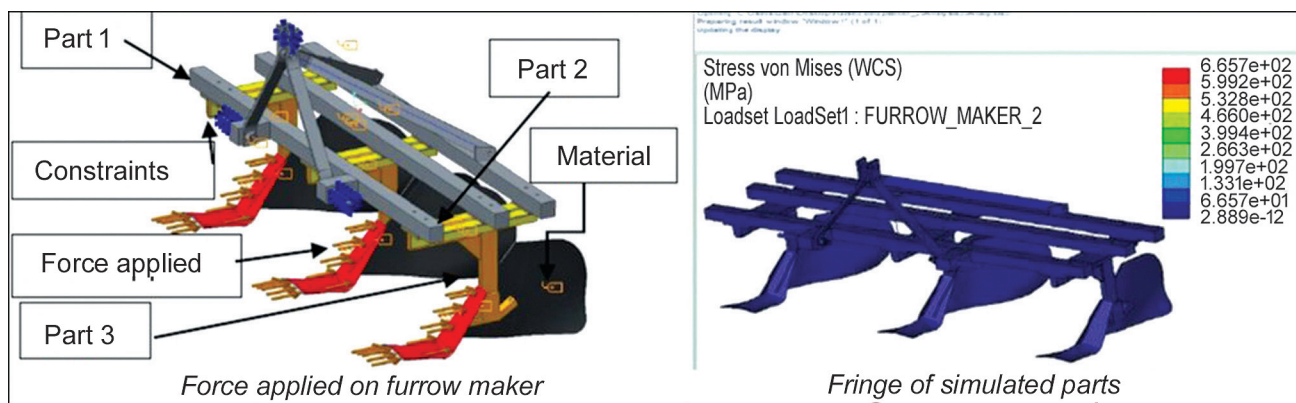
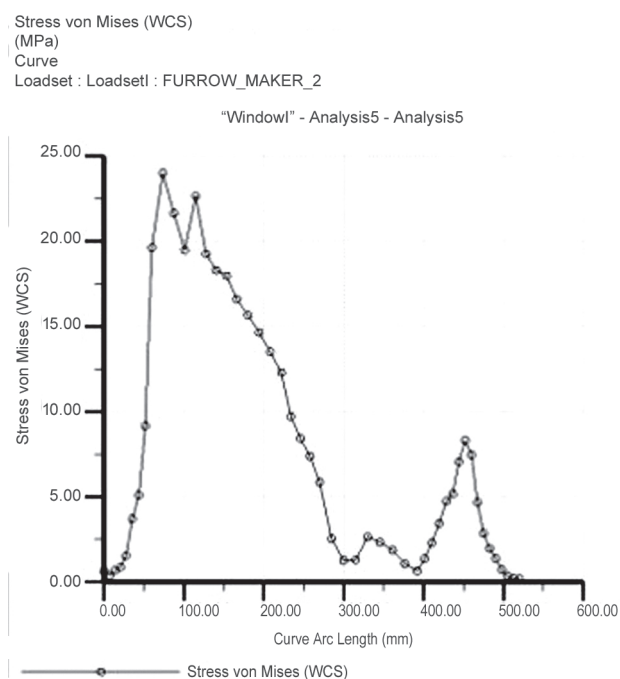
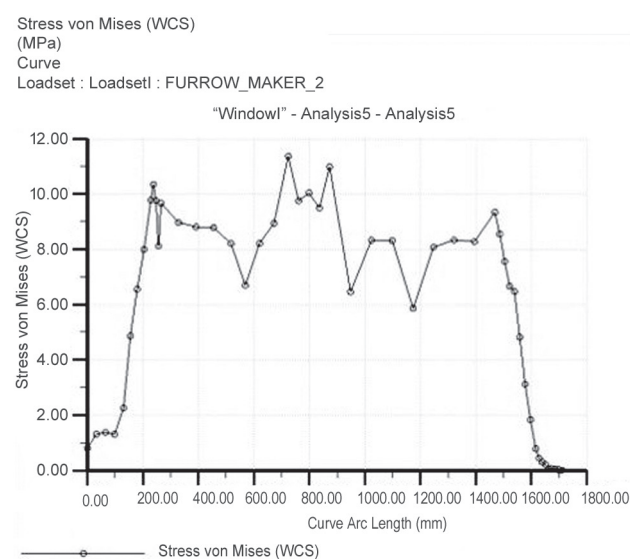


