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Optimization of Power Tiller Operated Pneumatic Planter under Laboratory Conditions for Enhancing Cotton Planting Efficiency

Kumudini Verma [a*], Santosh Kumar Mohanty [a], Rama Chandra Dash [a], Jayanarayan Mishra [a], Anup Behera [a] and Ipsita Rath [a]

[a] Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology, Odisha University of Agriculture and Technology, Bhubaneswar-751003, India.

Authors' contributions

This work was carried out in collaboration among all authors. Authors KV and SKM Conceptualize and Designed the experiments. Authors RCD and AB Contributed for arranging experimental materials and facility. Authors KV, IR and AB perform the execution of lab experiments and data collection. Authors KV and AB do the analysis of data and interpretation. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The study aimed to optimize the operational parameters *viz*. orifice diameter, suction pressure and forward speed of operation of a power tiller operated pneumatic planter specifically for cotton crops in laboratory condition, focusing on improving planting operation.
Study Design: A Central Composite Rotatable Design (CCRD) was employed to optimize the operational parameters.

**Corresponding author: E-mail: kumudverma1995@gmail.com;*

Place and Duration of Study: The study was conducted in a Soil test bin (sand bed test) in the Tillage and Traction Laboratory in the year 2023 to evaluate the effect of various operational parameters on seed uniformity.

Methodology: Based on the study of engineering properties of cotton seed, the size of the orifice on the seed drum was determined. The effect of operational parameters was examined by evaluating mean seed spacing, precision in spacing (coefficient of variation), miss index, multiple index, and quality of feed index.

Results: The study found that for achieving singulation of seeds, optimal parameters included a metering drum with an orifice size of 3 mm, a suction pressure of 2.78 kPa, and a forward speed of 1.36 km/h. Corresponding actual values of miss index, multiple index, quality feed index, and precision index were found 7.6±2.5, 6.8±1.6, 82.4±2.5 and 4.1±1.2 against predicted values of 4.40, 4.56, 90.1, and 3.90, respectively.

Conclusion: The findings suggest that optimizing operational parameters such as orifice size, suction pressure, and forward speed can significantly improve the performance of power tiller operated pneumatic planters for cotton seed planting. These results contribute to enhancing planting accuracy and efficiency in cotton sown areas.

Keywords: Cotton sowing; planting parameters; pneumatic planter; precision planting; optimization; sand bed test.

1. INTRODUCTION

Precise seeding involves the meticulous selection and individual placement of single seeds from the seed reservoir into designated cells. Researchers worldwide have extensively explored the process of seed singulation, leading to the development of numerous precision seeding systems tailored to different crops. Cotton, a globally significant crop revered for its diverse applications, serves as a linchpin in various industries. Cotton planting method holds critical significance in ensuring robust yields and efficient farming practices [1]. The contemporary agricultural landscape has transformed through the integration of technology and machinery, promising heightened precision, decreased labour requirements, and improved productivity in planting methods.

Placement of seeds in well prepared soil at equal spacing between rows promotes homogenous root growth, better crop management, lower production costs and increased crop yield when compared to broadcasting and drilling of seeds [2]. For placing the single seeds in soil, usually plant scientists use hand dibblers. Precision planting is the method of sowing single seed at equal distances in rows, and the machine used for precision sowing is known as precision planter. Precision planters save up to 90% on seed costs as compared to drilling, and they also eliminate the need for thinning [3]. For precision planting, mechanical seed metering devices such as horizontal plates, vertical plates, and inclined plates with cells on the periphery have been developed. However, due to centripetal forces associated with higher speed, the employment of these mechanical devices causes severe seed damage and multiple seed pick-up6. In addition, these seed metering machines have failed to manage irregularly shaped seeds properly. Furthermore, the usage of vertical and inclined seed metering plates has resulted in missed plantings due to seed dislodging from the plate's cells. In pneumatic seed metering devices apart from spherical seeds, there is an advantage to measure irregular shaped seeds [4]. The suction unit is the main component of pneumatic seed metering device which is mounted long with metering unit horizontally. Metering drum consists of seed holes of size less than the size of the seed in its periphery. Seeds are retained in the seed hole by a vacuum created by an aspirator blower on one side of the drum. Due to vacuum, the drum picks up seeds from the seed reservoir as it turns. When seed holes reach a point above the seed tube, airflow is blocked to release the seed from the seed drum. At the same point, vacuum force is absent and seed falls into seed delivery tube due to gravity. Accurate seed spacing is affected by the design of the metering drum, size of seed, vacuum pressure and operating parameters [5]. Due to high precision placement with minimum seed damage, good control and adjustment, high consistency or uniformity in intra row seed spacing, and applicability in a wide range of seed types [6,7,8].

