Optimization of Various Operational Parameters on Harvesting Efficiency of Developed Lathyrus Harvester Using Response Surface Methodology

Abstract

Lathyrus crop or grass pea is the third most important cool-season pulse crop of India, occupying an area of 0.58 million ha with an annual production of 0.43 million tonnes. The productivity is fluctuated between 369 to 605kg/ha. Till now traditional method (manually hand plucking/sickle) is the prevailing practice done in Chhattisgarh. These practices are tedious and time consuming as it required lot of man power. There is an urgent need of introducing modern practices for harvesting of the crop. Response surface methodology (RSM) was used for optimizing the performance parameters.Effects of various parameters viz. reel speed, cutter bar speed and height of cut which is considered as the heart of harvesting machine was evaluated to get optimum harvesting efficiency of developed tractor operated lathyrus harvester. The optimum harvesting efficiency of 90% was found at 30 mm height of cut, 250 rpm cutter bar speed and 12.5 rpm respectively.

1. Introduction

The grass pea [*Lathyrus sativus* (L.)] commonly known as *khesari* and*teora* is a food and fodder crop belonging to the family Leguminosae (Fabaceae). The cultivation of grass peas dated back to about 6000 BC and It contains 31.9 % protein (almost having twice the protein in wheat and thrice that of rice), 0.9% fat, 53.9% carbohydrate, 362.3 cal energy (Kuo *et al.,* 2000).Grass pea when compared to other legume crops found to have high yielding potential at low or zero levels of fertilization rate (Grela *et al*., 2010).The harvesting of grass pea is done when plant gets hard and changes colour from green to brownish. Indian agriculture witnessed unprecedented growth in farm mechanization. Mechanization conjointly helps in improving the utilization efficiency of other inputs, safety and comfort of the agricultural worker, enhancement within the quality and value addition of the produce.This shortage of unskilled labour also necessitates the development of appropriate machines to reduce dependence on manual labour.

Response Surface Methodology (RSM) is statistical analysis method extensively employed for optimizing performance parameters of an agricultural machine. It serves as a valuable tool in enhancing processes and systems by systematically adjusting factors to achieve optimal outcomes. This method reduces the number of experiment to be conducted to optimize the independent variable for the optimum performance of the machine.Myers *et al.* (2009) stated that the response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. It also had important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs.

2. Materials and Methods

Optimization method using RSM

The experiment was carried out by using second order polynomial equation in Central Composite Rotatable Design (CCRD). The three independent variable were selected i.e. reel speed, cutter bar speed and height of cut with selected dependent variableharvesting efficiency. Table 1 illustrates the description of the independent variables with response.

As per the CCRD design the selected four and five levels of each independent variable needs to be converted into coded variables. The selected five levels of coded variables in the design were -1.68, -1, 0, +1 and +1.68 **(**Myers *et al.*, 2009).The conversion of natural variables to the coded values was accomplished by using equations 1 to 4. The details of converted CCRD experimental levels are presented in Table 2.

$$x_i = \frac{X_i - X_m}{X_D} --- (1)$$

Where,

I = 1, 2, and 3

$$X_D = \frac{X_{max} - X_m}{a_m} --- (2)$$

$$x_m = \frac{X_{max} - X_{min}}{2} --- (3)$$

$$a_m = 2^{0.25k} --- (4)$$

Where,

x_i = Coded value of the ith variable;

X_i = Actual value of the ithvariable;

X_{max} = Maximum values of independent variables;

X_{min} = Minimum values of independent variables;

k = Number of independent variables considered for the optimization.

