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Studies on Controlling Variables of the Conveying Unit of a Power Tiller Operated Groundnut Digger

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Authors' contributions

All authors contributed to the final version of the manuscript. Author DB had the idea for the article. Author Kamendra performed the experimental work and authors DB, SKS and MM helped in analysis and interpretation of results. Authors USP and DC contributed in draft manuscript preparation. All authors reviewed the results and approved the final manuscript.

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ABSTRACT

A power tiller operated groundnut digger was designed and developed in the Dept. of Farm Machinery and Power Engineering, CAET, OUAT, Bhubaneswar during 2021–22. The objective of this project was to optimize the operational parameters of the digger's conveying unit using the RSM technique. The study analysed the effects of soil moisture content and conveyor speed, on the conveying efficiency and soil separation efficiency with two different types of peg geometries. The central composite rotatable design (CCRD) method with a quadratic model was utilized to

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correlate the independent parameters with the conveying and soil separation efficiencies. The results indicated that variations in soil moisture content and conveyor speed had a significant impact on the conveying and soil separation efficiencies. The optimum parameters for the conveying unit of a power tiller operated groundnut digger were found to be a soil moisture range of 9.0-12.0%, a conveyor speed of 1.0 m/s and straight shank with bending tip pegs, resulting in a conveying efficiency and soil separation efficiency of 89.45% and 71.45%, respectively.

Keywords: Groundnut digger; soil moisture content; conveyor speed; conveying efficiency; soil separation efficiency; optimization.

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a significant crop in India's agricultural economy, particularly in Odisha where it is the sixth highest producing state. The cultivation of oilseed crops covers 6.02 lakh ha, with groundnut alone occupying 2.05 lakh [1,2]. The major unit operations in groundnut cultivation involve several steps from seedbed preparation to harvesting and threshing. Mechanical digging is a crucial operation in groundnut harvesting, where the entire crop must be lifted from the soil without damaging or detaching the pods and subsequently conveyed by a conveyor for windrowing. The conveyor system picks up the dugout plants, shakes them to remove soil adhering to the pods and conveys them to the rear of the machine for easy collection on the harvested ground. The efficiency of the conveyor system is affected by operational parameters such as soil moisture content, conveyor speed and peg geometry [3,4,5]. Optimizing these parameters can enhance the efficiency of the mechanical digging process, which is essential for increasing yield and reducing labour costs.

2. MATERIALS AND METHODS

2.1 Design Considerations

The agronomic practices for cultivating groundnut crops include a row spacing of 300 mm, with pod distribution zones of 120-140 mm on either side of a plant and a pod depth of 40-70 mm [6-8,9]. The designed digger is capable of harvesting a single row of groundnut crop. To improve conveying efficiency and cover a wider range of groundnut varieties, the operating width of the digger and conveyor was set at 400 mm and 500 mm, respectively. The soil and operational parameters chosen for groundnut harvesting in this study are presented in Table 1.

2.2 Details of the Conveying Unit

The mounting frame of the conveyor was fabricated with 40 x 40 mm mild steel (MS) hollow square bar. The conveyor unit consisted of two shafts i.e., main shaft and driven shaft, mounting on the self–aligned bearings fixed at a distance of 500 mm. The two endless roller chains and four sprockets with 25 mm pitch were used to transmit the power from the main shaft to the driven shaft of the conveyor. The chain has an attachment on which the conveying flats were fastened at a spacing of 100 mm to form an endless conveying unit. The conveying pegs (Fig. 2 (a) and (b)) were welded at 120 mm spacing on each conveying flats in a staggered manner. The front end of the conveyor frame was attached with the side flange extension and the delivery end was supported by the power tiller handle using MS flat through nuts and bolts as shown in Fig. 1.