Pneumatic planters are very much popular for their quality of seed metering. Existing pneumatic planters generally use positive as well as negative air pressure for their operation [9]. Most of the planters use negative pressure for seed sucking and holding against the plate, also they use positive pressure for dropping seed pneumatically in the furrow [4]. Some planters drop the seed just by cutting the flow of negative air pressure and allowing seed to expose atmospheric pressure which causes seeds to drop by gravitational force [6]. Seeds having one or more dimensions pointed more likely the multiple seeds per orifice [10]. In some cases, mechanical droppings were also used. In general, pneumatic planters have individual suction chambers as well as positive pressure lines from blower for each row which is operated by PTO of tractor to the metering unit leading to high cost, while some recent experiments tried inside or outside filling single chamber for at least four to eight rows [11,12]. Research conducted on existing cotton planters worldwide has focused on improving precision planting techniques, enhancing seed placement accuracy, optimizing seed spacing, and developing innovative mechanisms for handling different soil conditions [5,13,14]. The preliminary survey was conducted in western part of Odisha where farmers sow the cotton seeds in traditional manner.

However, till date common suction chamber for multiple rows has been utilized mostly for seed drills. In addition to that existing planters have other limitations like mechanical damage to seed, lack of uniformity etc. To tackle all these limitations, research work was conducted to develop a power tiller operated pneumatic planter (PTPP) for cotton seeds. Developed PTPP used single chamber with negative pressure for two rows. Suction unit is developed to operate with was used as suction chamber. Seed churning device was provided to agitate the seeds in seed box. Seed cut-off plate was provided to prevent metering of excess seeds. In addition to that one spill out chamber was provided just before seed scraping device to collect the excess seeds not cleaned by cut-off device. Mechanical seed scraping device was provided to release the seeds in the row through furrow opener.

The developed power tiller operated pneumatic planter have a potential to marks a pivotal innovation in cotton planting, blending power tiller strength with precise pneumatic mechanisms for accurate seed placement and heightened efficiency. This study delves into optimizing these planters specifically for cotton cultivation, aiming beyond improved accuracy to address unique challenges in cotton farming scenarios. By illuminating these optimization efforts, this manuscript aims to significantly advance cotton cultivation practices, paving the way for more sustainable and effective planting methodologies. Identification of the best levels of operating parameters for the metering unit is required for the development of a compact metering unit.

2. MATERIALS AND METHODS

The prototype power tiller operated pneumatic planter (PTPP) was fabricated in the workshop of the department of farm machinery and power engineering, CAET, OUAT, Bhubaneswar with collaboration of Sheet Profile Company, Berhampur.

2.1 Raw Material

Some of the common high-yielding and hybrid varieties of cotton crops grown in Odisha and India are BS-279, RCH-659 and KCHH-2739. A Cotton seed of BS-279 variety was procured from AICRP on cotton, Bhawanipatna, Odisha and RCH-659 and KCHH-2739. The experiments were carried out at fixed moisture content (10%) db. The moisture content of the crops was determined with the help of the digital moisture analyzer (make: Indosaw; model: Universal 9800; accuracy: 0.1%). It worked on the principle of electrical conductivity of the material, which always proportional to the percentage content of the moisture.

2.2 Dependent Parameters

The performance indices of the planter, *viz*. miss index, multiple index, quality feed index, and precision index, were used for single seed metering [4,15,16,17,18].

Miss index:

$$MI = \frac{n_1}{N} \times 100 \tag{1}$$

Where,
n_1 = Number of seed spacings more than 1.5 times of desired spacings;
N = Total number of spacings.

Multiple index:

$$MUI = \frac{n_2}{N} \times 100 \tag{2}$$

Where;
n_2 = Number of hill spacings less than 0.5 times of desired spacings.

Quality feed index

$$QFI = 100 - (MI + MUI) \tag{3}$$

Precision index

$$PI = \frac{Std.Dev.of\ hill\ spacings\ between\ 0.5\ and\ 1.5\ times\ of\ the\ desired\ spacing}{Desired\ spacing} \tag{4}$$

2.3 Performance Parameters for Planter in Laboratory

In the development of power tiller operated two row pneumatic planter (PTPP) for cotton seed, it was necessary to carry out the performance of developed laboratory prototype. We focused on examining the performance of a single row within the developed laboratory prototype. The cotton planter prototype consisted of a two-row unit with a shared suction chamber for both rows. As a result, assessing the entire metering drum's performance simultaneously became essential. Consequently, the evaluation of the PTPP was conducted in a laboratory setting using a sand bed with a working width of 1 meter. Fig. 1 displays the laboratory setup of the sand bed test rig employed for this assessment.

