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Optimization of the Operational Parameters of a Picking-Type Pneumatic Planter using Response Surface Methodology

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ABSTRACT

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. A picking type metering mechanism was developed at CAET, AAU, Godhra, Gujarat, India. The performance was investigated under laboratory conditions to optimize the operating parameters *i.e.* hole diameters for the nozzle: 1.0, 1.5, 2.5 and 3.0 mm; forward speed: 0.37, 0.56, 0.83, 1.11 and 1.30 m/s and vacuum pressure: 19.33, 39.32, 43.98, 58.64 and 68.63 kPa were selected for the study. The miss index, multiple index, quality of feed index and precision parameters were measured. The optimum value for forward speed, vacuum pressure and the holes diameter of nozzle was 0.96 m/s, 36.25 kPa and 2.0 mm, respectively. The most important variable that governs planting phenomenon is the combination of hole diameter of nozzle and vacuum pressure.

KEYWORD

Precision; RSM; Optimization; Picking type mechanism; CCD

INTRODUCTION

Precision seeding 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). Among different sowing techniques, precision sowing is the preferred method at present, since it provides more uniform seed spacing than other methods, namely, broadcasting and drilling which is the random placement of seeds in a furrow. Among precision seeders, those with vacuum plates are widely used in agriculture for sowing seeds of various plants. Farmers using these kinds of precision seeders usually have sets of plates to match each size of seed to be planted. There are many factors that contribute the accuracy of seed spacing in precision spacing (Planning *et al.,* 2000 and Karayal *et al.,* 2006). In the design process, it is assumed that the spacing between seeds will be uniform but the uniformity may change depending upon soil conditions, machine-related properties and the most important among them is seed properties (Yozgi and Bayram, 2010 and 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 (Moody *et al.,* 2003 and Yasir *et al.,* 2012).

There exists no empirical or theoretical model that defines the relationship between the seeder performance and peripheral speed of the plate, hole diameter and vacuum pressure and optimisation-based studies that include all three variables that have not been found in the literature (Singh *et al.,* 2005). Hence, a study was conducted and a precision seeder with single seed picking was used for sowing lady's finger seeds and response methodology principles were applied to the physical system as described above. The objective of this study was to optimize the performance of a precision seeder using response surface methodology (RSM) and to verify the optimum level of variables considered in the study.

MATERIALS AND METHODS

The laboratory testing of picking type of seed metering mechanism was carried out at department of Agricultural Process Engineering, College of Agricultural Engineering & Technology, Anand Agricultural University, Godhra. The precision seeder used in the experimental study was a vacuum pick-up device as shown in Fig. 1. 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. Seed in the hopper, where vacuum created by a fan holds the seeds in the nozzle which has different hole diameters.

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. For optimization of design parameters of picking type metering mechanism with lady's finger vegetable seed (variety Gujarat Anand Okra – 5) was used in the experiment. The independent variables were **o**perational speed- 5 levels: 1.3, 2.0, 3.0, 4.0 and 4.4 km/h; vacuum pressure 5 levels: 19.33, 29.32, 43.98, 58.64 and 68.63 kPa and hole diameter 5 levels: 1.0, 1.5, 2.0, 2.5 and 3 mm. The miss index, multi index, quality feed index, precision, single seed and double seed parameters were measured.

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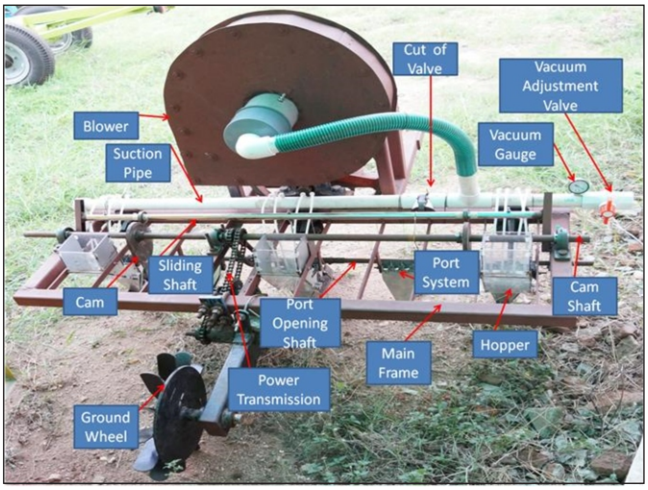


