OPTIMIZATION OF THE DESIGN AND OPERATIONAL PARAMETERS OF PLANTER FOR VEGETABLE PIGEON PEA (*CAJANUS CAJAN* L. MILLSP.) SEED

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सब्जी अरहर (*CAJANUS CAJAN* L. MILLSP.) को बोने के मशीन के लिए डिज़ाइनर और परिचालन पैरामीटर का चयन

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ABSTRACT

Precision machinery is one of the most important technology in the recent decades in respect to judicious use of resources. In precision machinery one of the most important machine is seeding machines because it picks the seed from the hopper and individually placed in field. An effort has been made to optimize the operational (forward speed and vacuum pressure) and design (nozzle diameter) parameters of the precision seed drill. For optimizing the metering mechanism three parameters i.e. nozzle diameters: 2.00, 2.50, 3.00, 3.50 and 4.0 mm; forward speed: 0.27, 0.55, 0.83, 1.11 and 1.38 m/s and vacuum pressure: 19.33, 39.32, 43.98, 58.64 and 68.63 kPa were selected. The seed to seed spacing was 300 mm. The RSM technique was used to optimize the above parameters. The machine was evaluated on the basis performance parameters like miss index, multiple index, quality of feed index and precision. The optimum value for forward speed, vacuum pressure and the nozzle holes diameter was 0.83 m/s, 43.98 kPa and 3.50 mm, respectively. The most important variable that governs planting phenomenon for vegetable pigeon pea seed is nozzle diameter as well as vacuum pressure.

सार

संसाधनों के विवेकपूर्ण उपयोग के संबंध में हाल के दशकों में सटीक मशीनरी सबसे महत्वपूर्ण प्रौद्योगिकी में से एक है। सटीक मशीनरी में, सबसे महत्वपूर्ण मशीन में से एक बोने की मशीन है क्योंकि यह हॉपर से बीज को उठाती है और व्यक्तिगत रूप से क्षेत्र में रखा जाता है। सटीक बीज ड्रिल के संचालन (आगे की गति और वैक्यूम दबाव) और डिजाइन (नोजल व्यास) मापदंडों को अनुकूलित करने का प्रयास किया गया है। पैमाइश तंत्र के अनुकूलन के लिए तीन पैरामीटर यानी नोजल व्यास: 2.00, 2.50, 3.00, 3.50 और 4.0 मिमी; आगे की गति: 0.27, 0.55, 0.83, 1.11 और 1.38 मीटर / से और वैक्यूम दबाव: 19.33, 39.32, 43.98, 58.64 और 68.63 kPa चुने गए। बीज से बीज की दूरी 300 मिमी रखी गई थी। आरएसएम तकनीक का उपयोग उपरोक्त मापदंडों को अनुकूलित करने के लिए किया गया था। मशीन को मिस इंडेक्स, मल्टीपल इंडेक्स, क्वालिटी ऑफ फीड इंडेक्स और प्रिसिजन जैसे आधार परफॉर्मेंस पैरामीटर पर आंका गया। आगे की गति, वैक्यूम दबाव और नोजल के छेद के व्यास के लिए इष्टतम मूल्य क्रमशः 0.83 मीटर / सेकंड, 43.98 केपीए और 3.50 मिमी था। सबसे महत्वपूर्ण चर जो वनस्पति कबूतर के बीज के लिए रोपण घटना को नियंत्रित करता है, नोजल व्यास के साथ-साथ वैक्यूम दबाव भी है।

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INTRODUCTION

Precision agriculture, which grew up with the help of remote sensing and on-line sensing technology in the middle of the 1980s, made agricultural production and agricultural management more accurate and effective (*Balafoutis et al, 2017*).

