Design and evaluation of a pneumatic metering mechanism for power tiller operated precision planter

Sandip Mandal[1,]*, G. V. Prasanna Kumar[2], Hetal Tanna[3] and Arvind Kumar[4]

[1]Central Institute of Agricultural Engineering, Nabibagh, Bhopal 462 038, India
[2]Department of Agricultural Engineering, Triguna Sen School of Technology, Silchar 788 001, India
[3]College of Agricultural Engineering and Technology, Anand Agricultural University, Godhra 389 001, India
[4]ICAR Research Complex for NEH Region, Umiam 793 103, India

Power tiller is the most common prime mover in medium and marginal farms due to its light weight, compact design and low cost. Many attachments for power tiller have been developed except for precision pneumatic planter which is necessary to plant irregular, small and expensive seeds. In the present work, a pneumatic seed metering mechanism was designed for the power tiller operated 3-row precision planter. It was tested for planting soybean, pigeon pea and corn seeds at 20 cm spacing. The best design and operating parameters of the modular seed metering device were identified by conducting experiments on the sticky belt test stand considering various performance indices on the basis of pareto dominance criterion. The seed metering disc having 8 holes of 3.5 mm diameter on pitch circle diameter of 116 mm and operated at 0.11 ms^{-1} peripheral speed and 6 kPa suction were found to be the best combination of design and operating parameters for the precise metering of seeds. More than 67% of the seeds got distributed in the range of 15–20 cm spacing.

Keywords: Pareto dominance, pneumatic seed metering, power tiller, precision planter.

COMPARED to broadcasting and drilling of seeds, placing seeds in well prepared soil at equal spacing within rows ensures uniform root growth, better crop management, reduction in cost of production and increase in crop yield[1,2]. The practice of sowing single seed at equal distance in rows is called precision planting and the machine used for precision planting is called precision planter[3]. Precision planters reduce the requirement of seeds up to 90% compared to drilling which also eliminate the requirement of thinning[4,5]. Mechanical seed metering devices such as, horizontal plate, vertical plate and inclined plate with cells on the periphery have been developed for precision planting of seeds. But use of these mechanical devices causes excessive seed damage and multiple pick-up of seeds due to centripetal forces associated with higher speed[6]. Further, these seed metering devices have failed to effectively handle irregular shaped seeds. In addition, use of vertical and inclined plates for seed metering has resulted in missed plantings due to dislodging of seeds from the cells of the plate. Pneumatic seed metering devices that were developed, can meter irregular shaped seeds, besides spherical seeds[3].

The main component of the pneumatic seed metering device is the modular disc which is mounted vertically. It has seed holes of size less than the size of the seed in its periphery. Seeds are held in the seed hole with the help of vacuum created on one side of the disc using an aspirator blower. As the disc rotates, it picks up seeds from seed reservoir due to vacuum. To release the seed from the seed disc, vacuum is blocked when seed holes reach a point above the seed tube. At this point, vacuum force is absent and due to gravity the seed falls into the seed delivery tube. Accurate seed spacing is affected by the size of seed, design of the modular disc, vacuum pressure and operating parameters[3]. Pneumatic seed metering devices are considered as precision metering mechanism due to high precision in seed placement with minimal seed damage, good control and adjustment, high uniformity in intra-row seed spacings and applicability in wide range of seed types[2,4,7,8].

In many Asian countries with rice, peanut, pigeon pea, soybean, corn and potato as major crops in medium and small farms, power tiller or 2-wheel walk-behind type hand tractor, rather than large tractor has gained popularity[9,10]. Power tiller is primarily used for tillage with rotary tiller, puddling of paddy fields, and shallow tillage to remove weeds. It is powered by a 6.75–10.58 kW diesel engine, and is used along with matching implements for multifarious farm applications such as ploughing, planting, reaping, threshing, winnowing, pumping irrigation water and haulage of farm produce[11,12]. Due to its light weight and easy control, it is the most preferred source of farm power for terraced cultivation in many countries.

Power tiller operated planters with horizontal plate, inclined plate and cup feed type devices have been developed for planting potato, peanut, pigeon pea, maize and

*For correspondence. (e-mail: smandal2604@gmail.com)

rice[12,13]. As the importance of pneumatic planter in the improvement of quality of planting, plant growth and grain yield requires no further emphasis, there is a genuine need to develop a power tiller operated pneumatic planter for small farms, small holdings and terraced cultivation.

Pneumatic planters operated by farm tractors with aspirator blower powered by the power take-off (PTO) of the tractor have been developed[3]. The rotating modular seed metering disc of the tractor-operated precision planter is not suitable for power tiller-operated pneumatic planter due to space constraint in the power tiller and weight of the modular unit. Development of a compact modular unit to match the space available in the power tiller necessitates identification of the best levels of operating parameters for the modular unit. In the present study, a pneumatic metering mechanism was developed for a power tiller operated precision planter, and its performance was evaluated for soybean, pigeon pea and corn seeds.