Table 1: Details of coded and converted CCRD experimental levels

S. No.	Variables	Level 1 (-1.68)	Level 2 (-1)	Level 3 (0)	Level 4 (+1)	Level 5 (+1.68)
1.	Reel speed, rpm	10	12.5	15	17.5	-

2.	Cutter bar speed, rpm	225	250	275	300	-
3.	Height of cut, mm	10	20	30	40	50

The following non linear second order regression equation 5 were developed for the independent variables in coded value to optimize the dependent parameter viz. harvesting efficiency.

$$\rho_e = b_0 + \sum_{i=0}^{3} b_i x_i + \sum_{i=1}^{3} b_{ii} x_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} b_{ij} x_i x_j --- (5)$$

Where,

ρ= Harvesting efficiency,%

Table 2: Experiment design for conducting the performance evaluation of the developed machine

Run	Reel speed, rpm	Cutter bar speed, rpm	Height of cut, mm
1	17.5	250	30
2	10	275	20
3	10	225	20
4	12.5	250	30
5	15	275	40
6	12.5	250	10
7	10	275	40
8	12.5	300	30
9	15	275	20
10	12.5	250	30
11	12.5	250	30
12	10	250	30
13	12.5	200	30
14	12.5	250	50
15	15	225	20
16	10	225	40
17	15	225	40
18	12.5	250	30
19	12.5	250	30
20	12.5	250	30

As per central composite rotatable design (CCRD), the different levels for each independent variable were fixed which gave the 20 experiments. The details of the 20 experiments are presented in Table 2. The performance evaluation of the developed machine was carried as per the given experimental design.

Harvesting efficiency

Number of lathyrus plants in 10 m length was counted before operation and the plants left in same 10 m length were counted after operation.

$$\text{Harvesting efficiency, \%} = \frac{W_1 - W_2}{W_1} \times 100 \qquad ---(6)$$

Where,

W_1 = Number of plants before cutting; and

W_2 = Number of plants after cutting.

Fig.1: Testing and performance evaluation of developed tractor operated lathyrus harvester at research farm, IGKV, Raipur

3. Result and Discussions

3.1 Effect of reel speed, cutter bar speed and height of cut on harvesting efficiency

The results obtained on by the experiment according to CCRD design on the reel speed, cutter bar speed and height of cut on harvesting efficiency is presented in Table 3. The results were recorded as per the experimental design setup given by the CCRD design.

Table 3: Results on effect of reel speed, cutter bar speed and height of cut on harvesting efficiency

Run	Reel speed, rpm	Cutter bar speed, rpm	Height of cut, mm	Harvesting efficiency,%
1	17.5	250	30	89.45
2	10.0	275	20	92.00
3	10.0	225	20	89.60
4	12.5	250	30	90.00
5	15.0	275	40	90.84
6	12.5	250	10	91.50
7	10.0	275	40	90.25
8	12.5	300	30	92.49
9	15.0	275	20	92.54
10	12.5	250	30	90.00
11	12.5	250	30	90.00
12	10.0	250	30	89.89
13	12.5	200	30	88.95
14	12.5	250	50	88.68
15	15.0	225	20	89.60
16	10.0	225	40	88.75
17	15.0	225	40	88.26
18	12.5	250	30	90.00
19	12.5	250	30	90.00
20	12.5	250	30	90.00

The ANOVA table for the effect of reel speed, cutter bar speed and height of cut on harvesting efficiency of developed harvester is represented in Table 4. The ANOVA table indicated F- value of model (56.99) suggesting the quadratic model as well as linear model could be successfully used to fit experimental data ($p < 0.0001$).

Table 4:ANOVA table for the on effect of reel speed, cutter bar speed and height of cut on harvesting efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value

Model	26.82	9	2.98	56.99	< 0.0001	Significant
R_S -reel speed	0.0124	1	0.0124	0.2367	0.6371	
C_S -cutter bar speed	17.02	1	17.02	325.38	< 0.0001	
H_C -height of cut	7.95	1	7.95	152.07	< 0.0001	
$R_S \times C_S$	0.3281	1	0.3281	6.27	0.0312	
$R_S \times H_C$	0.0242	1	0.0242	0.4628	0.5118	
$C_S \times H_C$	0.1985	1	0.1985	3.79	0.08	
R_S^2	0.1823	1	0.1823	3.49	0.0915	
$C_S^{\ 2}$	0.9745	1	0.9745	18.63	0.0015	
$H_C^{\ 2}$	0.0347	1	0.0347	0.6629	0.4345	
Residual	0.5229	10	0.0523			
Lack of Fit	0.5229	5	0.1046			Non-Significant
Pure Error	0	5	0			
Cor Total	27.35	19				