Precision seeding is one of the important parts of precision agriculture. Precision sowing is the preferred method at present, since it provides more uniform seed spacing than other methods. Precision seeding by planter requires single seeds to be picked from the hopper and individually placed in each cell. Singulation of seeds has been investigated extensively by researchers all over the world and a large number of precision seeding systems with design variations have been developed for different crops (*Gaikwad and Sirohi, 2008; Jin et al, 2019; Minfeng et al, 2018*).

Among precision seeders, those with vacuum plates are widely used in agriculture for sowing seeds of various plants. Many studies in the past were conducted in order to determine the performance of precision seeders (*Singh et al.* 2005). These studies revealed information about how a metering system of a precision seeder performed in the laboratory or in the field. The studies on the performance of a precision seeder mostly focused on vacuum pressure applied to the vacuum plate, the most common metering system in precision seeders *(Panning et al, 1999; Panning et al, 2000*).

There are many factors that contribute to the accuracy of seed spacing in precision spacing. In the design process, it is assumed that the spacing between seeds will be uniform but the uniformity may change depending on soil conditions, machine-related properties and the most important among them is seed properties (*Srivastava et al, 1993*). The mean particle diameter, geometry and mass of the seeds determine the level of vacuum, the diameter of holes and the peripheral speed of the vacuum plate (*Karayel et al, 2004; Moody et al, 2003*).

Optimum values of these parameters are very useful to the manufacture as well as researches for design of new planters for different crops (*Patel et al, 2019; Yazgi et al, 2010*). Very little techniques and information are available in the literature. Hence, a study was conducted on a planter with single seed picking technique for planting radish seeds and response methodology principles were applied to the physical system. The objective of this study was to optimize the performance of a precision seed metering unit for planting pigeon pea seed using response surface methodology (RSM).

MATERIALS AND METHODS

The laboratory study of picking type of seed metering mechanism was carried out at department of Processing and Food Engineering, College of Agricultural Engineering & Technology, Anand Agricultural University, Godhra. This consists of a vacuum pump which exhausts air from a reservoir that maintained below atmospheric pressure. A distributor connects the reservoir with a designed vacuum pick-up device, provided with an interchangeable nozzle. The vacuum is blocked as the hole reach a point above the seed hole and the seeds fall into the port knocking system under gravity. The vegetable pigeon pea seed (Anand Vegetable Pigeon pea-1) was used in the experiment for the tests and the physical properties of the seeds are given in Table 1.

Table 1

Mean values of physical properties of vegetable varieties

Crt. No.	Parameters	Mean Value
1	Length (*l*) (mm)	6.436
2	Width (w) (mm)	5.837
3	Thickness (t) (mm)	4.470
4	Equivalent diameter (D_e) (mm)	5.502
6	Sphericity (φ)	0.850
7	1000 seed weight (g)	117.748
8	Bulk Densities (g/cc)	0.781
9	Porosity (%)	39.882
10	Moisture Content (%)	7.747
11	Angle of repose (deg.)	21^o

The three parameters were selected for the study. The parameters are, operational speed 5 levels: 0.27, 0.55, 0.83, 1.11 and 1.38 m/s, vacuum pressure 5 levels i.e. 19.33, 29.32, 43.98, 58.64 and 68.63 kPa and nozzle diameter 5 levels: 2.00, 2.50, 3.00, 3.50 and 4.00 mm, respectively. The optimization of above parameters was based on the performance of picking type planter metering mechanism considering the values of miss index, multi index, quality feed index and precision.

Seed metering mechanism

In seed metering mechanism 1/2.88 rpm was available for seed picking and the rest 2/3.06 rpm was for the movement of nozzle from seed hopper to port knocking system, releasing of seed and again return back to the seed hopper. In the port knocking system 4 ports were used for desired seed placement. In this system one port was always open and remaining three ports were closed. First seed was directly dropped in the furrow remaining three seeds held in the three closed ports. After 90^0 revolute of port opening shaft second port was opened, dropped the seed in the furrow and closed the port, then next 90^0 revolute the third port was opened, dropped the seed in the furrow and closed the port, then next 90^0 fourth port was opened, dropped the seed in the furrow and closed the port. These processes repeated for every revolution of cam shaft. This process was calculated considering release of a seed from each row in one revolution of cam shaft (Fig. 1). Provisions were also provided for changing the vacuum nozzle, suction pressure and seed pickup height.