Fig 1: General view of the picking type seed metering planter

Experimental procedure

The test stand has a 600 mm wide belt with a 3.3 m long horizontal viewing surface. A grease belt test stand was used to determine sowing uniformity of each seed at the different operational speed, vacuum pressures and hole diameters of nozzle. The measurement of seed distances was carried out at a distance of 3.2 m for each test. The seed metering mechanism was mounted on the greased belt as close as possible to eliminate the seed bouncing. An electric motor having fan was used to create vacuum at different levels. The grease 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 had a ground-driven wheel that transfers the motion to the movable shaft with a combination of gears available. The metering mechanism was operated at five different operational speeds. These were 0.37, 0.56, 0.83, 1.11 and 1.30 m/s with the centre point of 0.83 m/s of belt speed correspond 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 lady's finger was 30 cm. The metering mechanism was operated (run number one) as per central composite design and this run was replicated three times. After, each run number seed on grease belt were collected and spacing between seed to seed were measured. The seeding uniformity performance of the precision planter was defined using measures based by Kachman and Smith (1995). The performance or uniformity parameters are 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). The observations were analyzed and collated to draw inferences about the responses in which the study of operational speed, vacuum pressure, hole diameter of nozzle and their interactions.

Table 1: Coded level for independent variables used in developing response surface functions

Variables	Code	-1.682 (-α)	Coded level -1	0	+1	+1.682 (+α)
Operating speed, m/s	X1	0.37	0.56	0.83	1.11	1.30
Vacuum pressure, kPa	X2	19.33	29.32	43.98	58.64	68.63
Hole dia, mm	X3	1.00	1.50	2.00	2.50	3.00

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

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-related variables (hole 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:

$$\sum=\sum\sum+=kiY1e+ijXiXj+2iiXi+iXi0\beta\beta\beta\beta \quad ....(1)$$

Where,

Y is the response;

β_0 is the intercept;

β_i, β_{ii}, β_{ij} are the regression coefficients;

X_i X_j are the coded variables; and

e is the error.

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

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

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 hole diameter was 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 hole diameter 2 mm for seed metering was chosen for lady's finger. A step value of 0.5 mm was selected and as a result of this, the selected hole diameters for the nozzle became 1, 1.5, 2.5 and 3 mm. The determination of the range for hole 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 centered at 43.98 kPa while the other levels were calculated based on the CCD principles at a step value of 19.33 kPa as 39.32, 43.98, 58.64 and 68.63 kPa for all crops. Table 1 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. All of the replications were used for the development of response surface functions. 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.

RESULTS AND DISCUSSION

Optimization of design parameters of metering mechanism

The experimental results carried out in the laboratory experiment based on Central Composite Design (CCD) are given in Table 2. It was observed that the planter operated at 0.83 m/s operating speed, 43.98 kPa vacuum pressure and 2.0 mm hole diameter (run no. 17-19) 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 independent variables 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 (hole diameter of nozzle) of picking type seeding mechanism are described below:

Table 2: Central composite design (CCD) design 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	-1 [0.56]	-1 [29.32]	-1 [1.5]	11	0 [0.83]	0 [43.98]	0 [2.0]
2	0 [0.83]	0 [43.9 8]	-1.682 [1.0]	12	-1 [0.56]	-1 [29.32]	1 [2.5]
3	1 [1.11]	-1 [29.32]	-1 [1.5]	13	1.682 [1.30]	0 [43.98]	0 [2.0]
4	0 [0.83]	-1.682 [19.33]	0 [2.0]	14	0 [0.83]	0 [43.98]	0 [2.0]
5	0 [0.83]	0 [43.98]	1.682 [3.0]	15	1 [1.11]	1 [58.64]	-1 [1.5]
6	0 [0.83]	0 [43.98]	0 [2.0]	16	1 [1.11]	1 [58.64]	1 [2.5]
7	-1.682 [0.37]	0 [43.98]	0 [2.0]	17	0 [0.83]	0 [43.98]	0 [2.0]
8	-1 [0.56]	1 [58.64]	-1 [1.5]	18	0 [0.83]	0 [43.98]	0 [2.0]
9	1 [1.11]	-1 [29.32]	1 [2.5]	19	0 [0.83]	0 [43.98]	0 [2.0]
10	0 [0.83]	1.682 [68.63]	0 [2.0]	20	-1 [0.56]	1 [58.64]	1 [2.5]

Effect of design parameters of metering mechanism on performance

Stepwise multiple quadratic model was 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 models for different seeds were significant (Table 3). It is only a 0.01 % chance that a model F value of this could occur due to noise, respectively. It was observed that significant miss index model factor was: X_2X_3, X_3^2 and X_1X_2. From the model factor, it is clear that hole diameter is the most important factor for miss index followed by vacuum pressure and operational speed. Values greater than 0.1000 indicate the model terms are significant. The lack of fit was not significant.