*** P < 0.001; **P< 0.01; ^{ns} Non significant

It was also observed based on the F-value for the linear term cutter bar speed, height of cut, and quadratic term of cutter bar speed had significant effect at 1 per cent level of significance on the harvesting efficiency (p<0.0001).The interaction term of reel speed and cutterbar speed, cutter bar speed and height of cut, and quadratic term of reel speed had significant effect on harvesting efficiency at 5 per cent level of significance. The other remaining terms *i.e reel* speed, interactive term of reel speed and height of cut, and quadratic term of height of cut had no significant effect on harvesting efficiency.

The predicted R^2 (0.8092) for these model was also found to be in agreement with the value of adjusted R^2 (0.9637) i.e. the difference is less than 0.2.

The variation of the harvesting efficiency (%) was represented by the regression equation 7with different independent variables i.e.reel speed, cutter bar speed and height of cut on harvesting efficiency. The accompanying information describe a mathematical model that predicts harvesting efficiency (ΨE) based on three key factors viz. reel speed, cutter bar speed and height of cut. The regression equation fitted in polynomial form is given below:

$$\Psi_E = +90.03+0.0343R_S+1.03C_S-0.7050H_S+0.2025R_S\times C_S-0.0550R_S\times H_S-0.1575C_S\times H_S-0.1181RS^2+0.1941CS^2+0.0366HS^2 \ldots (7)$$

Where,

Ψ_E = Harvesting efficiency, %;

R_S = Reel speed, rpm;

CS = Cutter bar speed, rpm; and

HC =Height of cut, mm.

Other researchers also work on the same line like Liang *et al.*2017 developed a threshing model and found that combine performance could be improved by analyzing and optimizing the structure and variables of the threshing unit. Siska and Hurburgh (1994) developed the corn breakage prediction model using multiple linear regression techniques, with R^2 of 0.65. Additionally, Maertens *et al.*(2001), Maertens and Baerdemaeker (2004)and Miu and Kutzbach (2007) forecasted the characteristics of the material moving inside combine harvesters.

3.2 Effect of reel speed and cutter bar speed on harvesting efficiency

The three dimensional graph depicting the effect of reel speed and cutter bar speed on harvesting efficiency is shown in Fig.2. It was concluded that the harvesting efficiency slightly decreased with increase in reel speed. It was also observed that by increasing cutter bar speed the harvesting efficiency was increased. The highest harvesting efficiency (92.54 %) was observed at 15 rpm reel speed and 275 rpm cutter bar speed. The contour of the effect of reel speed and cutter bar speed on harvesting efficiency in Fig. 3. A decreasing trend was also observed for the harvesting efficiency with the decrease in cutter bar speed. It might be due to availability of less opportunity time for cutter bar for cutting plants at lower cutter bar speed. A similar decreasing trend for was reported by Bheda*et al.* (2019) and Similar findings were also confirmed by Tanti *et al.* (2019), Ogunlowo and Olaoye (2017).