Experimental procedure

The test was carried out on 600 mm wide belt with a 3.3 m long horizontal belt having picking type metering mechanism arrangement. An electric motor having fan was used to create vacuum at different levels. The belt was driven separately and special care was given to provide the synchronization of the travel speed associated with the movement of the metering mechanism and belt speed. The metering mechanism used in this study (Fig.1) had a ground-driven wheel that transfers the motion to the movable shaft with a combination of gears available. The seed metering mechanism was mounted on the greased belt as close as possible to eliminate the seed bouncing. Grease was spread on belt so that seed was stick on the belt and sowing uniformity of each seed at the different operational speeds, vacuum pressures and nozzle diameters were determined. The metering mechanism was operated at five different operational speeds. These were 0.27, 0.55, 0.83, 1.11 and 1.38 m/s with the centre point of 0.83 m/s of belt speed corresponding to 0.83 m/s of operational speed. The selection of the belt speed was achieved by considering the travelling speed of the planter in the field. The theoretical seed to seed spacing of vegetable pigeon pea seed was 300 mm. The metering mechanism was operated (run number one) as per central composite design and data were collected. After each run, seeds on grease belt were collected and spacing from seed to seed was measured. At the same speed, experiments were replicated three times. The seeding uniformity performance of the precision planter was defined using measures based by *Kachman and Smith (1995)*. The performance or uniformity parameters miss index, multi index, quality feed index and precision were determined. This was followed by run no 2 to 20 as per CCD (Table 2) with three replications. The observations were analysed and collated to draw inferences about the responses in operational speed, vacuum pressure, nozzle diameter and their interactions.

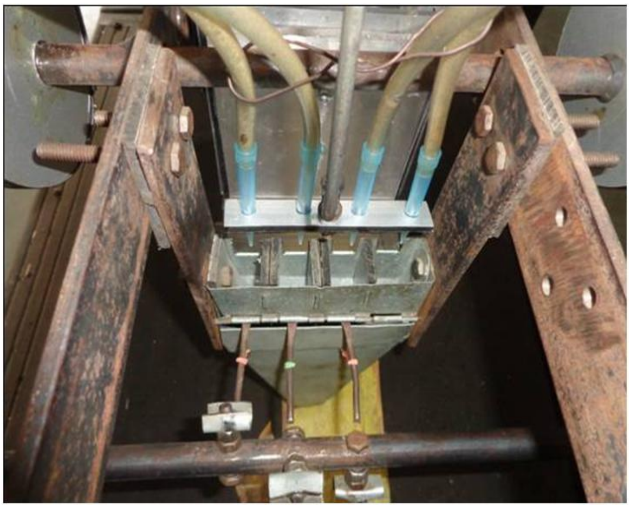


Fig. 1 - Metering mechanism

Models development and optimization procedure

A statistical and mathematical technique, Response Surface Methodology (RSM) (*Box and Draper, 1987*) was used to optimize the operating (forward speed and vacuum pressure) and constructional variables (nozzle diameter). The RSM designs are used for understanding the mechanism of the system to determine the optimum operating conditions of a system. It is less laborious and time-consuming than other approaches. It is an effective technique for optimizing complex processes since it reduces the number of experiments needed to evaluate multi parameters and their interactions.

The response surface problem usually centres on an interest in some response y, which is a function of k independent variables $x_1, x_2, ..., x_k$, that is,

$y = f(x_1, x_2, .., x_k)$

and response surface can take the different forms according to the function types of response and usually response function is defined in the quadratic polynomial form as follows:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i \cdot X_i + \sum \beta_{ii} \cdot X_i^2 + \sum \beta_{ij} \cdot X_i \cdot X_j + e \quad \text{....(1)}$$

where:

Y is the response;

β_0 is the intercept;

$\beta_i, \beta_{ii}, \beta_{ij}$ are the regression coefficients;

X_i X_j are the coded variables;

e is the error.