Table 1. Designed and recommended parameters for the experiment

Parameters	Designed and Recommended shapes/values	References
Conveyor, L × W (mm)	700 × 500	
Peg geometries	a. Straight shank with bending tip (135° end projection) b. Triangular	[4,10]
Conveyor speed (m/s)	0.8, 1.0, 1.2	[10,5]
Width of operation (mm)	400	
Forward speed of digger (m/s)	0.42	
Soil moisture content (%)	6.0–9.0, 9.0–12.0, 12.0–15.0	

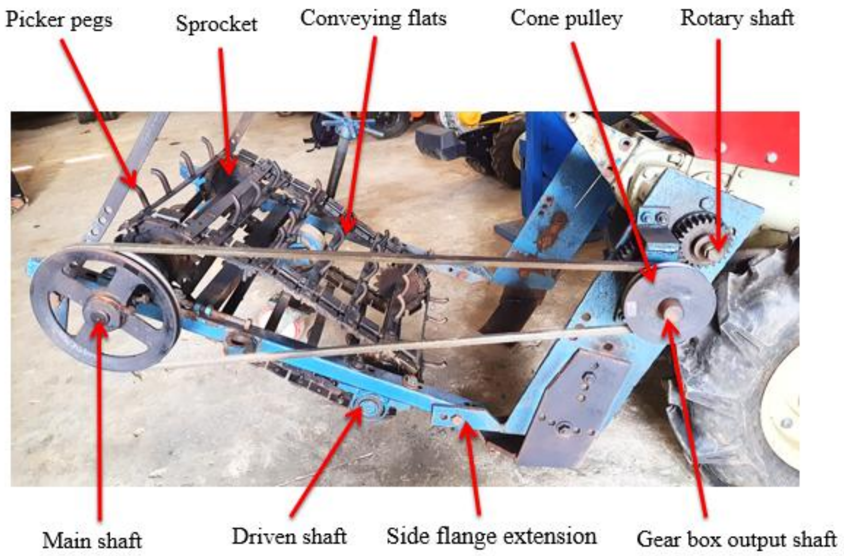


Fig. 1. Conveying unit of a power tiller operated groundnut digger

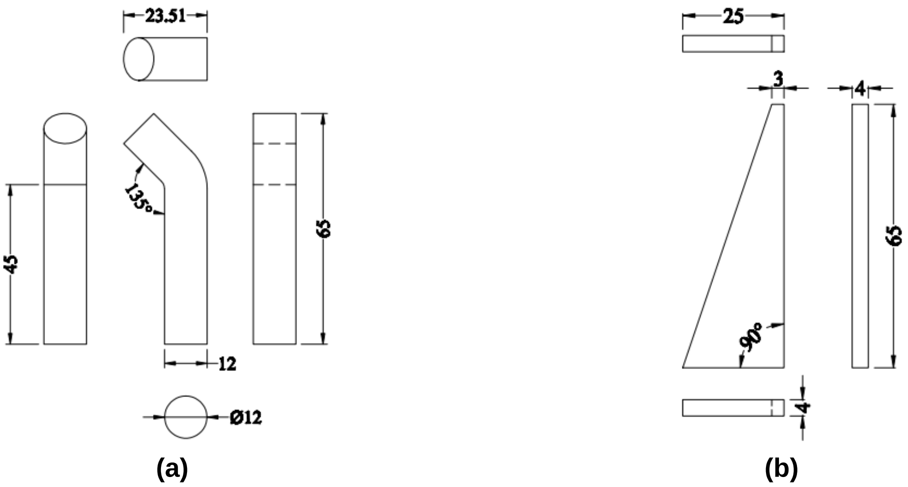


Fig. 2. Different views of peg (a) Straight shank with bending tip peg and (b) Triangular peg

2.3 Power Transmission of the Conveying Unit

The main shaft of the conveyor unit was operated by the rotary shaft of the power tiller through the output shaft of the gearbox using belt and pulley. A stepped cone drive pulley with diameters of 75, 100 and 125 mm was mounted on the output shaft of the gearbox and another driven pulley of 240 mm diameter was mounted on the main shaft of the conveyor in order to run the conveying unit at three different speeds of 0.8, 1.0, and 1.2 m/s. Both main shaft and driven shaft of the conveying unit was operated by using chain and sprocket as shown in Fig. 3. The effect of soil moisture content (6.0–9.0, 9.0–12.0 and 12.0–15.0%) and conveyor speed (0.8, 1.0 and 1.2 m/s) on conveying efficiency and soil separation efficiency were investigated in the experimental field of OUAT with two different types of peg geometries (straight shank with bending tip pegs and triangular pegs).