Length of setup was sufficient for recording spacing of 14 seed drops in one run. To avoid bouncing of seeds dropped from metering device, part of bed was filled with sand bed having total length of 10 m and depth of 0.5 m with soil into the soil test bin but to made it sand bed we modify it as sand bed having sand bed dimension of 1 m width, 10 m length and 15 cm depth spread uniformly to the whole test bin. To avoid damage to belt rubber due to grease application plastic strip was pasted on belt before putting grease. Sticky belt setup consisted of variable speed electric motor, power from which was provided at right angle to the belt pulley drum with the help of worm and pinion type gear box and chain drive. The setup was capable to provide linear speed of 0-3.5 km/h. Three-point linkages were provided for mounting implement on belt setup. The system for implement height adjustment of three-point linkage was hydraulically powered. The details of setup are shown in Fig. 1.

2.4 Central Composite Rotatable Experiment Design (CCRD)

Three independent variables, *viz*., orifice size (A), suction pressure (B) and forward speed (C) were considered for optimisation. The experimental plan for optimisation consisted of four dependent variables, *viz*., miss index (MI), multiple index (MUI), quality feed index (QFI) and precision index (PI). For this purpose, the RSM, using a CCRD in Design Expert software (Version 10.0.1.0) to fit a second-order polynomial equation, was employed [19]. Values of parameter A varies from 2.5 to 3.5 mm, B from 2 to 4 kPa and C from 1 to 2 km h^{-1}. The size of metering drum was based on ready-made sprockets available in the market. The transmission system of the developed PTPP was equipped with a set of eight sprockets and four chains. Inbuilt gear combinations in the rotary unit of VST Shakti-130 DI was used to achieve the required peripheral speed. Speed of operation was found to be 0.36 ms^{-1} (around walking speed of human), for operating the machine. For experimental purposes, an electric motor (already fitted in the test bin of 3.73kW power) was used as a power source. In the design (Tables 1), the coded values of independent variables, *viz*., X_1, X_2 and X_3 were converted into their real form as orifice size (A), suction pressure (B), and forward speed (C), respectively, using the following equations:

$$xi = \frac{Xi - Xm}{XD} \tag{5}$$

Here i = 1, 2 and 3

$$X_D = \frac{Xmax - Xm}{am} \tag{6}$$

$$X_m = \frac{X_{max} - X_{min}}{2} \tag{7}$$

$$a_m = 2^{0.25k} \tag{8}$$

Nonlinear second-order regression equations, Eqn. (9), was developed to optimise the miss index (MI), multiple index (MI), quality feed index (QFI) and precision index (PI) for response as functions of the coded value of the independent parameters.

Each treatment was recorded to evaluate the metering drum in terms of miss index, multiple index, quality feed index and precision index by taking 60 observations of the spacing between seeds on sand bed test setup. The experiment was conducted at three levels of orifice size (2.5, 3 and 3.5 mm), three levels of forward speed (1, 1.5 and 2 km h^{-1}), and three levels of suction pressure (2, 3 and 4 kPa). Regression equations (Second-order polynomial equation) as shown in equation 9 was generated to predict the values of dependent parameters.

$$R_v = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{12} AB + \beta_{13} AC + \beta_{23} BC \quad (9)$$

Where;
R_v is the response variable whose equation is to be determined. β_0, β_1, β_2, β_3, β_{11}, β_{22}, β_{33}, β_{12}, β_{23}, and β_{33} are regression coefficients. A, B, and C are the coded linear terms for orifice diameter, suction pressure, and drum rotational speed, respectively. A^2, B^2, C^2 are the quadratic terms respectively and AB, AC, and BC are interaction of independent parameters respectively. The objective was to achieve metering with minimized miss, multiple and precision indices and maximized quality feed index.

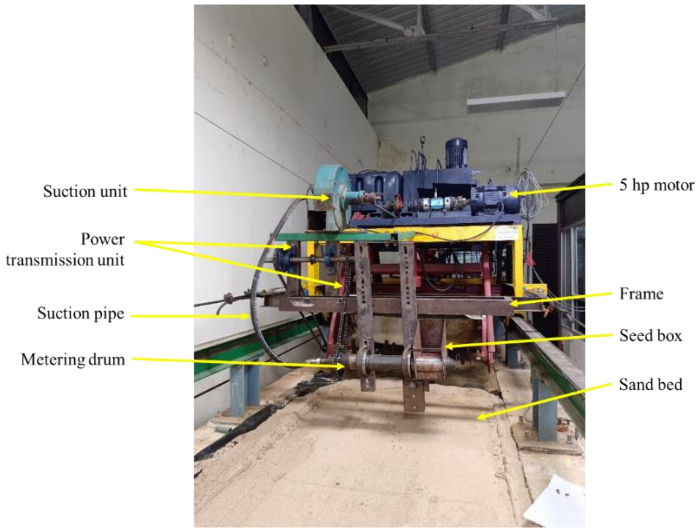


Fig. 1. Sand bed test rig setup for laboratory testing of developed PTPP in the soil test bin