Fig 7 Static-stress analysis simulation in Creo-Simulation 1.0 Software



Field evaluation of single-row/double-row raised-bed pulse-planter for pigeonpea

The developed 'single-row/double-row raised-bed pulse-planter for pigeonpea (SR/DR-RB-PP)' was field tested, modified and validated at Research Farm of Division of Agronomy, ICAR-IARI, New Delhi [28°03' N latitude; 77°15' E longitude; 228.6 m altitude] during 2017–2019 for consecutive three years in a Randomized Block Design replicated 4-times for its physical and agronomic performance as compared with manual sowing of pigeonpea. The field experiment comprised of 6 treatments, viz. T_1 = Flat-Bed Single-Row Manual-Sowing (FB-SR-MS), T_2 = Flat-Bed Double-Row Manual-Sowing (FB-DR-MS), T_3 = Raised-Bed Single-Row Manual-Sowing (RB-SR-MS), T_4 = Raised-Bed Double-Row Manual-Sowing (RB-DR-MS), T_5 = Raised-Bed Single-Row Pulse-Planter Sowing (RB-SR-PPS), and T_6 = Raised-Bed Double-Row Pulse-Planter Sowing (RB-DR-PPS). Both under single-row flat-beds or raised-beds sown manually or through SR/DR-RB-PP, the row to row spacing was 70 cm while plant

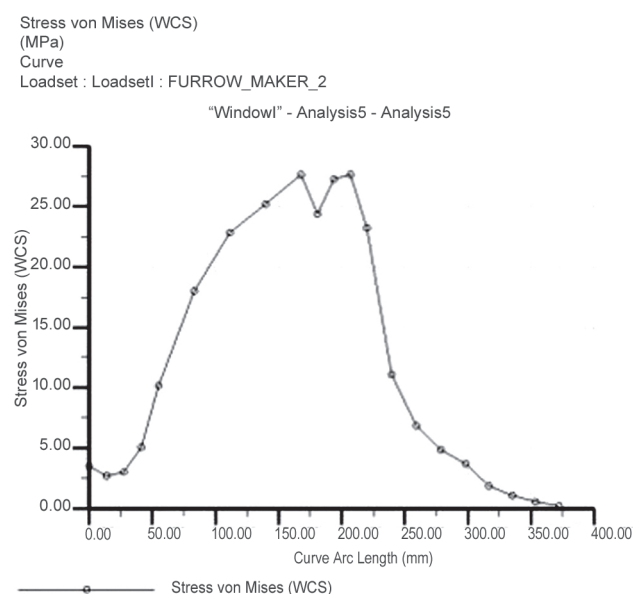


Fig 8 Stress distribution of different parts of chasis in developed SR/DR-RB-PP planter

to plant spacing of 20 cm was maintained. Both under double-row flat-beds or raised-beds sown manually or through SR/DR-RB-PP, the paired-row spacing was 20 cm while adjacent-row to row spacing was 50 cm with average plant to plant spacing of 40 cm both in paired-rows and adjacent-rows. The size of each experimental unit was 4.2 m $\times$ 10 m. Pigeonpea 'Var. Pusa-992' was used as test variety in this study. For crop management, standard package of practices were followed as suggested by Rana *et al.* (2014) and Choudhary *et al.* (2015). After harvesting, the crop was sun-dried, threshed plot-wise, cleaned and grains sun-dried till 10% seed moisture was obtained (Rana *et al.* 2014). The corresponding treatment-wise yield w.r.t. grain, stover, and biological yields (q/ha) as well as harvest index (%) were estimated following standard procedures (Varatharajan *et al.* 2019a, 2019b, 2019c), which were further subjected to statistical analysis (Rana *et al.* 2014).

RESULTS AND DISCUSSION

In this section, the draft exerted by the developed 'single-row/double-row raised-bed pulse-planter for pigeonpea (SR/DR-RB-PP)', the speed of operation, fuel consumption in litre per hour and litre per ha, soil moisture at the time of sowing, average depth of seed placement by the developed SR/DR-RB-PP planter, compaction of seed-bed, time required per ha and per hour, uniformity of seed distribution in seed calibration set-up in laboratory, hardness of furrow opener, field capacity, field efficiency have been discussed thoroughly. Fabricated 'single-row/double-row raised-bed pulse-planter for pigeonpea (SR/DR-RB-PP)' is shown in Fig 9. Raised-bed formed by the developed SR/DR-RB-PP planter is shown in Fig 10. Pigeonpea was sown using SR/DR-RB-PP planter at Research Farm of Division of Agronomy, ICAR-IARI, New Delhi. For sowing the pigeonpea seeds in single-row in each bed, seeds were filled in two hoppers out of four hoppers and end point of two seed tubes was fixed in such a way that seeds were dropped in the middle of raised-bed while maintaining the row spacing of 700 mm (70 cm). For sowing of seeds in

the two rows in each bed, all the four hoppers were filled with seeds. Seeds were allowed to drop from all the seed tubes to the furrow openers.