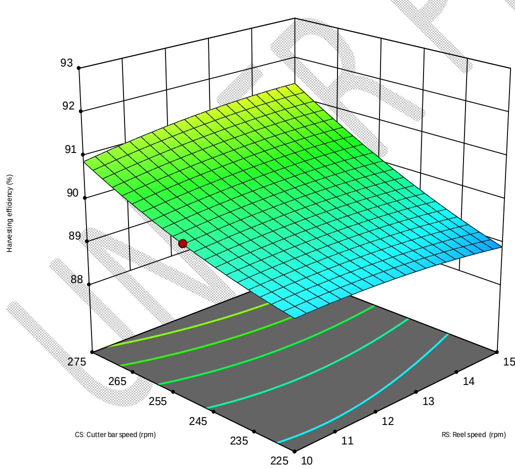

Fig.2: Effect of reel speed and cutter bar speed on harvesting efficiency

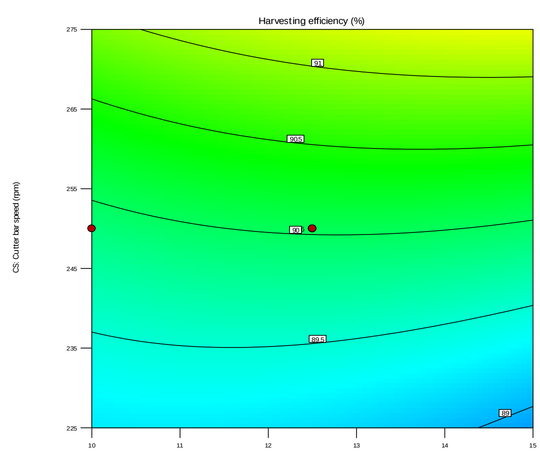

Fig. 3: Contour image on effect of reel speed and cutter bar speed on harvesting efficiency

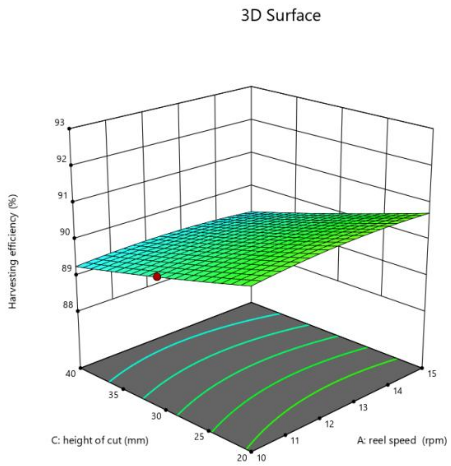

Fig. 4: Effect of reel speed and height of cut on harvesting efficiency

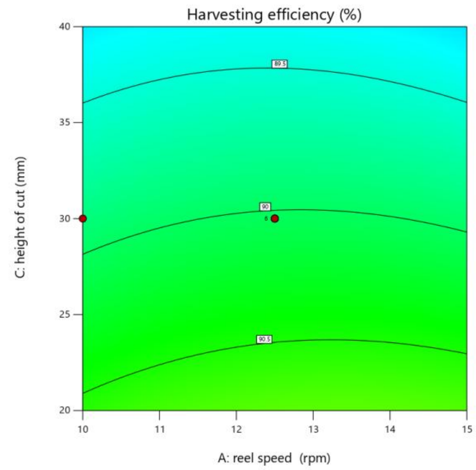

Fig. 5: Contour image on effect of reel speed and height of cut on harvesting efficiency

3.3 Effect of reel speed and height of cut on harvesting efficiency

The effect ofreelspeed and height of cut on harvesting efficiency was shown in Fig. 4. The data observed from the graph showed that the harvesting efficiency decreased with increase in reel speed as well as height of cut. The highest harvesting efficiency (92.54 %) was observed 15 rpm reel speed and 20mm height of cut. The contour of the reel speed and height of cut on harvesting efficiency is presented in Fig. 5. Similar findings were obtained by Junsiri and Chinsuwan(2009) showed that head grain loss increased with increase in reel rotational speed and reel height.

3.4 Effect of cutter bar speed and height of cut on harvesting efficiency

The effect of cutter bar speed and height of cut on harvesting efficiency is shown in Fig. 6. It was found that both the factors affect the harvesting efficiency. The highest harvesting efficiency (92.54%) was observed at 275 rpm cutter bar speed and 20mm height of cut while the lowest harvesting efficiency (88.26%) was found at 225rpm cutter bar speed and 40mm height of cut.The probable reason for this may be the bending and skipping of short height plants at higher cutting height because the top portion of the plant (seed portion) has less bending strength.