Table 1. Experimental design for conducting the study (design: CCRD, total no. of experiment: 20)

S. No.	Variable	Level 1 (-1.68)	Level 2 (-1)	Level 3 (0)	Level 4 (+1)	Level 5 (+1.68)
1	Orifice diameter (A), mm	2.15	2.5	3	3.5	3.84
2	Suction pressure (B), kPa	1.31	2	3	4	4.68
3	Forward speed (C), ms^{-1}	0.65	1	1.5	2	2.3

3. RESULTS AND DISCUSSION

A laboratory experiment was conducted to study the effect of orifice size (A), suction pressure (B) and forward speed (C) of PTPP for cotton seeds on missing index (MI), multiple index (MUI), and quality of feed index (QFI) and precision index (PI). Results of laboratory experiment at different combinations of independent parameters are given in Table 2.

The coefficients (in coded values) and ANOVA of second order polynomial regression models of the responses viz. orifice size (A), suction pressure (B) and forward speed (C) of PTPP for cotton seeds on missing index (MI), multiple index (MUI), and quality of feed index (QFI) and precision index (PI) are presented in Table 3.

3.1 Evaluation of Metering System of Pneumatic Planter under Laboratory Condition

In assessing the metering system of the pneumatic planter under controlled laboratory conditions, the decision to employ a quadratic equation for the dependent parameter stems from its ability to capture nonlinear relationships between variables. The selection of this equation is justified by the recognition that the performance of the metering system may not strictly adhere to linear patterns, especially considering factors such as varying seed size, air pressure, and mechanical inconsistencies. Jadhav [20] and Manoharan [21] also presented the equation in same manner. By opting for a quadratic model, the evaluation can better accommodate the potential curvature and intricate interactions among these variables, thereby enhancing the accuracy and robustness of the analysis. This approach allows for a more comprehensive understanding of behaviour of the metering system and facilitates the identification of optimal settings for improved performance and efficiency in pneumatic planting operation.

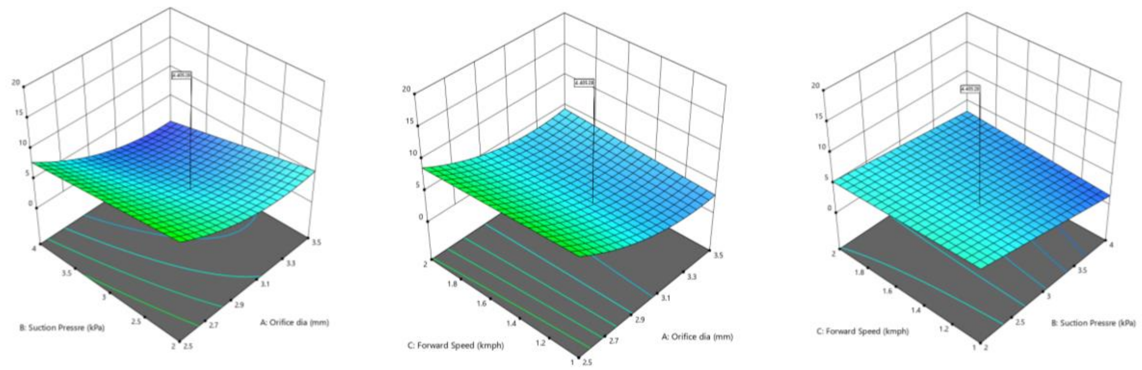
Miss Index (MI): The ANOVA analysis highlighted significant impacts of orifice size, suction pressure, and forward speed on the missing index (MI) of developed planter, as shown in Table 2. The model for the missing index achieved statistical significance at the 0.05 level. Fig. 2(a) visually represents the significant two-way interactions affecting the missing index. Notably, increasing orifice diameter under constant suction pressure and vice versa led to decreases in the missing index (Fig. 2(a)). Further investigation showed that at an optimized suction pressure of 2.7 kPa, initial decreases in the missing index with increasing orifice diameter transitioned to gradual decreases at higher levels of orifice diameter (Fig. 2(b)). Conversely, variations in forward speeds at a specific orifice size had minimal impact on the missing index (Fig. 2(c)). At an optimized orifice diameter of 3 mm, an initial steep decline in the missing index was observed with increasing suction pressure at a constant forward speed, as depicted in Fig. 2. The regression equation for miss index for optimum operational parameters are given as

$$\text{Miss Index (MI)} = 106.83 - 55.93\,A + 8.34\,A^2 \quad (10)$$

Where,
A is the coded orifice size, B is the coded suction pressure and C is the coded forward speed.