Draft measurement

Draft of developed SR/DR-RB-PP planter was measured using the 3-point hitch dynamometer. In this dynamometer, three half bridge load cells were attached in all three points connected between planter and tractor. Non linearity, non-repeatability and hysteresis were ± 0.01 , 0.01 and 0.005 of rated output. This dynamometer display has the remotely controlled facility. The average draft for pulling the developed planter was 480 ± 75 kgf. Minimum and maximum drafts during the operation for smooth operation were found 304 and 684 kgf, respectively.

Performance evaluation of SR/DR-RB-PP planter

Field test was done using the New Holland-3630 Turbo-Super Tractor of 55 hp (Fig 10). Developed SR/DR-RB-PP planter was operated at different speeds of operation. Speed of operation was calculated as 50 m length divided by time to cover this 50 m during field-testing. It was observed that 1.5 ± 0.5 km/h is the best speed for operating the developed SR/DR-RB-PP planter (Table 2). Average working width was measured as average of width of three passes of operation, i.e. 1.41 ± 0.065 m. Fuel consumption during the field operation was measured by top-up method, i.e. before the start of operation the fuel tank of tractor was filled fully and after the operation fuel was measured by re-filling the fuel tank again. It was found that average soil moisture at the time of sowing was measured as 21.2 ± 4 % using soil moisture meter. Operated area was measured using 100 m measuring tape. Time of operation and turning time were measured using stopwatch. Actual field capacity of SR/DR-RB-PP planter was measured as actual area covered divided by total time operation of this actual area covered (Table 3). Theoretical field capacity of planter was calculated as average speed of operation multiplying with working width of operation. Field efficiency was calculated as actual field



Fig 9 Fabricated SR/DR-RB-PP planter



Fig 10 Field testing of developed SR/DR-RB-PP planter

Table 2 Field testing of tractor drawn 'SR/DR-RB-PP' pulse-planter.

	Speed of operation (km/h)	Average working width (m)	Fuel (Litre)	Area (ha)	Time (h)	Wheel slip (%)
	1.58	1.425	10.5	0.3528	1.73	8.25
	1.56	1.416	20.1	0.6392	3.24	9.24
	1.78	1.428	21.2	0.6956	3.46	7.56
	1.82	1.427	17.9	0.5804	2.93	8.62
Av. value	1.69	1.424	-	-	-	8.42

Table 3 Performance indicators of tractor-drawn 'SR/DR-RB-PP' pulse-planter.

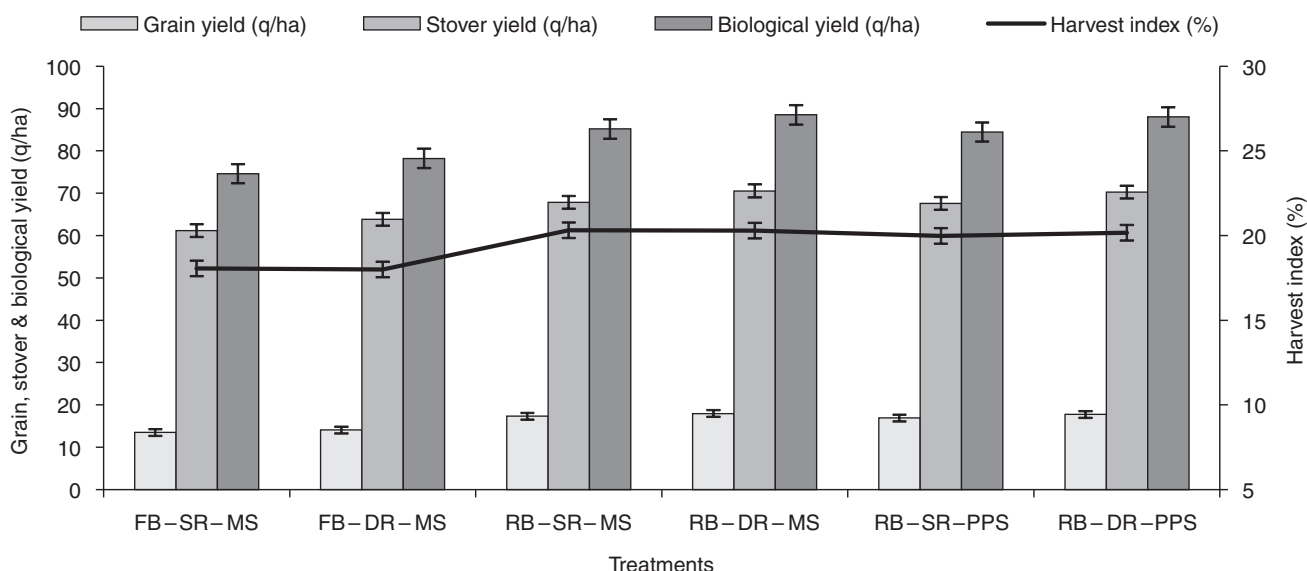
	Actual field capacity (ha/h)	Theoretical field capacity (ha/h)	Field efficiency (%)	Fuel consumption	
				L/h	L/ha
	0.204	0.225	90.575	6.069	29.762
	0.197	0.221	89.311	6.204	31.446
	0.201	0.254	79.092	6.127	30.477
	0.198	0.260	76.272	6.109	30.841
Av. value	0.200	0.240	83.813	6.127	30.632