Table 3: Results from the stepwise regression analysis for the miss index model

Variable	Coefficient	Standard error	Probability (P)	Coefficient of determination (R^2),%
Constant	0.17	9.25×10^{-3}	-	-
X2X3	0.059	3.364×10^{-3}	<0.0001	89.18
X3^2	0.031	8.446×10^{-3}	0.0065	93.09
X1X2	-9.42×10^{-3}	3.364×10^{-3}	0.0128	95.39

The coded and un-coded factors models for different seeds are given in Eqs. 1 & 2. The results from stepwise regression analysis for each function are given in Table 5. The "Pre R-squared" of miss index is 0.90. A negative "Pre R-squared" implies that the overall mean is a better predictor of response than the current model and it having reasonable agreement with the "Adj R-squared" of 0.95, 0.64, 0.67, and 0.98, respectively for same order. Adeq precision of greater than & indicates an adequate signal. 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 is the combination of hole diameter and vacuum

Table 4: Coefficient of determination and precision adequacy of miss index model

Parameter	R-square	Adj R-square	Pred R-square	Adeq precision
Miss index	0.96	0.95	0.90	27.66
Multi index	0.73	0.61	0.31	8.63
Quality feed index	0.63	0.45	0.23	7.79
Precision	0.64	0.59	0.25	12.37

pressure accounts 89.18 per cent. The optimum level of the hole diameter and vacuum pressure obtained from different models are close and they are in good agreement (Table 4).

Graphical view of some response surfaces as drawn using polynomial functions are depicted in Fig 2. This could be considered to be a consistent behavior of the metering unit as response to constructional and operating conditions. During the test, it was observed that the double seed were observed in run 5, run 10, run 14, run 16 and run 20 and remaining were single seeds.

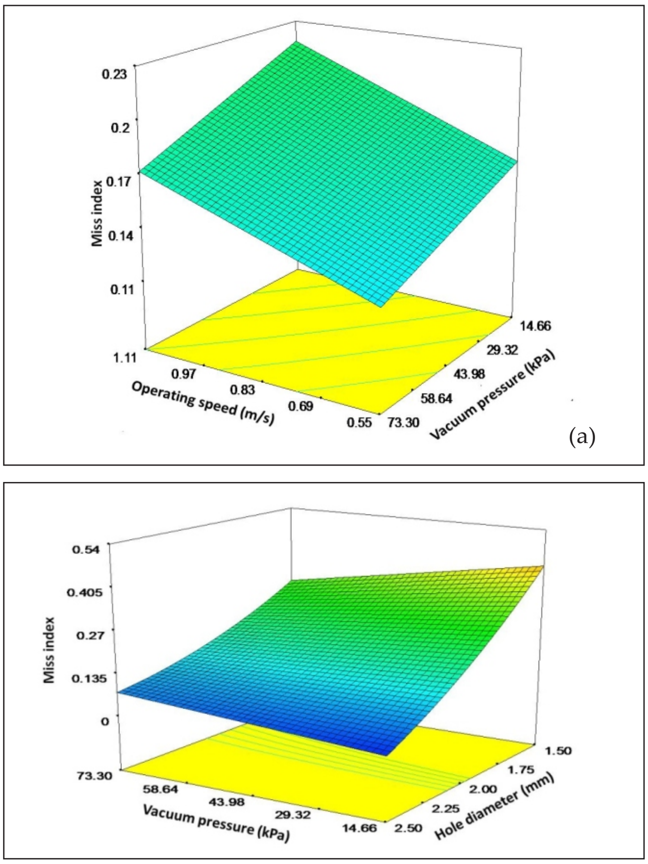


Fig. 2: Miss index as a function of (a) operating speed and vacuum pressure (b) vacuum pressure and hole diameter

Miss index model in terms of un-coded factors

$$I_{miss} = 1.5218 + 0.097733x_1 - 7.1700\times10^{-3}\,x_2 - 0.9490x_3 - 2.3157\times10^{-4}\,x_1x_2 + 3.3287\times10^{-3}\,x_2x_3 + 0.12416\,x_3^2 \quad \ldots(3)$$