The coding of independent variables into X_i is expressed by the following equation:

$$X_i = \frac{x_1 - x^*}{d_S} \quad \text{... (2)}$$

where:

x_i is the actual value in original units;

x^* is the mean value (centre point) and

d_s is the step value.

The determination of the centre point for each independent variable was based on field conditions and the physical properties of the seed used. The design of such experiments special care has to be given for the selection of centre point as well as the minimum and maximum levels in order to construct polynomial functions from which the optimum levels of the independent variables are to be calculated.

The design used in this study is a rotatable CCD and it requires five levels for each independent variable. These levels were coded, -1.682, -1, 0, 1 and 1.682, respectively.

The different nozzle diameters were used. These were determined based on the CCD principles. The centre point in this design is coded as zero and as a centre point for the nozzle diameter was 3.00 mm. A step value of 0.50 mm was selected and as a result of this, the selected nozzle diameters became 2.00, 2.50, 3.00, 3.50 and 4.00 mm. The determination of the range for nozzle diameter was based upon the physical properties of seeds.

The vacuum at five levels was provided by the vacuum regulating valve of the vacuum pump. The vacuum level was centred at 43.98 kPa while the other levels were calculated based on the CCD principles at a step value of 19.33 kPa as 19.33, 39.32, 43.98, 58.64 and 68.63 kPa. Table 2 gives a list of independent variables and the coded factor levels.

The performance data were then transferred into a design expert statistical package program for further analysis. The response surface functions were developed for each performance criteria. The functions developed were defined as full quadratic polynomials in design expert, a statistical package program and stepwise procedure used for the selection of the variables as they enter the model in linear, interaction and quadratic form. The planter was then operated at optimum levels to verify the results from each model.

Table 2

Coded level for independent variables used in developing response surface functions

Variables	Code	Coded level				
		-1.682 (-α)	**-1**	**0**	**+1**	**+1.682 (+α)**
Operating speed, m/s	X_1	0.37	0.56	0.83	1.11	1.30
Vacuum pressure, kPa	X_2	19.33	29.32	43.98	58.64	68.63
Nozzle diameter, mm	X_3	2.00	2.50	3.00	3.50	4.00

α is defined as $[2^k]^{1/4}$ *and k is the number of factors (independent variables).*

RESULTS AND DISCUSSION

Optimization of design parameters of metering mechanism

The experimental results were carried out in the laboratory experiment based on Central Composite Design (CCD) are given in Table 3. It was observed that the planter operated at run no. 12, 17 and 20 gave satisfactory results in terms of miss index, multi-index, quality of feed index and precision. This result could be explained as the good selection of the ranges for the design and operational parameters and their step values. The stepwise multi second order model was tested for its adequacy to describe the response surface.

The effect of operational speed (speed of operation), vacuum pressure and constructional variables (nozzle diameter) of planter are described below.