2.4 Experimental Procedure

The experimental field was irrigated before harvesting of the crop in order to maintain the soil moisture content in the above specified ranges. The selected conveyor speed of 0.8, 1.0 and 1.2 m/s were obtained by changing the pulley ratio. The groundnut digger (Fig. 4 (a) and (b)) was run for 20 meters at a forward speed of

0.42 m/s and the observations were recorded. The data on number of plants in a given distance, the number of plants conveyed, number of plants not conveyed, weight of the plant at picking end and delivery end were recorded during the performance evaluation of the digger. The experiment was replicated at all three ranges of soil moisture content (6.0–9.0, 9.0–12.0 and 12.0–15.0%) and conveyor speeds (0.8, 1.0 and 1.2 m/s) for both peg geometries.

The conveying efficiency and soil separation efficiency of the conveyor was calculated by the following formula [4]:

$$\text{Conveying efficiency (\%)} = \frac{\text{Total number of plants conveyed at the delivery end}}{\text{Total number of dugout plants in given distance}} \times 100 \ldots \quad (1)$$

$$\text{Soil separation efficiency (\%)} = \frac{\text{Total weight of the plant at the delivery end}}{\text{Total weight of the plant fed at the picking end}} \times 100 \ldots \quad (2)$$

2.5 Data Analysis, Statistical Modelling and Numerical Optimization of Independent Parameters

Data analysis, statistical modelling and optimization were performed using response surface method (RSM), a technique suitable for optimizing experimental parameters with fewer experiments and analyzing parameter interactions [11]. To reduce the number of experiments and optimize parameters, the central composite rotatable design (CCRD) with a quadratic model was employed. Experimental data regression analysis was conducted using Design Expert software (Version 13.0, Stat–Ease, Statistics Made Easy, Minneapolis, MN, USA). The desirability function technique was used to determine the optimal combination of operational parameters (soil moisture content and conveyor speed) for maximizing conveying and soil separation efficiency [12].

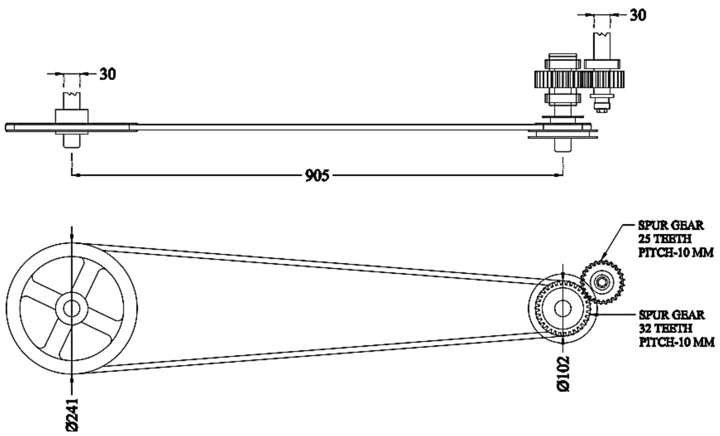
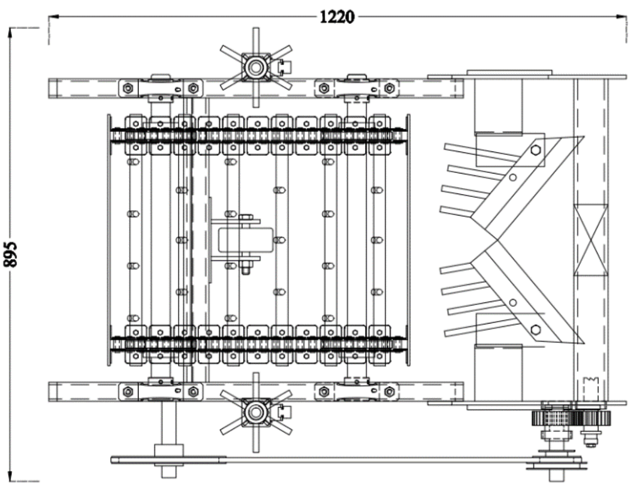
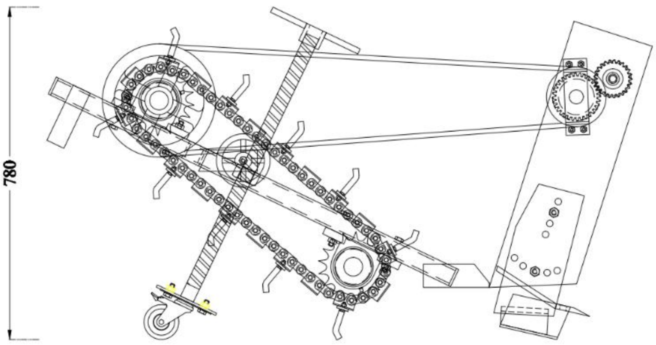