The models are valid for the following conditions:

$2.5 \text{ mm} \geq A \geq 3.5 \text{ mm}$,
$2 \text{ kPa} \geq B \geq 4 \text{ kPa}$,
$1 \text{ m/s} \geq C \geq 2 \text{ m/s}$,



(a) Orifice size x Suction pressure (AB) **(b) Orifice size x Forward speed (AC)** **(c) Suction pressure x Forward speed (BC)**

Fig. 2. Comparison of different performance indices (level of significance, 5) for miss index

Table 2. ANOVA for responses (multiple, feed and precision) index of power tiller cotton planter

Source	MI, %	MUI, %	QFI, %	PI, %
	"F" value with significance			
Model	3.55*	5.67**	47.84***	6.67**
A- Orifice diameter	12.65**	0.0343	184.98***	6.29*
B- Suction pressure	4.29^{ns}	29.67***	57.96***	7.06*
C- Forward speed	0.09^{ns}	0.9571^{ns}	2.64^{ns}	30.77***
AB	0.33^{ns}	9.24*	40.63***	0.74^{ns}
AC	0.34^{ns}	2.31^{ns}	40.63***	0.10^{ns}
BC	0.34^{ns}	2.31^{ns}	40.63***	2.59^{ns}
A^2	6.81*	0.3382^{ns}	53.55***	2.92^{ns}
B^2	ns	0.7414^{ns}	10.79**	7.26*
C^2	ns	5.31*	0.55^{ns}	4.65^{ns}
Mean	5.5	6	88.5	4.77
R^2	0.67	0.83	0.97	0.85

***= highly significant (p<0. 01), **= significant at 1% level of significance (0.01<= p<0.05), *= significant at 5% level of significance (0.05 <= p< 0.10), ns= Not significant (>= 0.10), SOV= Source of variation, R^2 = coefficient of determination

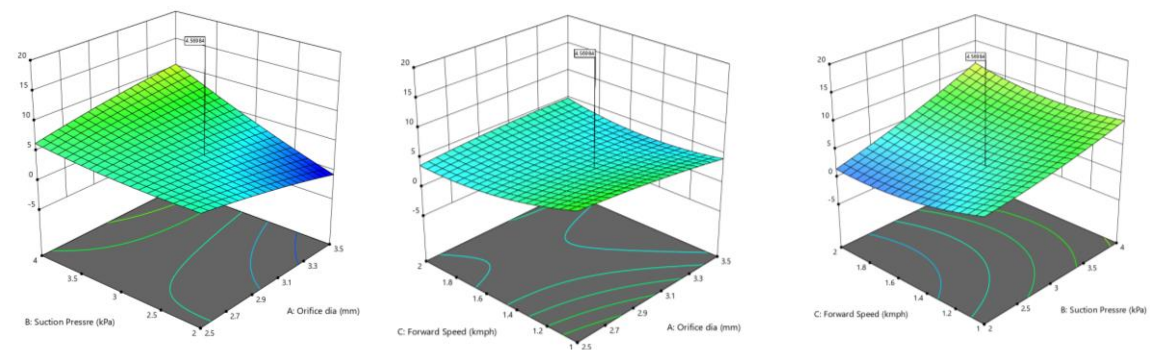
Table 3. Regression model coefficients (coded values) and ANOVA of second order polynomial regression models of the responses

Source	MI, %	MUI, %	QFI, %	PI, %
	Coded values of regression coefficients			
Intercept	+5.11	+4.92	+89.97	+4.07
A	-2.95*	-0.12 ^{ns}	3.06***	-0.40*
B	-1.71*	+3.43***	-1.71***	-0.43*
C	+0.25 ^{ns}	-0.62 ^{ns}	0.37 ^{ns}	0.89***
A × B	-0.63 ^{ns}	+2.50*	-1.87***	0.18 ^{ns}
A × C	+0.63 ^{ns}	+1.25 ^{ns}	-1.88***	0.068 ^{ns}
B × C	+0.63 ^{ns}	+1.25 ^{ns}	-1.88***	0.34 ^{ns}
A^2	+1.96*	-0.36 ^{ns}	-1.60***	0.27 ^{ns}
B^2	+0.19 ^{ns}	+0.53 ^{ns}	-0.72**	0.42*
C^2	-1.58 ^{ns}	+1.41*	0.16 ^{ns}	0.34 ^{ns}
	ANOVA			
Model	3.55*	5.67**	47.84***	6.67**
LoF	ns	ns	ns	ns
R^2	0.78	0.83	0.97	0.85
Adj. R^2	0.58	0.68	0.95	0.72
Pred. R^2	-0.65	-0.24	0.81	0.08
Adeq. Pre.	8.63	8.72	24.72	8.19