Materials and methods

Design of pneumatic seed metering mechanism

A pneumatic seed metering mechanism was developed along the same lines as that of Singh *et al.*[3], but with some modifications. The aim was to reduce the diameter of seed metering disc so that the whole modular unit could be accommodated in the space available behind the gearbox of the power tiller. Therefore, a disc (diameter 150 mm, thickness 5 mm) was used as the seed metering disc in this study. Diameter of ground wheel of the planter, velocity ratio between the drive shaft of seed metering disc and ground wheel shaft, and the number of seed holes and pitch circle diameter for the seed holes on seed metering disc were decided based on the following relationships

$$N_g = \frac{1000}{60} \times \frac{V}{\pi D_g}, \tag{1}$$

$$V_d = \frac{\pi D_g \, N_g}{S} \times \frac{\pi D_d}{60 n_h}, \tag{2}$$

where D_g and N_g refer to diameter and rotary speed of ground wheel of the planter in metres (m) and rpm respectively; V refers to the forward speed of power tiller in km h^{-1}; D_d and V_d refer to pitch circle diameter of seed holes and peripheral speed of the disc at the pitch circle of the seed holes in m and m s^{-1} respectively; S the seed spacing in rows in m; and n_h is the number of seed holes on seed metering disc. The two equations indicate that the appropriate values for D_g, D_d and n_h have to be selected such that the values of V, N_g, the number of seeds to be metered per unit time and V_d are within practical range for the effective working of seed metering device.

Considering the forward speed of power tiller in the range of 1.32–2.1 km h^{-1} (average speed in second low and third low gear) and diameter of ground wheel of the planter as 0.4 m, rotary speed of ground wheel was obtained in the range of 17–28 rpm. For seed spacing of 0.2 m, it was found that 110–176 seeds have to be metered in one minute. By providing 8 seed holes on the disc, the disc has to be operated in the range 13–22 rpm. Taking pitch circle diameter of seed holes as 116 mm, peripheral speed of the disc at the pitch circle of seed holes was found to be in the range 0.085–0.133 m s^{-1}. This is within the range of peripheral speed of seed metering disc (0.05–0.19 m s^{-1}) recommended by other studies[14,15]. Hence, ground wheel of 0.4 m diameter and seed metering disc with 8 seed holes on 116 mm pitch circle diameter were used to develop the pneumatic seed metering device. In this setting, the required velocity ratio between the drive shaft of the seed metering disc and ground wheel shaft was 1.3. The full range of recommended peripheral speed of the seed metering disc can be obtained by using chain drive.

The seed metering disc rotates over a vacuum retaining plate which has a circular vacuum channel. The vacuum retaining plate and housing of the seed metering system were made of aluminum. They were cast in one piece to reduce the complexity of assembly and maintenance. A vacuum channel of 8 mm × 8 mm cross-section was engraved in the casted piece to create vacuum on one side of the metering disc (Figure 1). Material of the dimension

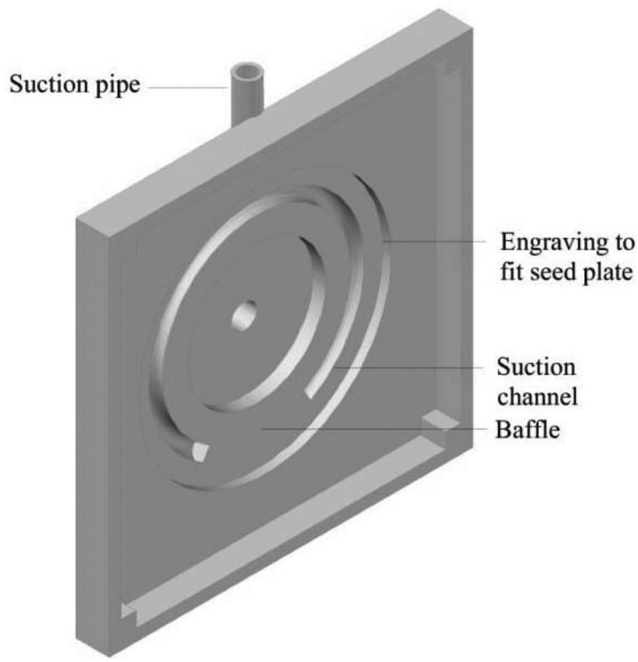

Figure 1. Modular type pneumatic seed metering device.