Fig. 3. Power transmission system of the conveying unit



(a)



(b)

Fig. 4. CAD views (a) Top view (b) Side view of prototype groundnut digger

3. RESULTS AND DISCUSSION

The power tiller operated groundnut digger was evaluated in the field with various combinations of independent parameters. The performance of the conveying unit of the digger was studied with respect to conveying efficiency and soil separation efficiency at the different levels of independent parameters.

3.1 Effect of Soil Moisture Content and Conveyor Speed on Conveying Efficiency for Both the Peg Geometries

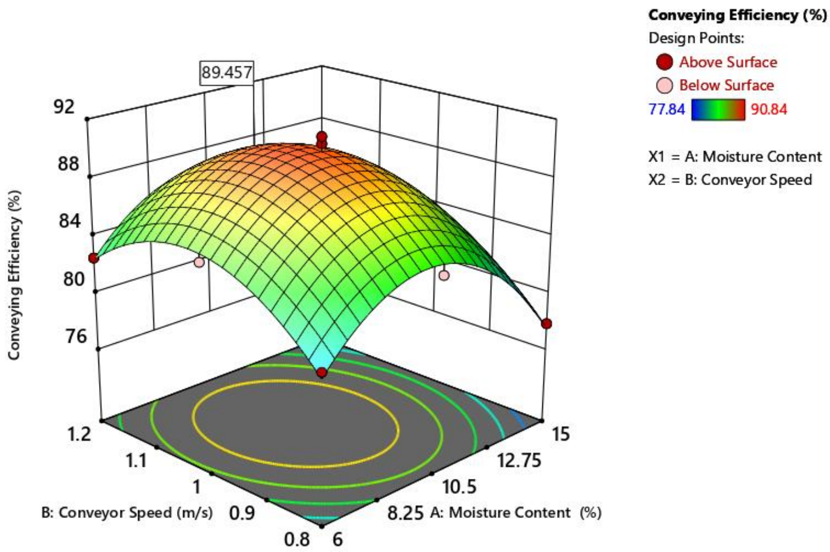
The effect of soil moisture content and conveyor speed on conveying efficiency of the groundnut digger for straight shank with bending tip pegs and triangular pegs has been shown in Fig. 5. The response surface plot shows the interaction of conveying efficiency, soil moisture content and conveyor speed.

For the straight shank with bending tip pegs, it was observed that at a soil moisture content of 12.0-15.0%, the conveying efficiency was 77.84, 82.21 and 79.24% at the conveyor speed of 0.8, 1.0 and 1.2 ms^{-1}, respectively. At soil moisture content of 9.0-12.0% and 6.0-9.0%, the conveying efficiencies were found to be 84.04, 90.84 & 86.54% and 80.78, 84.90 & 82.52% at the conveyor speed of 0.8, 1.0 and 1.2 ms^{-1}, respectively.