Table 3

Central composite design (CCD) with coded and un-coded independent variables

Run no.	Independent variables			Run no.	Independent variables		
	X_1 [x_1] m/s	X_2 [x_2] kPa	X_3 [x_3] mm		X_1 [x_1] m/s	X_2 [x_2] kPa	X_3 [x_3] mm
1	0 [0.83]	0 [43.98]	-1.682 [2.0]	11	0 [0.83]	0 [43.98]	0 [0.83]
2	1 [1.11]	1 [58.64]	-1 [2.5]	12	0 [0.83]	0 [43.98]	0 [0.83]
3	0 [0.83]	1.682 [8.63]	0 [3.0]	13	0 [0.83]	-1.682 [19.33]	0 [0.83]
4	-1 [0.56]	0 [43.98]	-1 [2.5]	14	0 [0.83]	0 [43.98]	0 [0.83]
5	-1 [0.56]	1 [58.64]	-1 [2.5]	15	1.682 [1.30]	0 [43.98]	1.682 [1.30]
6	0 [0.83]	0 [43.98]	0 [3.0]	16	0 [0.83]	0 [43.98]	0 [0.83]
7	1 [1.11]	-1 [29.32]	1 [3.5]	17	-1 [0.56]	-1 [29.32]	-1 [0.56]
8	1 [1.11]	1 [58.64]	1 [3.5]	18	0 [0.83]	0 [43.98]	0 [0.83]
9	-1 [0.56]	1 [58.64]	1 [3.5]	19	-1.682 [0.37]	0 [43.98]	-1.682 [0.37]
10	1 [1.11]	-1 [29.32]	-1 [2.5]	20	0 [0.83]	0 [43.98]	0 [0.83]

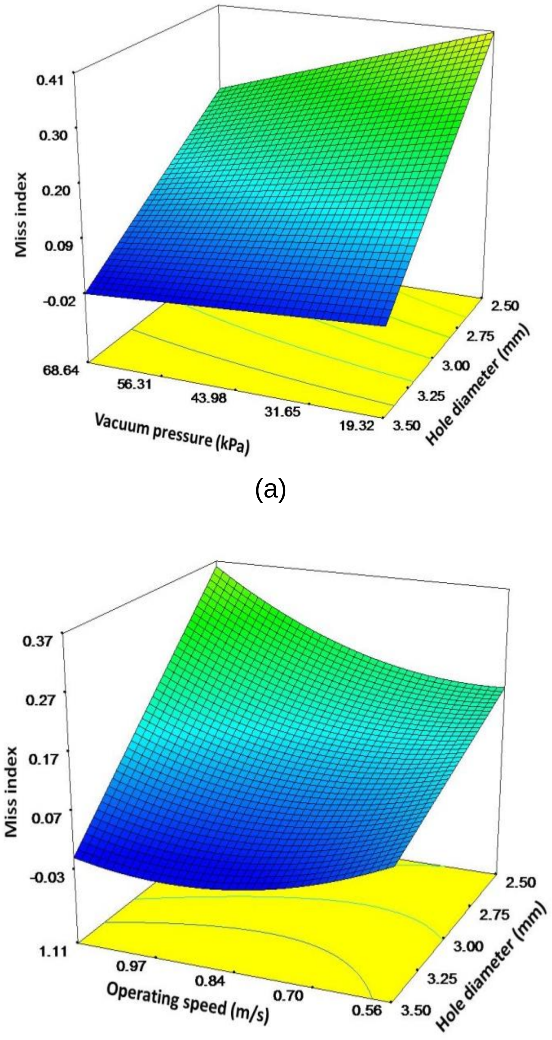
Effect of design parameters of metering mechanism on performance

Stepwise multiple quadratic models were tested for its adequacy to describe the response surface of miss index, multi-index, quality feed index and precision. The analysis of variance shows the model for vegetable pigeon pea seeds were significant. There is only a 0.013 % chance that this large "model F value" could occur due to noise. It was observed that significant miss index model factor was X_2X_3, X_2^2 and X_1X_3. From the model factor, it is clear that nozzle diameter along with pressure is the most important factor for miss index followed by nozzle diameter and vacuum pressure. Values greater than 0.100 indicate the model terms are significant. The lack of fit was not significant (Table 4).

The coded and un-coded factor models are given in Eqs. 1 & 2. The results from stepwise regression analysis for each function are given in Table 4. The "Pre R-squared" of miss index, quality feed index and precision were 0.78, 0.75 and 0.54, respectively. A "Pre R-squared" implies that the overall mean is a better predictor of response than the current model and it has reasonable agreement with the "Adj R-squared" of 0.67, 0.66, and 0.52, respectively for same order (Table 5). Pred R-squared and Adeq precision for different performance models are given in Table 5. No relation was observed for multi-index. This model can be used to navigate the design space (*Montgomery, 2001*).