equal to the seed metering disc was removed from the casted housing to fit the metering disc perfectly to avoid air leakage. The seed metering disc was vertically mounted on a shaft driven by chain and sprockets, and was held pressed against the housing using a spring. The vacuum channel was blocked with a baffle at the point of seed release to interrupt the suction and to allow the seed to be released from the disc. The other side of the housing was covered by a metal sheet which also supported the seed box. Suction required for holding the seeds against holes was generated by a centrifugal pump with backward curved fins. The pump was connected with the metering unit using a suction hose. The pump was powered from the belt pulley shaft of the power tiller at the required speed to generate sufficient vacuum to hold the seeds. The diameter of seed holes was decided based on ≤50% of geometric mean of seeds. The geometric mean of seeds was determined using the following formula

$$d_g = (lht)^{1/3}, \tag{3}$$

where l, h and t are the length, height and thickness of seed in mm. The holes were made in conical shape with an included angle of 120° as suggested by Singh *et al.*[3].

Testing of pneumatic seed metering system

The seed placement accuracy of a vacuum seed metering mechanism is affected by the design and operating parameters such as disc hole size and angle, metering disc speed and suction pressure[2,3,7,13,14,16]. The pneumatic seed metering system was tested to identify the best combination of suction pressure for single seed pickup, seed hole diameter and disc speed to achieve uniform distribution of seeds.

The seed metering system was tested on a sticky belt test stand (Figure 2). The length of the belt was 15 m and supported on two pulleys. Pulleys were driven by the wheel axle shaft of a power tiller which was mounted on a stationary jack. To simulate the field conditions, the sticky belt was rolled below the seed metering device at the same operational speed as that of the power tiller[3,5,8]. The vertical gap between seed delivery port and sticky belt was kept at 25 mm. Seed metering disc was driven by the same wheel axle shaft of the jack-mounted power tiller that operated the sticky belt using a chain drive. The velocity ratio of chain drive was varied to acquire the required peripheral speed of seed disc. The suction for the metering disc was created by a centrifugal pump driven by an electric motor. Suction can be varied by varying the speed of the pump which was done by a variable frequency drive attached with the motor. A vacuum gauge with least count of 0.1 kPa was used to measure vacuum pressure. Rotational speed of metering shaft and speed of the sticky belt were measured using a digital tachometer.

The design and operating parameters (independent parameters) chosen for the test were seed hole diameter and peripheral speed of metering disc and suction pressure. The levels of the independent parameters for the test were selected based on practical considerations, preliminary trials and range of each parameter considered by past researchers. High quality seeds of soybean (variety, JS 335), pigeon pea (variety, UPAS 120) and corn (variety, RCM 1-1) were chosen for the test. Dimensional properties of seeds such as length, width, thickness and frontal area were measured by image processing method[17] which are presented in Table 1. The geometric mean of soybean, pigeon pea and corn seed was found to be 6.96, 6.28 and 7.25 mm respectively. Therefore, in this study, three seed metering discs having seed hole sizes of 2.5, 3.5 and 4.0 mm were chosen. Operating speed of sticky belt was chosen corresponding to forward speed of power tiller at second low (1.32 km h^{-1} at 50% throttle) and third low (2.1 km h^{-1} at 50% throttle) gears. Singh *et al.*[3] studied the performance of a pneumatic seed metering device for cotton seeds at the peripheral speed of the disc in the range 0.34–0.44 m s^{-1} with seed holes of size ≤50% of the geometric mean diameter of the seeds. The seed spacing uniformity of cotton seeds was studied[14] at the speed of seed metering disc in the range 0.05–0.19 m s^{-1}, with 0.12 m s^{-1} as the central value. In this study, two levels of peripheral speeds (0.11 and 0.18 m s^{-1}) of the seed disc at the pitch circle of the seed holes were selected to achieve a seed spacing of 20 cm. Karayel *et al.*[7] estimated the negative pressure (suction) for picking of single seed of various crops. They predicted vacuum

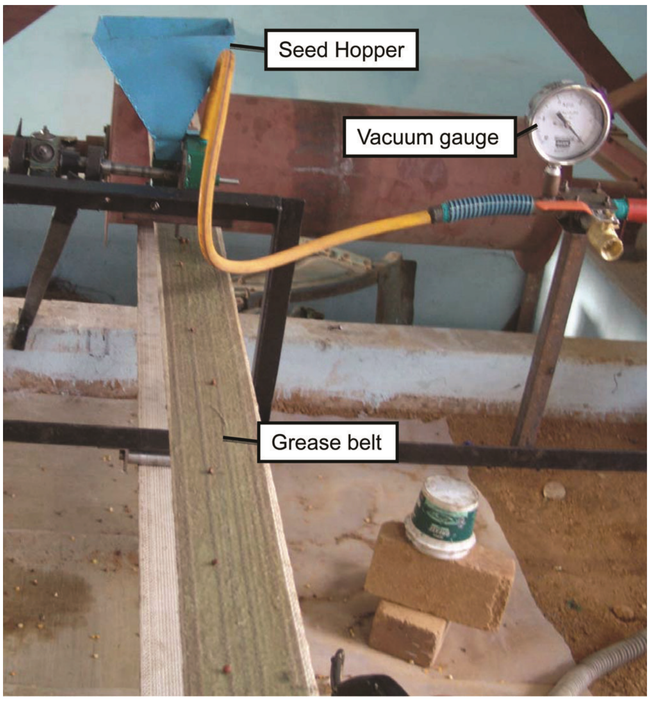

Figure 2. Laboratory set up for testing pneumatic seed metering unit.