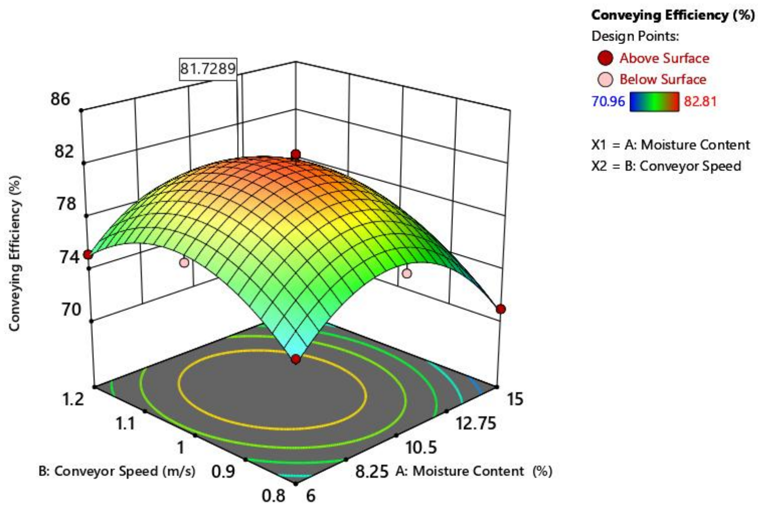
For the triangular pegs, the conveying efficiency was found to be 70.96, 74.95 and 72.23% at the conveyor speed of 0.8, 1.0 and 1.2 ms^{-1}, respectively, within a soil moisture content of 12.0-15.0%. For soil moisture content of 9.0-12.0% and 6.0-9.0%, the conveying efficiencies were 76.61, 82.81 & 78.89% and 73.64, 77.39 & 75.22% at the conveyor speed of 0.8, 1.0 and 1.2 ms^{-1}, respectively.

It is observed that the conveying efficiency increased with soil moisture content ranging from 6.0-9.0% to 9.0-12.0%, but decreased when soil moisture content increased from 9.0-12.0% to 12.0-15.0% for both peg geometries. Lower soil moisture content (6.0-9.0%) caused plants to be uprooted with large clods, making them heavier and harder for the pegs to gather, resulting in lower conveying efficiency. Higher soil moisture content (12.0-15.0%) led to lower soil strength, causing the entire plant to be uprooted instead of being cut. This caused the plants to move with the blades in the field, making it difficult for the conveying unit's pegs to pick them up, resulting in lower conveying efficiency.

It is also observed that the conveying efficiency increased with increase in conveyor speed from 0.8 to 1.0 ms^{-1} and then decreased with the increase in conveyor speed from 1.0 to 1.2 ms^{-1}. The reason may be due to fact that at lowest conveyor speed of 0.8 ms^{-1}, the quantity of crop harvested by the digging unit is unable to be handled by the conveying unit resulting in clogging. At a highest conveyor speed of 1.2 ms^{-1}, although there was no clogging but some of the harvested crop kept rolling over the conveying unit continuously. However, at a conveyor speed of 1.0 ms^{-1}, neither of these problems occurred, which could be due to better synchronization of the forward speed and conveying unit speed [13].



(a)



(b)

Fig. 5. Response surface and contour plots for the conveying efficiency with soil moisture content and conveyor speed (a) straight shank with bending tip pegs (b) triangular pegs

3.2 Effect of Soil Moisture Content and Conveyor Speed on Soil Separation Efficiency for Both the Peg Geometries

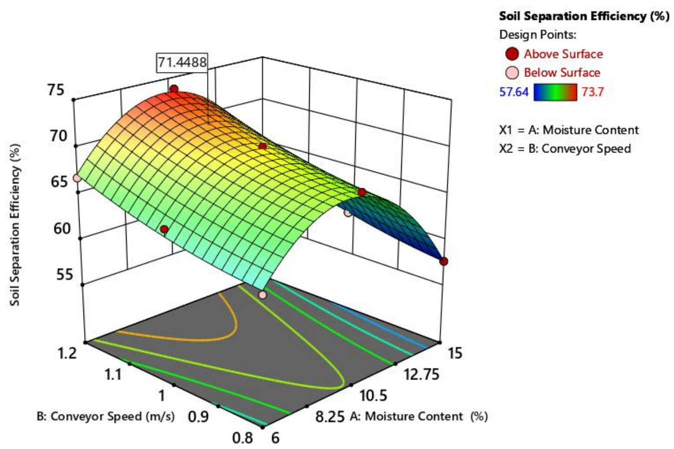
The effect of soil moisture content and conveyor speed on soil separation efficiency of the groundnut digger for both straight shank with bending tip pegs and triangular pegs geometries has been shown in Fig. 6. The response surface plot demonstrates the interaction of soil separation efficiency, soil moisture content and conveyor speed.