Miss index model in terms of coded factors

$$I_{miss} = -0.031 + 5.968E\text{-}003\,X_1 - 0.078\,X_2 + 0.32\,X_3 - 7.132E\text{-}003\,X_1X_2 + 0.18\,X_2X_3 + 0.031\,X_3^2 \quad \ldots(4)$$

From the Eqs. 5 & 6 it is clear that for multi index the significant factors for model are X_2, X_1X_2, X_3, X_1X_3 and X_1^2. There is only a 0.01 % chance that a model F value of this could occur due to noise. The analysis of variance shows the model for multi index was significant at 1 % level of significant. The important factor for multi index of different seeds was vacuum pressure and hole diameter. The multi index increased with increase in vacuum pressure. Similarly, the multi index increased with increase in hole diameter. Values greater than 0.1000 indicate the model terms are significant. The lack of fit of the model was not significant. The "Pre R-squared" of the different models is 0.31 whereas, the "Adj R-squared" of the same was 0.61. The results from stepwise regression analysis for each function is given in Table 5. The major contribution of vacuum pressure is 20.73 per cent.

Table 5: Results from the stepwise regression analysis for the multi index model

Variable	Coefficient	Standard error	Probability (P)	Coefficient of determination (R^2),%
Constant	1.950	0.560	-	-
X2	0.710	0.220	0.0437	20.73
X1X2	-0.038	0.012	0.0330	39.64
X3	0.086	0.031	0.0375	54.32
X1X3	0.100	0.041	0.0397	65.87
$X1^2$	0.058	0.030	0.0773	72.90

Taking the partial derivatives of Eqs 5 & 6 with respect to each independent variable yields the optimum levels for different seeds. The optimum value of the hole diameter and vacuum pressure obtained from different models are close and they are in good agreement (Table 4).

Graphical view of some response surfaces as drawn using polynomial functions are depicted in Fig. 3.

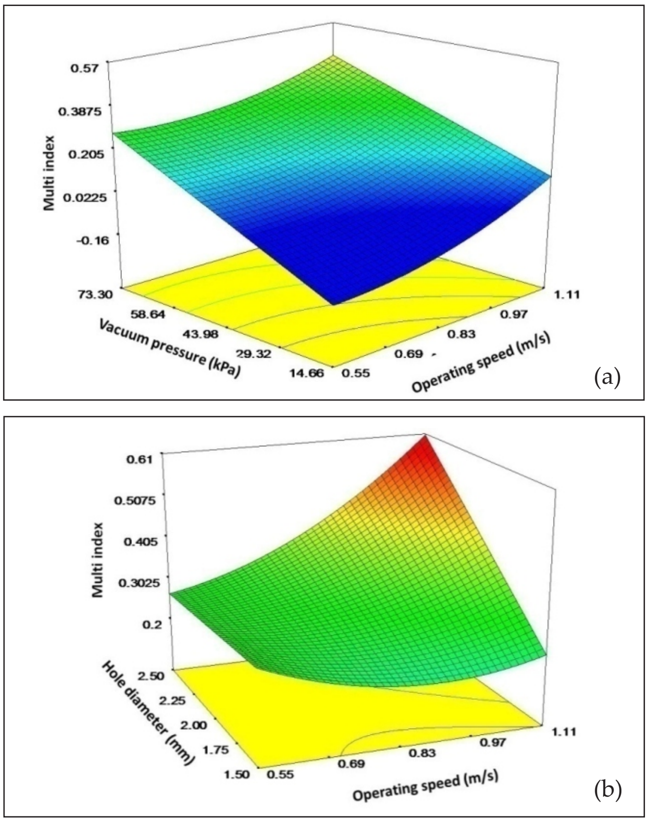


Fig 3: Multi index as a function of (a) vacuum pressure and operating speed (b) hole diameter and operating speed (lady's finger).