capacity divided by Theoretical field capacity.

Agronomic performance

The tractor drawn 'single-row/double-row raised-bed pulse-planter for pigeonpea (SR/DR-RB-PP)' was field tested, refined and validated at Research Farm of Division of Agronomy, ICAR-IARI, New Delhi during Kharif 2017–2019 for consecutive three years in a Randomized Block Design. On an average, the germination of seeds with developed SR/DR-RB-PP planter was 89.7% while through manual sowing it was ~90.1%. The bulk density, true density, 100-seed weight, equivalent diameter and sphericity of the pigeonpea seed 'Var. Pusa-992' were computed as 0.804 g/cc, 1.28 g/cc kg/m³, 8.52 g, 4.69 mm and 0.81, respectively. With SR/DR-RB-PP planter sowing, the distribution of seeds per hill was 54% double seed, 38% single seed, 5% triple seed and 3% no seed(s) hill. Overall, germination of seeds, plant growth and yield were significantly better in the plots sown by manually sowing of pigeon pea. The

germination of seeds, plant growth and grain yield was higher in raised-beds over flat-beds both through manual sowing and SR/DR-RB-PP planter sowing. The perusal of data averaged over three years (kharif 2017–2019) in Fig 11 revealed that raised-bed double-row manual-sowing (RB–DR–MS) exhibited significantly highest grain (17.96 q/ha), stover (70.56 q/ha) and biological yield (88.51 q/ha) as well as harvest index (20.29%), however, it remained at par with raised-bed double-row pulse-planter sowing (RB–DR–PPS) w.r.t. grain (17.75 q/ha), stover (70.27 q/ha) and biological yield (88.02 q/ha) as well as harvest index (20.16%). Similarly, raised-bed single-row manual-sowing (RB–SR–MS) exhibited significantly highest grain (17.31 q/ha), stover (67.87 q/ha) and biological yield (85.18 q/ha) as well as harvest index (20.32%), which again remained at par with raised-bed single-row pulse-planter sowing (RB–SR–PPS) w.r.t. grain (16.90 q/ha), stover (67.58 q/ha) and biological yield (84.48 q/ha) as well as harvest index (19.99%).



Note: FB–SR–MS = Flat-Bed Single-Row Manual-Sowing (T₁); FB–DR–MS = Flat-Bed Double-Row Manual-Sowing (T₂); RB–SR–MS = Raised-Bed Single-Row Manual-Sowing (T₃); RB–DR–MS = Raised-Bed Double-Row Manual-Sowing (T₄); RB–SR–PPS = Raised-Bed Single-Row Pulse-Planter Sowing (T₅); and RB–DR–PPS = Raised-Bed Double-Row Pulse-Planter Sowing (T₆).