For the straight shank with bending tip pegs, it was observed that at 12.0-15.0% soil moisture content the soil separation efficiency was found to be 57.64, 59.71 and 63.54% at the conveyor speed of 0.8, 1.0 and 1.2 ms^{-1}, respectively. At soil moisture content of 9.0-12.0% and 6.0-9.0%, the soil separation efficiencies were observed to be 68.42, 70.08 & 73.70% and 61.81, 64.68 & 66.78% at the conveyor speed of 0.8, 1.0 and 1.2 ms^{-1}, respectively.

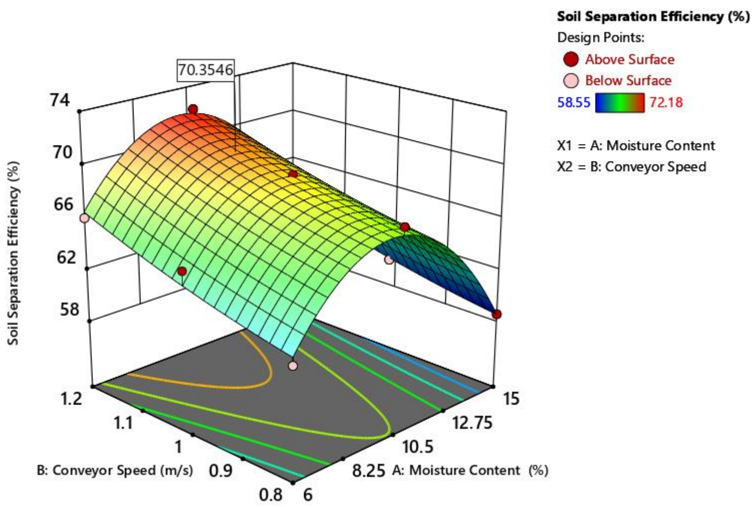
For the triangular pegs, it was observed that at a soil moisture content of 12.0-15.0%, the soil separation efficiency was observed to be 58.55, 60.08 and 62.88% at the conveyor speed of 0.8, 1.0 and 1.2 ms^{-1}, respectively. At soil moisture content of 9.0-12.0% and 6.0-9.0%, the soil separation efficiencies were found to be 67.96, 68.49 & 72.18% and 61.13, 64.79 & 66.05% at the conveyor speed of 0.8, 1.0 and 1.2 ms^{-1}, respectively.

It is observed that the soil separation efficiency increased with the decrease in soil moisture content from 12.0-15.0% to 9.0-12.0% and then decreased as the moisture level decreased further to 6.0-9.0% for both the peg geometries. The increase in adhesive forces between soil and pods with higher moisture content made it challenging for the conveyor to separate the pods from the soil, resulting in reduced soil separation efficiency [14]. At lower moisture content (6.0-9.0%), cohesive forces between soil particles increased, leading to larger clods that were difficult for the conveyor to break [15]. In the moisture content range of 9.0-12.0%, the soil was drier and more friable, resulting in weaker adhesive forces between soil and pods [16], which improved soil separation efficiency as the soil was more likely to fall away from the harvested pods [17].

It is also observed that the soil separation efficiency increased with increase in conveyor speed from 0.8 to 1.2 ms^{-1}. This may be due to the fact that increase in conveyor speed increases the level of vibration of the conveyor [4].



(a)



(b)

Fig. 6. Response surface and contour plots for the soil separation efficiency with soil moisture content and conveyor speed (a) straight shank with bending tip pegs (b) triangular pegs

Table 2. ANOVA for the effect of parameters on conveying efficiency and soil separation efficiency for a Quadratic model