Multi index model in terms of un-coded factors

I_{multi} = 0.7603 -2.15846 x_1 +9.0553 ×10^{-3} x_2-0.4196 x_3-3.1363 ×10^{-3} x_1 x_2+0.7131x_1 x_3+0.7339 x_1^2 …(5)

Multi index model in terms of coded factors

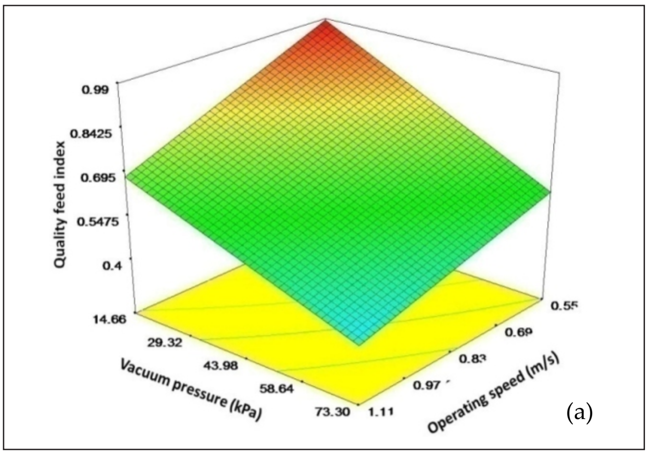
I_{multi} = 1.95 -0.15 X_1+0.71 X_2+0.086 X_3-0.097 X_1X_2+0.100 X_1X3 +0.058 X_1^2 …(6)

Similar to multi index response the important variable that governs the quality feed index of lady's finger is the operational speed of seeding, vacuum pressure and hole diameter of nozzle. The interaction of operational speed & vacuum pressure and vacuum pressure and hole diameter alone contribute 25.92 and 66.26 per cent. The coded and un-coded models for quality feed index are given in Eq. 7 and 8. The results from the stepwise regression analysis for each function are given in Table 4. The model is significant at the 99 per cent probability level.

The lack of fit for different seeds was significant. The "Pre R-squared" and "Adj R-squared" of the different model is given in Table 6. Graphical view of some response surface as drawn using polynomial functional depicted in Fig 4. This could be considered to be a consistent behavior of the metering unit of a response to constructional and operating condition.

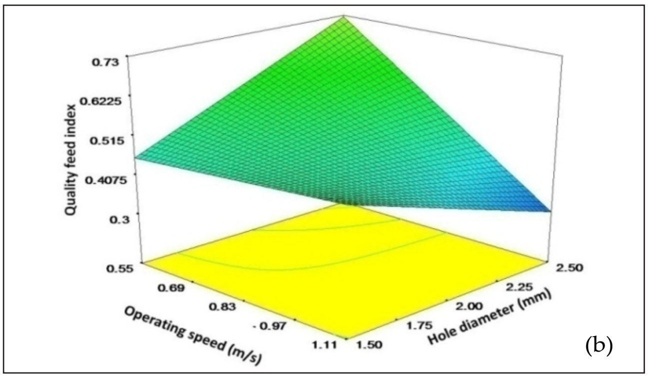
Table 6: Results from the stepwise regression analysis for the quality feed index model

Variable	Coefficient	Standard error	Probability (P)	Coefficient of determination (R^2) %
Constant	-0.978	0.736	-	-
X1	+0.148	1.041	0.8893	63.67
X2	-0.632	0.283	0.0436	72.38
X3	-0.419	1.041	0.6938	80.41
X1X2	+0.104	0.400	0.7995	84.23
X1X3	-0.116	0.053	0.0479	87.81
X2X3	-0.187	0.400	0.6481	



Quuality feed index model in terms of un-coded factors

I_{qf} = -0.5429 +1.0792 x_1 -1.7477 ×10^{-3} x_2+0.97319 x_3+3.3678 ×10^{-3} x_1 x_2-0.8315 x_1 x_3-3.3975 ×10^{-3} x_2 …(7)



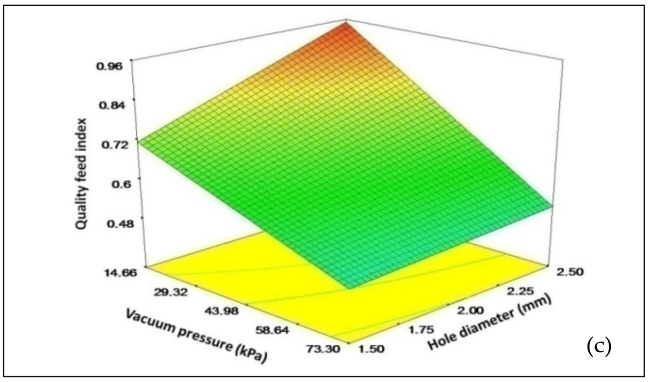


Fig 4: Quality feed index as a function of (a) vacuum pressure and operating speed (b) operating speed and hole diameter (c) vacuum pressure and hole diameter

Quality feed index model in terms of coded factors

I_{qf} = -0.98 +0.15 X_1- 0.63 X_2- 0.42 X_3+ 0.10 X_1X_2- 0.12 X_1X_3 - 0.19 X_2X_3 …(8)

Akin to above response, the precision of metering mechanism depends on hole diameter of the nozzle. There is only a 0.01 % chance that a model F value of this could occur due to noise. This means the operational parameter *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 Tables 7.