Based on the results obtained from the stepwise regression analysis, the most important variable that governs seeding phenomenon for vegetable pigeon pea crop was the combination of nozzle diameter and vacuum pressure accounting for 62.23%.

Graphical view of some response surfaces as drawn using polynomial functions are depicted in Fig. 2. The figure shows the consistent behaviour of the metering unit as response to constructional and operating parameters.



(a)

(b)

Fig. 2 - Miss index as a function of (a) vacuum pressure and hole diameter (b) operating speed and hole diameter

Miss index model in terms of un-coded factors

$$I_{miss} = 0.8712 + 0.3384x_1 - 0.0110x_2 - 0.0801x_3 - 0.4413x_1x_3 + 2.9283 \times 10^{-3}x_2x_3 + 0.6402{x_1}^2 \quad \dots (3)$$

Miss index model in terms of coded factors

$$I_{miss} = 0.47 + 0.023X_1 - 0.24X_2 + 0.26X_3 - 0.061X_1X_3 + 0.16X_2X_3 + 0.048{X_1}^2 \quad \dots (4)$$

Table 4

Results from the stepwise regression analysis for the miss index model

Variable	Coefficient	Standard error	Probability (P)	Coefficient of determination (R^2), %
Constant	0.160	0.028	-	-
X_2X_3	0.062	0.010	<0.0001	62.23
X_1^2	0.048	0.025	0.0882	68.32
X_1X_3	-0.061	0.034	0.0946	73.54

Table 5

Coefficient of determination and precision adequacy of miss index, multi-index, quality feed index and precision model

Seeds	R-square	Adj R-square	Pred R-square	Adeq precision
Miss index	0.78	0.67	0.51	10.52
Quality feed index	0.75	0.66	0.47	10.06
Precision	0.54	0.52	0.44	13.33

No model for multi-index I_{multi} was obtained from the analysis of the data. Graphical view of some response surfaces as drawn using polynomial functions are depicted in Fig. 3.

It is interesting to observe that the multi-index surfaces are very different in shape for all the seeds.

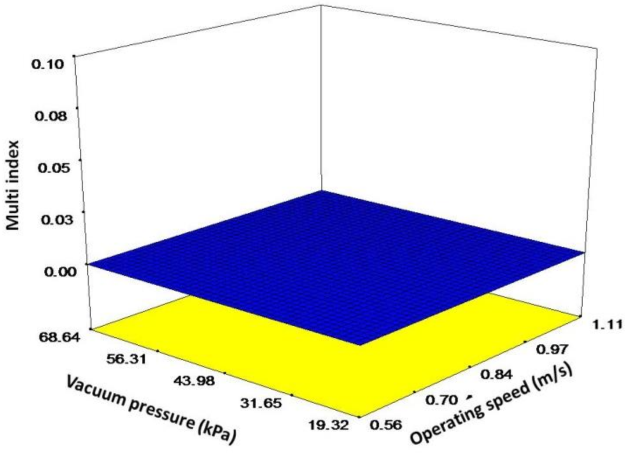


Fig. 3 - Multi index as a function of nozzle diameter

The coded and un-coded models for quality feed index are given in Eqs. 5 and 6. The results from the stepwise regression analysis for each function are given in Table 7. The entire model is significant at the 99% probability level. The lack of fit was significant. The “Pre R-squared” and “Adj R-squared” are given in Table 5. Graphical view of some response surface as drawn using polynomial functions are depicted in fig. 4. This could be considered to be a consistent behaviour of the metering unit as a response to constructional and operating condition.