*MI = Miss index; MUI = Multiple index; QFI = Quality feed index; PI = Precision index; D = Orifice diameter, mm; P = Suction pressure, kPa; S = Forward speed, km/h; LoF = Lack of fit; R^2 = Coefficient of determination; Adj. R^2 = Adjusted R^2; Pred. R^2 = Predicted R^2; Adeq. Pre. = Adequate precision; *** = Highly significant at <0.01% level of significance; ** = Significant at 1% level of significance, * = Significant at 5% level of significance; ns= non-significant.*

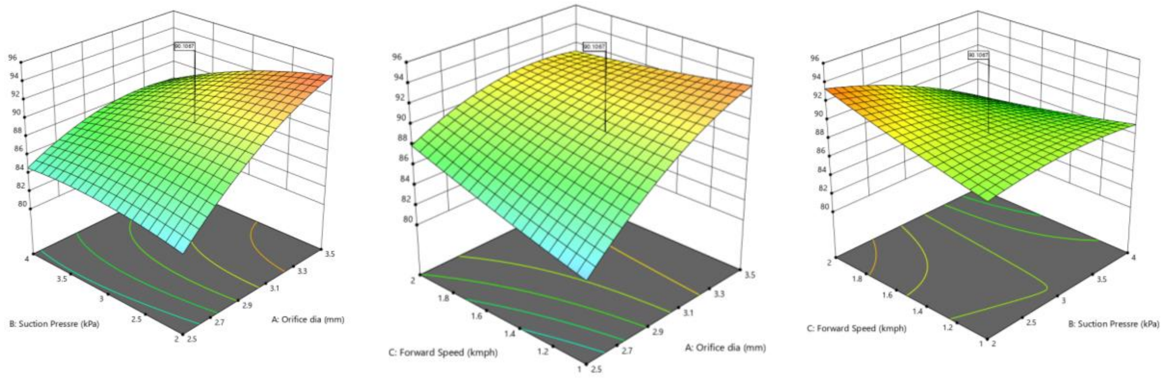
Multiple Index (MUI): The Multiple Index (MUI) represents the percentage of spacings equal to or less than half the set plant distance S in mm. Table 2 indicates the significant model for the multiple index at less than 1% level of significance. Fig. 3 illustrates the three-dimensional graphs depicting the significant two-way interactions influencing the multiple index. Notably, increasing orifice diameter under constant suction pressure and vice versa resulted in increased multiple index (Fig. 3(a)). Similarly, at an optimized suction pressure of 2.7 kPa, initially decreasing the orifice diameter at a constant forward speed led to a gradual decrease in the multiple index at higher levels of orifice diameter (Fig. 3(b)). The change in the multiple index for various forward speeds at a specific orifice size initially displayed a sharp decrease, which gradually became more gradual at the highest level of forward speed (Fig. 3(c)). At an optimized orifice diameter of 3 mm, increasing suction pressure at a constant forward speed sharply increased the multiple index, as depicted in Fig. 3. Panning et al. [22], and Singh et al. [4] also reported similar findings. The regression equation for multiple index for optimum operational parameters are given as:

$$\text{Multiple Index (MUI)} = 80.55 - 18.48\,B + 5\,AB + 5.64\,C^2 \quad (11)$$



(a) Orifice size x Suction pressure (AB) **(b) Orifice size x Forward speed (AC)** **(c) Suction pressure x Forward speed (BC)**

Fig. 3. Comparison of different performance indices (level of significance, 5) for multiple index



(a) Orifice size x Suction pressure (AB) **(b) Orifice size x Forward speed (AC)** **(c) Suction pressure x Forward speed (BC)**

Fig. 4. Comparison of different performance indices (level of significance, 5) for quality feed index