Table 7: Results from the stepwise regression analysis for the precision model

Variable	Coefficient	Standard error	Probability, (P)	Coefficient of determination (R^2)%
Constant	0.16	0.32	-	-
X2X3	0.16	0.18	0.0002	53.97
X2	0.036	0.017	0.0416	64.20

The highest coefficient of determination was observed 0.64. The coded and un-coded factor models for different seeds are given in Eq. 9 & 10. The major contributing factor is vacuum pressure i.e. 64.20 per cent. Graphical view of some response surface is drawn using polynomial functions are depicted in Fig 5.

Precision model in terms of un-coded factors

I_{prec} = 1.41206 - 0.00618514 x_2 - 0.88589x_3 + 0.00299442 x_2x_3 + 0.14554x3^2 …(9)

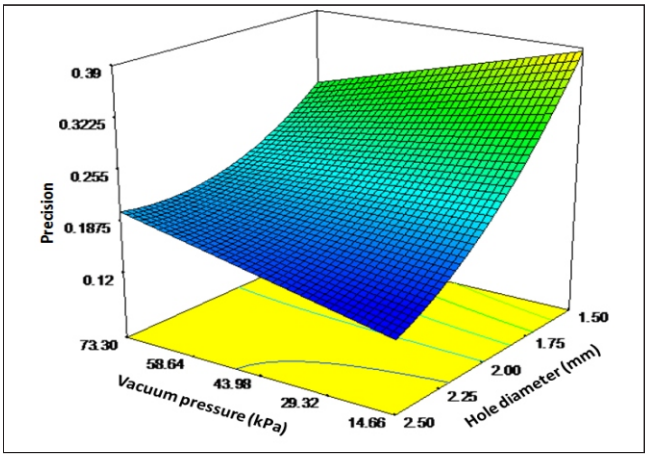


Fig. 5: Precision as a function of vacuum pressure and hole diameter

Precision model in terms of coded factors

$I_{prec} = 0.16 - 0.022\ X_2 + 0.34X_3 + 0.16\ X_2X_3 + 0.036X_3^2$ …(10)

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 > 58.64 m/s

1.5 mm < d > 2.5 mm

In order to find, the optimum value of operating speed, vacuum pressure and hole diameter of nozzle for different crops. Taking the partial derivatives of Eq. 1 to 8 with respect to each independent variable yields the optimum levels for different crops. The optimum level of the hole diameter i.e. 2.00 mm and vacuum pressure i.e. 36.25 kPa and operating speed i.e. 0.96 m/s was obtained from different model.

Verification of the optimum settings

The optimum settings were tested in the field condition and in order to carry out the subjective tests, the planter was operated with a hole diameter of 2.0 mm and vacuum adjusted to a value of 36.25 kPa. The optimum operating speed of the planter was 0.97 m/s which corresponded to 3.5 km/h travel speed of the planter in the field. This travel speed was considered to be a reasonable speed in order to achieve a desirable planting capacity in the field.

Table 8: Verification of optimum value in field condition

Sr. No.	Miss index	Multi index	Quality feed index	Precision
R1	0.1765	0.1176	0.7059	0.2368
R2	0.1875	0.1250	0.6875	0.2240
R3	0.1250	0.1875	0.6875	0.2213
R4	0.2500	0.1250	0.6250	0.2338
R5	0.2000	0.1333	0.6667	0.2466
Avg.	0.1878	0.1377	0.6745	0.2325
Value obtained by developed model	0.1885	0.1193	0.6459	0.2153

The results of these five replications indicate that the optimum levels observed from the models yield satisfactory results in precise seeding of lady's finger seed. The values of miss index, multi index, quality feed and precision at optimum value in field condition and value obtained by the models at optimum value obtained under RSM method are given in Table 8.

CONCLUSIONS

Based on the present study, (i) the accuracy in seed spacing is mostly affected by the hole diameter of the nozzle. (ii) the level of vacuum pressure is another importance factor and optimum value is about 36.25 kPa and (iii) the operating speed also affects the accuracy in seed spacing.

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