Table 1. Dimension of corn, soybean and pigeon pea seeds selected for the experiment

	Soybean			Pigeon pea			Corn		
	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
Length (mm)	7.66	6.5–9.3	0.6	6.99	6.2–6.7	0.3	9.79	8.7–11.0	0.5
Width (mm)	6.55	5.8–7.6	0.4	5.86	5.2–6.7	0.3	8.87	6.5–9.8	0.7
Thickness (mm)	6.52	5.3–7.3	0.4	5.77	5.2–6.6	0.3	4.55	3.2–7.0	1.1
Geometric mean diameter (mm)	6.96	6.3–7.7	0.5	6.28	5.7–6.6	0.2	7.25	6.3–8.7	0.4
Frontal area (mm^2)	39.49	29.9–53.2	5.4	32.08	27.0–38.9	2.6	67.56	49.9–83.1	7.8
1000 seed mass (g)	136.6	134.5–139.0	2.26	130.8	123.6–139.9	8.2	239.3	231.7–243.8	6.6

pressure of 4 kPa for maize, 3 kPa for soybean, 2.5 kPa for watermelon, 2 kPa for cucumber and sugar beet, and 1.5 kPa for onion seeds. Therefore, in this study, vacuum pressures of 3.0, 4.5 and 6.0 kPa were chosen for the test. The vacuum pump was operated at 3000, 4000 and 4600 RPM to obtain the vacuum pressure of 3.0, 4.5 and 6.0 kPa respectively.

The sticky belt was prepared by smearing grease on the top surface of the belt to capture the seeds and prevent them from bouncing or rolling. The required vacuum pressure was generated by the vacuum pump at a speed corresponding to 50% engine throttle of the power tiller. The sticky belt and seed metering disc were operated according to the levels of independent parameters. The seed spacing on the sticky belt was measured using a metric tape[5].

A full factorial design of experiment with three factors was chosen. Each test run was carried out three times and the results analysed using statistical software (SAS, Ver 9.3). The effect of independent parameters was assessed based on performance indices (dependent parameters), which were miss index, multiple index, mean seed spacing, quality of feed index (QFI) and precision in spacing. Miss index is calculated as the percentage of spacing greater than 1.5 times of set spacing and multiple index is the percentage of spacing less than or equal to half of set spacing. The QFI is calculated as the percentage of spacing that is more than half but less than 1.5 times the set spacing. The variability in seed spacing resulting from both multiples and misses is expressed by precision in spacing[3]. The dependent parameters were determined as follows

$$\text{Miss index} = \frac{n_1}{N}, \tag{4}$$

$$\text{Multiple index} = \frac{n_2}{N}, \tag{5}$$

$$\text{Mean seed spacing} = \frac{1}{n}\sum_{i=1}^{n} x_i, \tag{6}$$

$$\text{Quality of feed index} = 100 - (\text{miss index} + \text{multiple index}), \tag{7}$$

$$\text{Precision in spacing} = \frac{S_d}{S}, \tag{8}$$

where x is the spacing between seeds (in mm), S the set spacing (in mm), n_1 the number of spacings $>1.5S$, n_2 the number of spacings $\leq 0.5S$, N the total number of spacings measured, S_d is the standard deviation of the spacings more than or half but less than equal to 1.5 times the set spacing S (in mm)[5]. The best combination of independent parameters was selected based on the fact that these should result in high QFI and low miss and multiple indices, and low precision in spacing.

Identification of the best combination of design and operating parameters

Pareto dominance criterion was used to identify the best combination of design and operating parameters. In this technique, the best combination of design and operating parameters (solution) is identified from the combinations of parameters based on the desired maximum or minimum values of performance indices (objective function values). This technique involves straightforward comparison of the performance indices for each combination of design and operating parameters, and arranging the combination of parameters based on the definition of dominance. The combination of design and operating parameters that is dominated by no other combination of parameters is considered as the best combination of parameters for the design and development.