Quality feed index model in terms of un-coded factors

$$I_{qf} = 0.81352 + 1.06260 * x_1 + 5.1479 \times 10^{-3} x_2 + 0.38597 x_3 - 1.1598 \times 10^{-3} x_2 x_3 - 0.6698 {x_1}^2 \quad \dots (5)$$

Quality feed index model in terms of coded factors

$$I_{qf} = 1.32 - 0.015 X_1 + 0.18 X_2 + 1.62 \times 10^{-3} X_3 - 0.064 X_2 X_3 - 0.051 {X_1}^2 \quad \dots (6)$$

Table 7

Results from the stepwise regression analysis for the quality feed index model

Variable	Coefficient	Standard error	Probability (P)	Coefficient of determination (R^2), %
Constant	0.840	0.028	-	-
X_2X_3	-0.064	0.010	<0.0001	66.26
X_1^2	-0.051	0.025	0.0599	72.77

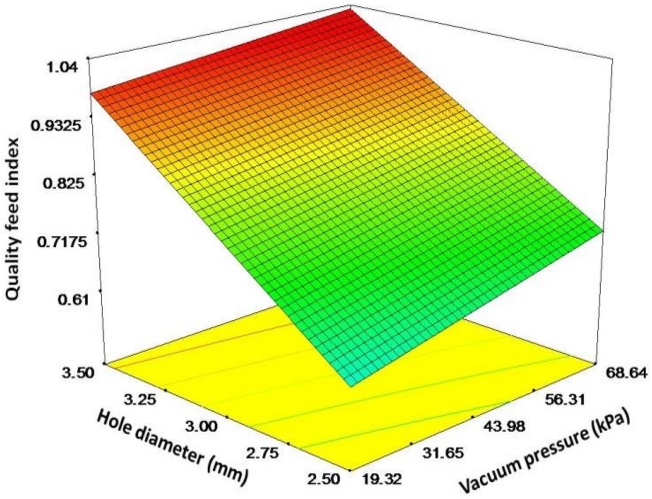


Fig. 4 - Quality feed index as a function of hole diameter and vacuum pressure

Akin to above response, the precision of metering mechanism depends on nozzle diameter. There is only a 0.01% chance that this "model F-value" could occur due to noise. This means the operational parameters, i.e. speed of the planter, had no effect on quality feed index.

A stepwise quadratic multiple regression was developed. The developed model was highly significant. The results of the models are given in Table 8. The highest coefficient of determination was observed 0.54. The coded and un-coded factor models for different seeds are given in Eq. 7 & 8. The major contributing factor is nozzle diameter i.e. 54.40%.

Graphical view of some response surfaces is drawn using polynomial functions as depicted in Fig 5.

Precision model in terms of un-coded factors

$$I_{prec} = 2.91738 - 0.79117x_3 \quad \ldots (7)$$

Precision model in terms of coded factors

$$I_{prec} = 0.54 - 0.40X_3 \quad \ldots (8)$$

Table 8

Results from the stepwise regression analysis for the precision model

Variable	Coefficient	Standard error	Probability (P)	Coefficient of determination (R^2) %
Constant	0.54	0.071	-	-
X_3	-0.40	0.085	0.0002	54.40

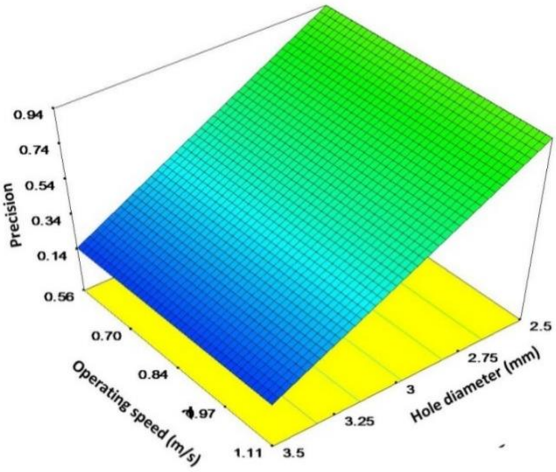


Fig. 5 - Precision as a function of vacuum pressure and nozzle diameter

Optimum Value of the Design

Based on the results from the stepwise quadratic regression analysis, the models are valid for the following conditions:

0.56 m/s < v > 1.11 m/s
29.32 kPa < p > 68.63 kPa
1.50 mm < d > 4.00 mm

The partial derivatives of Eq. 3 to 8 with respect to each independent variable have been considered to obtain the optimum value of operating speed, vacuum pressure and nozzle diameter for vegetable pigeon pea crop. The optimum levels of the nozzle diameter i.e. 3.50 mm, vacuum pressure i.e. 43.98 kPa and operating speed i.e. 0.83 m/s were obtained from different models.

CONCLUSIONS

Based on the present study the main conclusions are:

- Response surface methodology (RSM) is a useful tool for optimizing the performance of a picking type pneumatic planter.
- The coefficient of determination of miss index, quality feed index and precision adequacy are 0.78, 0.75 and 0.54, respectively.
- The nozzle diameter is the most important factor of seed metering mechanism of precision planter for deciding the performance of pigeon pea seed.
- The optimum values of nozzle diameter, vacuum pressure and operating speed are 3.50 mm, 43.98 kPa and 0.83 m/s, respectively.

REFERENCES

[1] Bhimani, J.B., Patel, S.K., Yaduvanshi, B.K., Gupta P. (2019). Optimization of the operational parameters of a picking-type pneumatic planter using response surface methodology. *Journal of AgriSearch*, 6(1): 38-43.

[2] Gaikwad, B. B. & Sirohi N. P. S. (2008). Design of a low-cost pneumatic seeder for nursery plug trays. *Biosystem Engineering*, 99, 322-329.

[3] Jin, X., Li, Q., Zhao, K., Zhao, B., He, Z. & Qi, Z. (2019). Development and test of an electric precision seeder for small-size vegetable seeds. *J Agric & Biol Eng*. 12 (2), 75-81.

[4] Karayel, D., Wiesehoff, M., Ozmerzi, A. and Muller, J. (2006). Laboratory measurement of seed drill seed spacing and velocity of fall of seeds using high-speed camera system. *Computers and Electronics in Agriculture*, 50, 89–96.

[5] Minfeng, J., Yongqian, D., Hongfeng, Y., Haitao, L., Yizhuo, J. & Fu Xiuqing (2018). Optimal Structure Design and Performance Tests of Seed metering Device with Fluted Rollers for Precision Wheat Seeding Machine. *IFAC PapersOnLine*, 51-17, 509–514.

[6] Moody, F. H., Hancock, J. H. and Wilkerson, J. B. (2003). Evaluating planter performance-cotton seed placement accuracy. *Transactions of the ASAE,* Paper No. 03 1146, St Joseph, Michigan, USA.

[7] Panneton, B., Philion, H., Dutilleul, P., Theriault, R. and Khelifi, M. (1999). Full factorial design versus central composite design: Statistical comparison and implications for spray droplet deposition experiments. *Transactions of the ASAE*, 42(4):877–883.

[8] Panning, J. W., Kocher, M. F., Smith, J. A. and Kachman, S. D. (2000). Laboratory and field testing of seed spacing uniformity for sugar beet planters. *Applied Engineering in Agriculture,* 16(1), 7-13.

[9] Singh, R. C., Singh, G. and Saraswat, D. C. (2005). Optimization of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. *Biosystems Engineering*, 92(4), 429-438.

[10] Srivastava, A. K., C. E. Goering, R. P. Rohrbach. 1993. Engineering Principles of Agricultural Machines. *American Society of Agricultural Engineers: ASAE*, St. Joseph-Michigan.

[11] Yazgi, Degirmencioglu & Bayram (2010). Optimization of the Seed Spacing Uniformity Performance of a Precision Seeder Using Spherical Materials and Response Surface Methodology. *Paper presented in ASABE conference*, ASABE Paper 1008560.