Source	Conveying efficiency (%)						Soil Separation Efficiency (%)					
	Straight shank with bending tip pegs			Triangular pegs			Straight shank with bending tip pegs			Triangular pegs		
	F–value	P–value	Regression Coefficient	P–value	F– value	Regression Coefficient	F–value	P–value	Regression Coefficient	P–value	F–value	Regression Coefficient
Model	61.22	0.0002**		52.75	0.0003**		139.19	< 0.0001**		65.79	0.0001**	
A	21.13	0.0059**	-1.49	17.74	0.0084**	-1.35	74.26	0.0003**	-2.06	32.02	0.0024**	-1.74
B	8.47	0.0334*	0.94	7.1	0.0447*	0.855	126.37	< 0.0001**	2.69	53.09	0.0008**	2.25
AB	0.046	0.8384^{ns}	-0.085	0.038	0.8515^{ns}	-0.0775	0.6286	0.4638^{ns}	0.23	0.1528	0.712^{ns}	-0.14
A^2	137.48	< 0.0001**	-5.83	118.35	0.0001**	-5.37	480	< 0.0001**	-8.07	232.56	< 0.0001**	-7.23
B^2	67.82	0.0004**	-4.09	58.98	0.0006**	-3.79	4.62	0.0844^{ns}	0.79	0.7257	0.4332^{ns}	-0.40
Lack of Fit	0.59	0.6747^{ns}		0.577	0.6839^{ns}		2.66	0.2848^{ns}		4.85	0.1758^{ns}	
Statistical measures												
R^2	0.983			0.981			0.992			0.985		
Adjusted R^2	0.967			0.962			0.985			0.970		
Predicted R^2	0.926			0.916			0.950			0.884		
SD (±)	0.791			0.786			0.586			0.754		
CV (%)	0.938			1.02			0.889			1.150		

*** Significant at 1% level of significance, * Significant at 5% level of significance, ns- Not significant*

Table 3. Optimized solutions for straight shank with bending tip pegs and triangular pegs with V-blade geometry

Peg geometry	Soil moisture content (%)	Conveyor speed (m/s)	Conveying efficiency (%)	Soil separation efficiency (%)	Desirability
Straight shank with bending tip pegs	9.93	1.09	89.45	71.45	0.877
Triangular peg	9.92	1.08	81.72	70.35	0.887

3.3 Data Analysis and Statistical Modelling for Conveying Efficiency and Soil Separation Efficiency

The analysis of variance (ANOVA) of the conveying efficiency and soil separation efficiency for fitting of quadratic model to experimental data was performed and is shown in Table 2. It was observed that the soil moisture content (A) and conveyor speed (B) had a significant effect on the conveying efficiency and soil separation efficiency but their interaction (AB) was found to be non-significant for both the peg geometries. The empirical model (Eq. 3, Eq. 4, Eq.5 and Eq. 6) in terms of coded factors has been developed to express the relationship between the independent parameters and responses for straight shank with bending tip pegs and triangular pegs, respectively.

Straight shank with bending tip pegs,

$$\text{Conveying efficiency (\%)} = 89.81 - 1.49A + 0.94B - 0.085AB - 5.83A^2 - 4.09B^2 \ldots \quad (3)$$

$$\text{Soil separation efficiency (\%)} = 69.91 - 2.06A + 2.69B + 0.23AB - 8.07A^2 + 0.79B^2 \ldots \quad (4)$$

Triangular pegs,

$$\text{Conveying efficiency (\%)} = 81.97 - 1.35A + 0.85B - 0.076AB - 5.37A^2 - 3.79B^2 \ldots \quad (5)$$

$$\text{Soil separation efficiency (\%)} = 69.21 - 1.74A + 2.25B - 0.14AB - 7.23A^2 - 0.40B^2 \ldots \quad (6)$$

3.4 Numerical Optimization of the Independent Parameters

For optimization of conveying efficiency and soil separation efficiency, they were set to their possible maximum and the solution with maximum desirability for both peg geometries (0.877 for straight shank with bending tip pegs and 0.887 triangular pegs) were considered as the optimum solution, as given in Table 3. The values for straight shank with bending tip pegs at 0.877 desirability were found to be 9.93% soil moisture content, 1.09 m/s conveyor speed, 89.45% conveying efficiency and 71.45% soil separation efficiency. The corresponding values for the triangular pegs at 0.887 desirability were found to be 9.92%, 1.08 m/s, 81.72% and 70.35%, respectively.

4. CONCLUSIONS

The results revealed that the conveying efficiency and soil separation efficiency were significantly influenced by the soil moisture content and conveyor speed. The conveying efficiency and soil separation efficiency of straight shank with bending tip pegs (90.84% and 73.70 %) is found to be more than triangular pegs (82.81% and 72.18%) under similar conditions. The optimum values for straight shank with bending tip pegs at 0.877 desirability were found to be 9.93% soil moisture content, 1.09 m/s conveyor speed, 89.45% conveying efficiency and 71.45 % soil separation efficiency. The straight shank with bending tip pegs was the best for the design simplicity and should be used as a peg geometry in the conveying unit.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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