In a minimization problem of m performance indices, a combination of design and operating parameters x dominates another combination of design and operating parameters y is defined by

$$x \prec y \mid \forall_i : f_i(x) \leq f_i(y) \quad \text{and} \quad \exists_j : f_j(x) < f_i(y), \tag{9}$$

where $f_i(x)$ and $f_i(y)$ are the values of the ith performance index corresponding to x and y respectively. The meaning of the above definition is that all the performance indices corresponding to the combination of design and operating parameters corresponding to $x \leq y$, and at least one performance index whose value for x is smaller than that for y. The two are said to be non-dominated if x does not dominate y and vice versa. A set of non-dominated solutions is termed as non-dominated front[15].

Procedure for non-dominated sorting

In the present study, miss index, multiple index and the precision in spacing have to be minimized, whereas QFI has to be maximized. Therefore, to convert this into a minimization problem of all the performance indices, reciprocal of QFI was taken. Steps involved in non-dominated sorting are given as: (i) One individual combination of design and operating parameters (p) was taken up. (ii) This combination of design and operating parameters was compared with other combinations of design and operating parameters. As per the definition of Pareto dominance, a set (S_p) of the combination of design and operating parameters in which p dominated was generated. The number of combinations of design and operating parameters that dominated this combination was also noted. (iii) Steps (i) and (ii) were repeated for each individual combination of design and operating parameters. (iv) The non-dominated front (F_1) was developed with combination of design and operating parameters that was dominated by none. The front F_1 was stored.

Any combination of design and operating parameters in the front F_1 containing the speed of metering disc, suction and hole size can be selected as the best combination of design and operating parameters.

Results and discussion

Effect of design and operating parameters on performance indices

Variations in performance parameters with each independent parameter were plotted (Figure 3). The analysis of variance of the QFI, miss and multiple index, and precision in spacing are presented in Tables 2–4.

It is evident from Table 2 that precision in seed spacing was significantly affected by suction and miss index, by interaction of metering disc speed and suction. The speed of metering disc had the highest influence on QFI and multiple index in case of soybean seeds. At the disc speed of 0.11 m s^{-1}, QFI was significantly higher and multiple index was significantly lower than at the disc speed of 0.18 m s^{-1} as shown in Figure 3. The combination of 0.11 m s^{-1} disc speed and 4.5 kPa suction resulted in significantly higher QFI and lower miss and multiple indices. The spacing had significantly lower variation at a suction of 4.5 kPa. The combination of 0.11 m s^{-1} disc speed and 3.5 mm hole size increased the QFI and reduced the multiple index. The suction of 4.5 kPa for soybean seeds was higher than that reported by Karayel *et al.*[7]. The hole diameter of 3.5 mm gave the hole to seed size ratio of 0.502, and Karayel *et al.*[7] found the hole to seed size ratio of 0.505 to be most suitable for metering of soybean seeds.

For metering of pigeon pea seeds, miss index was significantly affected by the main and interaction effects of the independent parameters (Table 3). Multiple index was highly influenced by suction and hole size. The speed of metering disc and suction significantly affected QFI. The combination of 0.11 m s^{-1} metering disc speed, 4.5 kPa suction and 4 mm hole diameter resulted in significantly lower miss index. The main and interaction effects of the speed of the metering disc and hole size, and interaction of suction and hole size affected the precision in spacing. The metering disc speed of 0.11 m s^{-1} increased the QFI and reduced the variation in seed spacing (Figure 3). The suction of 3 kPa significantly reduced multiple index and increased QFI. Multiple index was also low for the hole diameter of less than 3.5 mm.

The main and interaction effects of all the independent parameters significantly affected the miss index for corn seeds (Table 4). The suction affected QFI, and the hole size significantly affected QFI and precision in spacing. The lowest miss index was observed in the combination of 0.11 m s^{-1} metering disc speed, 6 kPa suction and 4 mm diameter of hole. The suction of 6 kPa resulted in significantly higher QFI (Figure 3). The hole diameter of 4 mm increased the QFI, and hole diameter of 3.5 mm decreased the variation in spacing. The values of miss index observed were higher for corn seeds compared to other seeds. This might be due to the irregular shape of seeds. The metering disc speed of 0.11 m s^{-1} is lower than that reported by Barut and Ozmerzi[18] for corn seed at the suction of 4 kPa. Therefore, it seems better to increase the number of holes in seed plate instead of increasing the disc speed for the close planting of seeds. The suction requirement of 6 kPa was higher than that reported by Karayel *et al.*[7]. This hole size of 3.5–4.0 mm gives the hole to seed size ratio of 0.48–0.55, which is also higher than that reported by Karayel *et al.*[7].

Overall, no single combination of suction, metering disc speed and hole size (design and operating parameters) resulted in the occurrence of high QFI, low miss and multiple indices and low variation in spacing at a time. In this situation, a certain level of trade-off among all performance indices is represented by the best combination of design and operating parameters. The set containing all the trade-off design and operating parameters is called the Pareto front[19], and the set of parameters on the Pareto front are also called non-dominated set. Therefore, selecting a best combination of design and operating parameters refers to obtaining a subset of the combination of parameters on the Pareto front instead of getting the best combination for each performance index.