Fig 11 Comparative performance single-row/double-row flat-bed and raised-bed manual and SR/DR-RB-PP pulse-planter assisted pigeonpea sowing on productivity (q ha⁻¹) and harvest index (%) of pigeonpea (average of three years 2017–2019) (The vertical bars represent LSD_{0.05} values)

On an average, the variation in grain yield under raised-bed double-row manual-sowing (RB-DR-MS) and raised-bed double-row pulse-planter sowing (RB-DR-PPS) was 1.18% while in raised-bed single-row manual-sowing (RB-SR-MS) and raised-bed single-row pulse-planter sowing (RB-SR-PPS) was 2.43% (Fig 11). This indicates that both single-row and double-row raised-bed planting through SR/DR-RB-PP planter is as precise as the manual sowing both in single-row raised-beds and double-row raised-beds (Fig 12). Likewise, the grain yield under raised-bed double-row pulse-planter sowing (RB-DR-PPS) was significantly higher by ~26.1% over flat-bed double-row manual-sowing (FB-DR-MS), while in raised-bed single-row pulse-planter sowing (RB-SR-PPS) it was higher by ~25.4% over flat-bed single-row manual-sowing (FB-SR-MS). This again indicates the superiority of SR/DR-RB-PP pulse-planter over the conventional manual sown pigeonpea in flat-beds both sown in single-rows and double-rows.

The increase in grain yield due to SR/DR-RB-PP pulse-planter over the conventional manual sown pigeonpea mainly stemmed from significant improvement in the harvest index

(about 17.99–18.06 in manual sown single-row/double-row flat-beds and about 19.99–20.16% in SR/DR-RB-PP pulse-planter sown plots). Moreover, raised-bed sowing performed well over flat-beds in terms of seed and stalk yield which might be due to less water stagnation in rainy spells and more moisture conservation in rainless span leading to better crop growth and yield in pigeonpea (Varatharajan *et al.* 2019a, 2019b, 2019c; Rajpoot *et al.* 2016, 2018). The inducement of better growth and more efficiently-functioning root system in raised-beds over flat-beds might have buffered the effects of drought, water stagnation and extreme temperatures (Rajpoot *et al.* 2016, 2018), besides better soil physico-chemical and microbiological properties leading to higher yields in raised-beds (Kushwaha *et al.* 2019; Varatharajan *et al.* 2019a, 2019b, 2019c). Higher grain, stover and biological yield in double-row flat-beds/raised-beds over single-row flat-beds/raised-beds both under manual and SR/DR-RB-PP pulse-planter sowing might be due to better vegetative growth leading and more leaf area index and weed suppression as well (Dass *et al.* 2016; Rajpoot *et al.* 2016, 2018), all of which ultimately