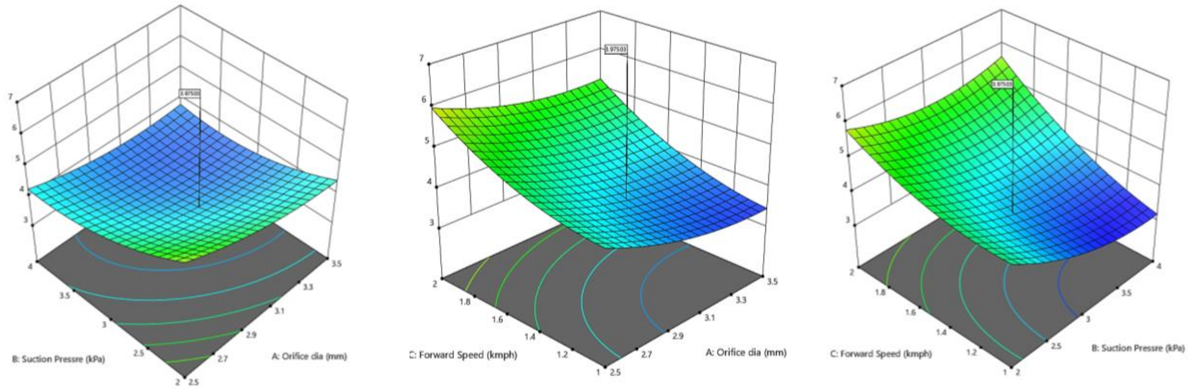
Quality Feed Index (QFI): Quality of feed index (QFI) is an important parameter for the assessment of the performance of the metering device. The occurrence of single seed drops in the furrow during the sowing operation. Both Table 2 and Table 3 demonstrate the highly significant model for QFI at less than 0.01% level of significance. All individual terms show a high significant effect on QFI, except for forward speed, possibly due to its limited range, further investigate interactions with highly significant effects (Table 2). Fig. 4 illustrates the 3D graphs of the interaction effect of orifice diameter and suction pressure at an optimized forward speed (1.3 km/h) on the QFI parameter, showing a significant increase in QFI with increasing orifice diameter and suction pressure (Fig. 4(a)). Similarly, in the interaction between orifice diameter and forward speed at an optimized suction pressure (2.7 kPa), QFI increased with increasing orifice diameter at a constant forward speed, while a gradual decrease in QFI was observed with increasing forward speed at a specific orifice size (Fig. 4(b)). At an optimized orifice diameter of 3 mm, the quality feed index improved with higher suction pressure at a constant forward speed, as depicted in Fig. 4(c). The regression equation for quality index for optimum operational parameters are given as

$$\text{Quality Feed Index (QFI)} = -71.47 + 67.11\,A + 19.48\,B - 3.77\,AB - 7.50\,AC - 3.75\,BC - 6.41\,A^2 - 0.71\,B^2 \qquad (12)$$

Precision Index (PI): Precision index is a function of the seed spacing and deviation of seed from its targeted point. Observations from the ANOVA presented in Tables 2 and 3 indicate that the model for the quality feed index is statistically significant, at a level of significance below 0.1%. Notably, both the linear and quadratic terms of suction pressure individually exhibit significant effects on the precision index (Fig. 5) whereas, the linear term of forward speed does not demonstrate a significant impact. Additionally, the combined influence of any two independent parameters does not affect the precision index. Consequently, graphical interactions are not addressed for the precision index. The model reveals that the linear term of forward speed carries a negative sign, while the quadratic term exhibits a positive sign. This behaviour suggests that the precision index decreases up to a central value and increases thereafter. The regression equation for precision index for optimum operational parameters are given as

$$\text{Precision Index (PI)} = 29.07 - 8.71\,A - 5.05\,B - 5.10\,C + 1.34\,C^2 \qquad (13)$$

The optimization of metering operation is facilitated through a graphical approach utilizing the overlay plot tool of Design Expert software. Fig. 6 illustrates the graph generated based on the solution proposed by the numerical approach. In this graph, the curves representing all responses are overlaid in a single figure to depict the interaction between orifice diameter and suction pressure at the optimized forward speed of 1.3 km/h. The desirable area is highlighted in yellow on the graph, bounded by the curves of various responses from all sides. This plot provides a comprehensive understanding of the behavior of all responses simultaneously.



(a) Orifice size x Suction pressure (AB) **(b) Orifice size x Forward speed (AC)** **(c) Suction pressure x Forward speed (BC)**

Fig. 5. Comparison of different performance indices (level of significance, 5) for Precision index