Best combination of design and operating parameters

The non-dominated set of combination of design and operating parameters of the pneumatic seed metering device for metering of soybean, pigeon pea and corn

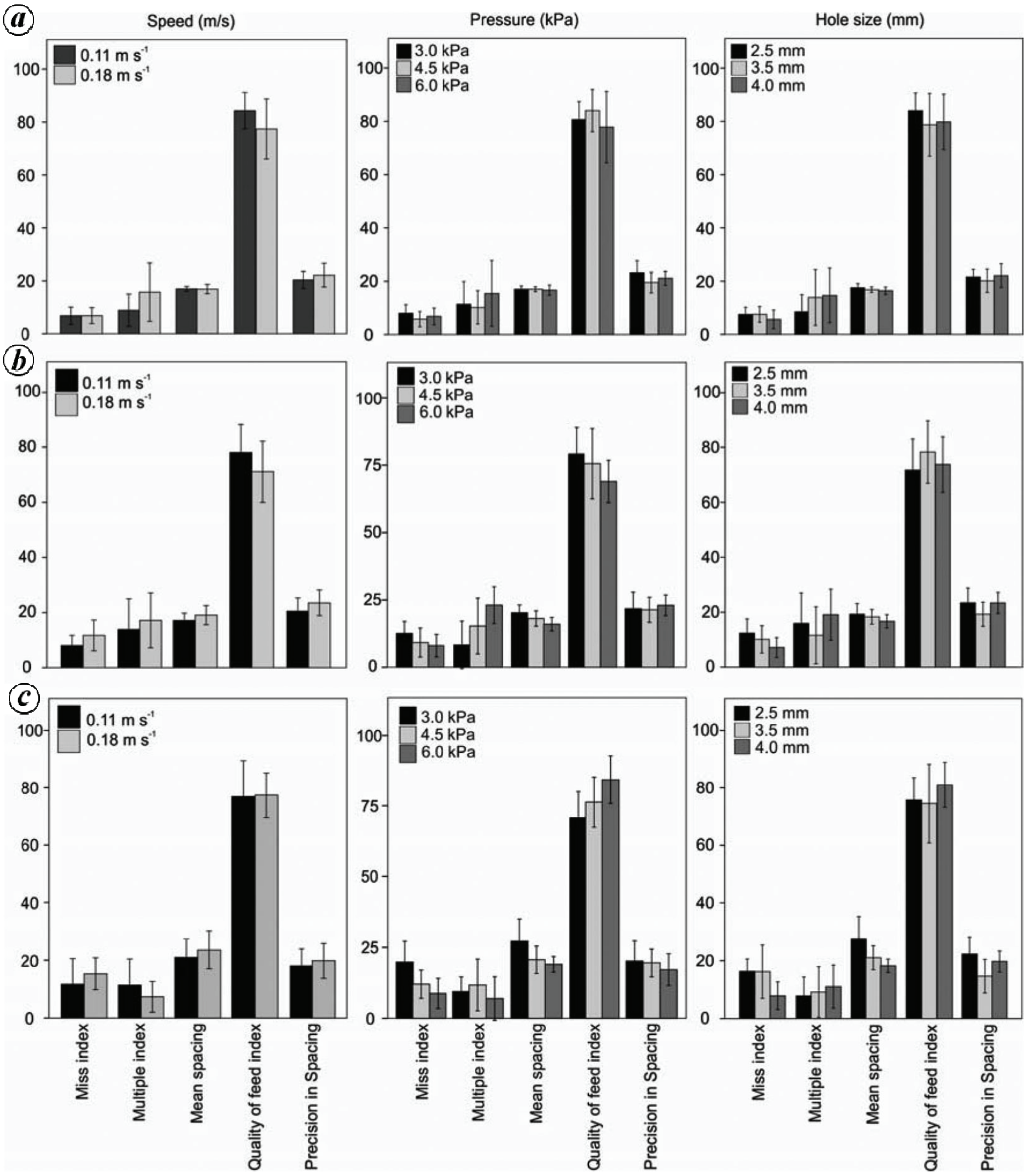

Figure 3. Variation in performance indices of the pneumatic metering device for (***a***) soybean, (***b***) pigeon pea and (***c***) corn seeds at various levels of independent parameters (unit of all indices is % and of mean spacing is cm).

seeds is shown in Table 5. Among the 18 combinations of design and operating parameters for soybean seeds, only 4 combinations of parameters were found to be non-dominated. A close look at those indicates that the first combination of parameters had the lowest value of precision in spacing, the second had the lowest miss index, and the third had the lowest multiple index and highest QFI. The fourth combination of parameters had better miss index than the first, better multiple index and QFI than the first and second and better precision than the third combination of parameters. Hence, these four combinations of parameters are non-dominated. At least one of these four combinations of parameters had all values of performance indices better than corresponding values for other combinations of parameters. Therefore, other combinations of parameters are not shown in Table 5.