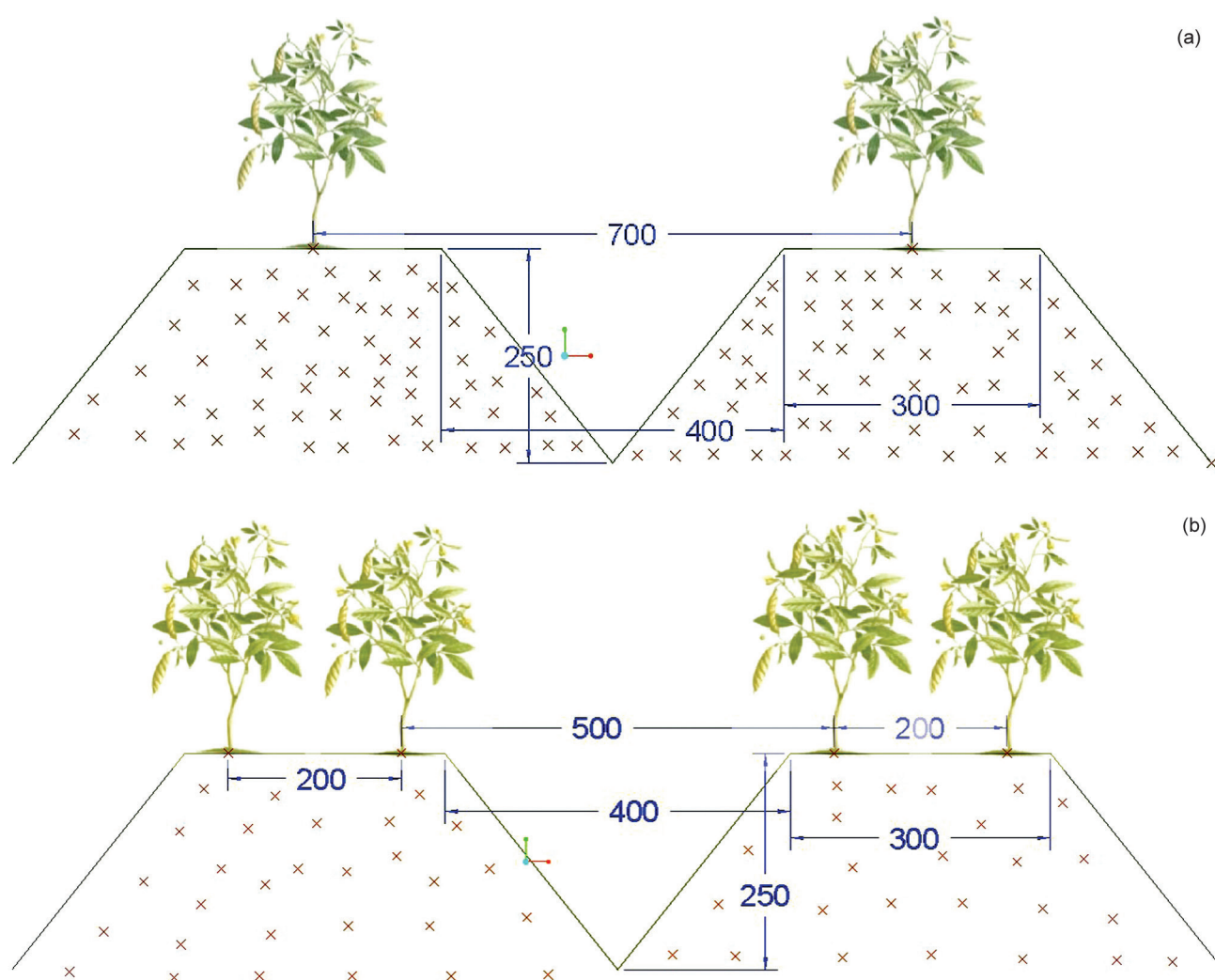


Fig 12 Pictorial view and dimensions of (a) single-row raised-beds and (b) double-row raised-beds using SR/DR-RB-PP planter (All dimensions in mm).

led to more light interception, more photosynthesis and attained higher grain and stover yield (Varatharajan *et al.* 2019c). Overall, raised-bed double-row pulse-planter sowing (RB-DR-PPS) and raised-bed double-row manual-sowing (RB-DR-MS) equally remained higher yielder w.r.t. grain and stover yield in pigeonpea followed by RB-SR-MS, RB-SR-PPS, FB-DR-MS and FB-SR-MS, respectively.

Conclusion

Seed metering unit and seed box of tractor drawn 'single-row/double-row raised-bed pulse-planter for pigeonpea (SR/DR-RB-PP)' was designed based on pigeonpea seed properties. Seed distribution in developed metering unit was found as 54% double seed, 38% single seed, 5% triple seed and 3% no seed(s) hill. Recommended sowing travel speed of tractor with SR/DR-RB-PP planter was 1.5–2.0 km/h. Field capacity and field efficiency of the tractor drawn 'SR/DR-RB-PP pulse-planter' was 0.2 ha/h and 83.8%, respectively. SR/DR-RB-PP planter worked satisfactory during field test. It has the capability to make two raised-beds for pigeonpea seed sowing in one pass in prepared field. It has the flexible capability to sow pigeonpea seeds in single- and double-rows in each raised-bed. Field performance of SR/DR-RB-PP pulse-planter was compared with both flat-bed and raised-bed manual sowing. On an average, the variation in grain yield under raised-bed double-row manual-sowing (RB-DR-MS) and raised-bed double-row pulse-planter sowing (RB-DR-PPS) was 1.18% while in raised-bed single-row manual-sowing (RB-SR-MS) and raised-bed single-row pulse-planter sowing (RB-SR-PPS) was 2.43%. The grain, stover and biological yield followed the trend of RB-DR-MS>RB-DR-PPS>RB-SR-MS>RB-SR-PPS>FB-DR-MS>FB-SR-MS, respectively. Overall, raised-bed double-row pulse-planter sowing (RB-DR-PPS) and raised-bed double-row manual-sowing (RB-DR-MS) equally remained higher yielders' w.r.t. grain and stover yield in pigeonpea. Thus, 'SR/DR-RB-PP pulse-planter' holds great feasibility in mechanization and precision pigeonpea sowing both in single-row and double-row raised-beds for improving the pigeonpea acreage and productivity in the country. The 'SR/DR-RB-PP pulse-planter' vis-a-vis the adoption and spread of single-row and double-row raised-bed technology would ultimately lead to drudgery reduction, time saving, and higher farm productivity and profitability.

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