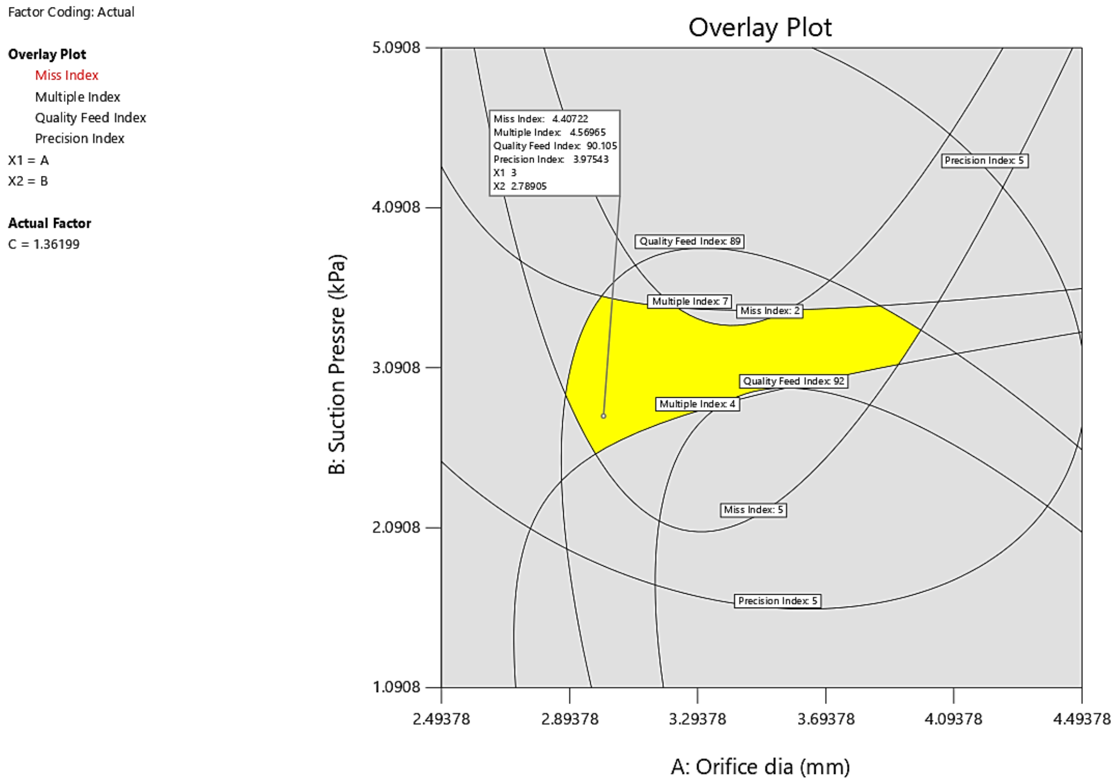


Fig. 6. Overlay plot between orifice size and suction pressure

3.2 Optimization of Operating Parameters

An instrumented test rig of sand bed was prepared to study the effect of orifice size, suction pressure and forward speed on performance of pneumatic metering mechanism for cotton seeds. The optimum values of independent parameters that maximize the performance of planter were obtained from the numerical optimization technique facilitated by software and compared with the actual field data presented in Table 4. The models for different dependent parameters were developed with the help of the quadratic equation of independent parameters. The ANOVA showed that the models of missing index, multiple index, quality of feed index and precision index are significant.

Table 4. Predicted and optimized values of parameters

Constraints	Goal	Optimized/predicted values	Actual Values
Orifice size, mm	In range	3.00	3.00
Suction pressure, kPa	In range	2.78	2.78±0.15
Forward speed, m/s	In range	1.36	1.35±0.10
Miss Index, %	Minimize	4.40	7.6±2.5
Multiple Index, %	Minimize	4.56	6.8±1.6
Quality Feed Index, %	Maximize	90.1	82.4±2.5
Precision Index, %	Minimize	3.90	4.1±1.2

Table 5. Validation of regression model through confirmation tool

Response	Mean	Median	SD	n	SE prediction	95% PI low	Data mean	95% PI high
Miss index	5.10	5.10	2.73	5	1.66	1.42	5.68	8.79
Multiple index	4.91	4.92	2.32	5	1.41	1.78	4.83	8.06
Quality feed index	89.97	89.98	0.83	5	0.50	88.85	89.49	91.10
Precision index	4.06	4.07	0.59	5	0.36	3.27	4.82	4.87

SD = Standard deviation; n= number of observations; SE= Standard error; PI = Prediction interval.

3.3 Validation

Validation involves comparing the outcomes forecasted by established regression models with the actual experimental values of the responses under the same independent parameter settings. This step is crucial to assess the appropriateness of the developed models for performance prediction. In this study, five replicates were carried out in the laboratory using optimized settings for orifice diameter (3 mm), suction pressure (2.7 kPa), and forward speed (1.3 km/h). The validation process was conducted using the confirmation tool in Design Expert software. The validation outcomes obtained from the confirmation tool are summarized in Table 5. The confirmation experiment was conducted at a significance level of 5%. It is observed that the mean values of all responses fall within the prediction interval of the confirmation tool. Consequently, the developed regression models accurately predict the behavior of the responses with reasonable precision.

4. CONCLUSION

Following meticulous experimentation, the optimization of parameters for developing a power tiller operated pneumatic planter for cotton seeds has yielded significant insights. Predictive analysis has revealed forward speed as the foremost determinant, profoundly influencing the missing index, multiple index, quality of feed index and precision index. Meanwhile, orifice size emerges as a critical factor significantly shaping the precision index. By optimizing to minimize the miss index, multiple index, and precision index, while maximizing the quality of feed index, optimal values for independent variables were discerned. Specifically, these optimized parameters entail an orifice size of 3 mm, suction pressure of 2.78 kPa, and forward speed of 1.36 km/h. Corresponding actual values of miss index, multiple index, quality feed index, and precision index were found 7.6±2.5, 6.8±1.6, 82.4±2.5 and 4.1±1.2 against predicted values of 4.40, 4.56, 90.1, and 3.90, respectively. These findings offer practical guidance for optimizing planting operations and hold promise for enhancing the efficiency and effectiveness of pneumatic planting technologies available for cotton seed cultivation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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