For pigeon pea seeds, the first combination of parameters had the lowest value of multiple index and precision in spacing, and highest value of QFI, and the third combination of parameters had the lowest value of miss index. The second combination of parameters had a better miss index than the first and better precision than the third combination of parameters. The fourth combination of parameters had a better miss index than the first and second, and better precision than the third combination of parameters. The fifth combination of parameters had a better miss index than the first, second and fourth, and better in all other indices than the third combination of

Table 2. Analysis of variance of the performance parameters of the pneumatic seed metering device for soybean seeds

		Miss index		Multiple index		QFI		Precision in spacing	
Parameters*	d*f*	mss	*F*	mss	*F*	mss	*F*	mss	*F*
M	1	0.10	0.02	634.17	12.79**	649.97	11.85**	43.72	3.55
P	2	21.72	3.82*	135.71	2.74	174.35	3.18	63.10	5.12**
H	2	21.40	3.76*	202.41	4.08*	144.71	2.64	18.41	1.49
M × P	2	69.76	12.26**	308.86	6.23**	375.97	6.86**	26.04	2.11
M × H	2	16.02	2.81	230.35	4.65*	306.45	5.59**	17.52	1.42
P × H	4	9.72	1.71	76.63	1.55	111.43	2.03	16.73	1.36
M × P × H	4	5.49	0.96	69.09	1.39	42.69	0.78	7.92	0.64
Error	16	5.69		49.58		54.85		12.32	
Total	54								

*M, P, H indicate metering speed (m s^{-1}), suction pressure (kPa) and hole size (mm) respectively.

Table 3. Analysis of variance of the performance parameters of the pneumatic seed metering device for pigeon pea seeds

		Miss index		Multiple index		QFI		Precision in spacing	
Parameters*	d*f*	mss	*F*	mss	*F*	mss	*F*	mss	*F*
M	1	179.72	24.29**	146.81	2.27	651.40	8.26**	120.79	11.89**
P	2	101.23	13.68**	980.91	15.19**	482.04	6.11**	13.30	1.31
H	2	123.55	16.70**	254.81	3.95*	205.64	2.61	103.43	10.18**
M × P	2	5.64	0.76	98.25	1.52	94.86	1.20	5.66	0.56
M × H	2	51.81	7.00**	124.99	1.94	21.06	0.27	105.07	10.34**
P × H	4	15.34	2.07	84.69	1.31	159.14	2.02	73.69	7.25**
M × P × H	4	66.07	8.93**	43.39	0.67	200.35	2.54	12.02	1.18
Error	16	7.40		64.60		78.84		10.16	
Total	54								

*M, P, H indicate metering speed (m s^{-1}), suction pressure (kPa) and hole size (mm) respectively.

Table 4. Analysis of variance of the performance parameters of the pneumatic seed metering device for corn seeds

		Miss index		Multiple index		QFI		Precision in spacing	
Parameters*	d*f*	mss	*F*	mss	*F*	mss	*F*	mss	*F*
M	1	176.17	40.95**	225.83	3.87	3.08	0.05	42.14	1.67
P	2	575.93	133.86**	102.01	1.75	831.81	12.92**	44.52	1.76
H	2	423.24	98.37**	45.26	0.78	215.32	3.35*	273.09	10.79**
M × P	2	72.20	16.78**	23.13	0.40	53.18	0.83	27.60	1.09
M × H	2	15.75	3.66*	23.98	0.41	2.95	0.05	14.70	0.58
P × H	4	69.89	16.24**	22.70	0.39	118.66	1.84	25.23	0.10
M × P × H	4	51.66	12.01**	65.52	1.12	171.67	2.67	35.97	1.42
Error	16	4.30		58.42		64.37		25.30	
Total	54								

*M, P, H indicate metering speed (m s^{-1}), suction pressure (kPa) and hole size (mm) respectively.

parameters. The sixth combination of parameters had better miss index than the first, second and fourth, and better precision than the third and fifth combination of parameters. All other combinations of parameters had all four values of performance indices poorer than one of these six combinations of parameters. Therefore, these six combinations of parameters are shown in Table 5, while the rest were discarded.

For corn seeds, miss index was lowest for the third combination of parameters, multiple index was lowest for the fourth, QFI was highest for the sixth and precision was lowest for the fifth combination of parameters. The second combination of parameters had a better miss index than the third, fourth and fifth combination of parameters, and better in all other indices than the third combination of parameters. The first combination of parameters had a better miss index than the fourth and fifth, better multiple index than the second, third, fifth and sixth, better QFI than the third, fourth and fifth, and better precision than the fourth combination of parameters. All other

Table 5. Non-dominated set of design and operating parameters of the pneumatic seed metering device

Design and operating parameters			Performance indices			
Speed of metering disc (m s^{-1})	Suction (kPa)	Hole diameter (mm)	Miss index (%)	Multiple index (%)	QFI (%)	Precision in spacing
Soybean						
0.11	4.5	3.5	6.60	10.02	83.39	16.81
0.11	4.5	4.0	2.95	12.02	85.03	19.45
0.11	*6.0*	*3.5*	*4.23*	*2.95*	*92.82*	*19.25*
0.18	4.5	4.0	4.44	5.83	89.72	18.44
Pigeon pea						
0.11	3.0	3.5	10.74	0.00	89.26	13.09
0.11	4.5	2.5	8.62	16.88	74.50	16.94
0.11	4.5	4.0	3.04	13.46	83.51	24.65
0.11	*6.0*	*3.5*	*7.44*	*18.33*	*74.22*	*20.67*
0.18	4.5	3.5	3.27	11.80	84.93	20.91
0.18	6.0	4.0	4.06	24.39	71.56	20.77
Corn						
0.11	6.0	2.5	10.02	3.25	86.73	20.67
0.11	*6.0*	*3.5*	*4.70*	*5.80*	*89.50*	*12.93*
0.11	6.0	4.0	2.90	15.93	81.17	19.47
0.18	4.5	2.5	17.78	2.78	79.44	21.59
0.18	6.0	3.5	14.23	5.26	80.51	8.85
0.18	6.0	4.0	4.77	4.62	90.61	17.89

combinations of parameters had all four performance indices poorer than at least one of these six combinations of parameters. Therefore, these six combinations of parameters were non-dominated, and are only listed in Table 5.

The four combinations of parameters for soybean seeds, and six parameters each for pigeon pea and corn seeds shown in Table 5 are equally the best combinations of design and operating parameters for the pneumatic seed metering mechanism for the respective crops. Any one of the combinations of design and operating parameters in Table 5 for each crop can be taken for the design and development of pneumatic seed metering mechanism. However, the speed of metering disc of 0.11 m s^{-1}, suction of 6 kPa and hole diameter of 3.5 mm was in the pareto front for the three types of seeds taken in the study, and can be used for the design of power tiller operated pneumatic planter.

The classical method of identification of the optimum combination of design and operating parameters requires the development of a regression or soft computing based model, and the search for the optimum solution in the design space by numerical or nature inspired techniques[3,7,13,18,19]. The optimum solution depends on the accuracy of the model, and the cost of computation for the search for an optimal solution is also high[13]. The pareto dominance criterion does not search for an optimum solution, but only identifies the best solution among the available solutions in design space. Identification of the solution is fast, and the cost of computation is very low.

The design of pneumatic seed metering mechanism is unique in the sense that, a 3-row precision planter matching the space, power and operational constraints of the power tiller can be developed based on the outcome of the study. The heart of the mechanism is the centrifugal pump used for generating the suction to hold the seed in the seed hole of the disc. The 6 kPa suction required can be generated at the impeller speed of 4600 RPM. At the rated engine speed of 1800 RPM, V-pulley shaft of the power tiller rotates at 1200 RPM. A V-belt drive of velocity ratio 4 : 1 can be used to drive the pump shaft from the V-pully shaft of power tiller. The required speed of the metering disc can be obtained from the ground wheel of the planter through a chain drive at the second low forward speed (50% throttle) of the power tiller.

Use of the power tiller operated precision planter with the developed pneumatic seed metering mechanism resulted in planting of more than 67% of the seeds in the range of 150–200 mm spacing. Compared to the available design of power tiller operated planters, precision planter developed in the present work can be operated at higher speed with uniform distribution of seeds in the field. Use of developed precision pneumatic planter mechanism is expected to assist in precise planting of seeds, maintain the required plant population and enhance the quality of produce and yield in medium and small farms.

Conclusion

A pneumatic metering mechanism for power tiller-operated precision planter was developed. The laboratory experiments revealed that the performance of the pneumatic seed metering device was satisfactory. Seed metering disc of 150 mm diameter with 8 holes of 3.5 mm diameter on the 116 mm pitch circle diameter and operated at the peripheral speed of 0.11 m s^{-1}, and a suction of 6 kPa were found to be the best combination of design and operating parameters for the precise metering of soybean, pigeon pea and corn seeds. These design and operating parameters can be used as the basis for the development of a power tiller operated pneumatic planter for precise planting of seeds, uniform plant distribution and enhancement of the quality of produce and yield in medium and small farms.

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