Bawatharani*et al*. (2016) also reported that at increased cutter bar heights, crops with lower height cannot be cut by the cutter bar. The contour of the effect of effect of cutter bar speed and height of cut on harvesting efficiency was presented in Fig. 7.

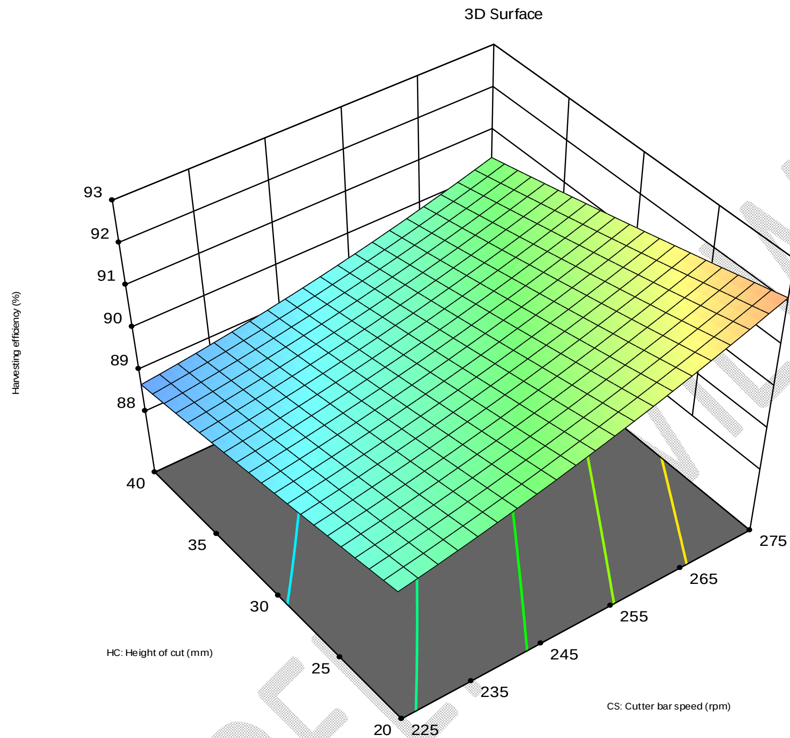

Fig.6: Effect of cutter bar speed and height of cut on harvesting efficiency

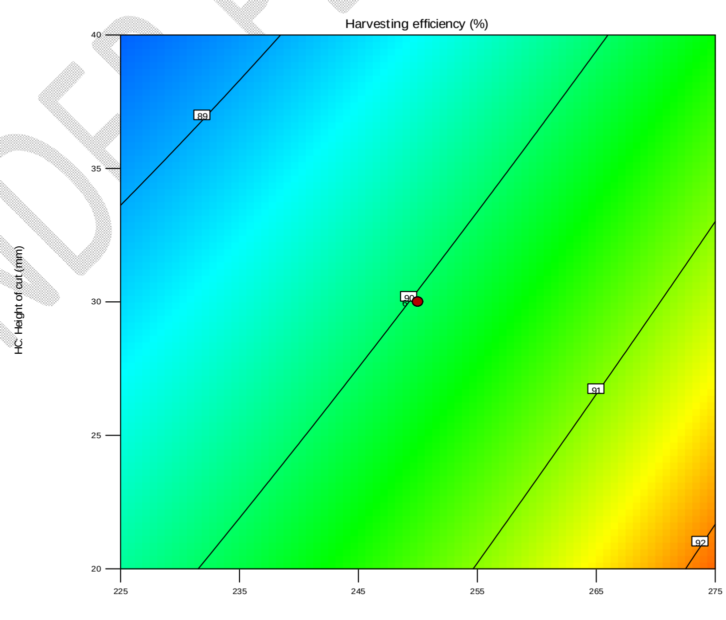

Fig.7: Contour image on effect of cutter bar speed and height of cut on harvesting efficiency

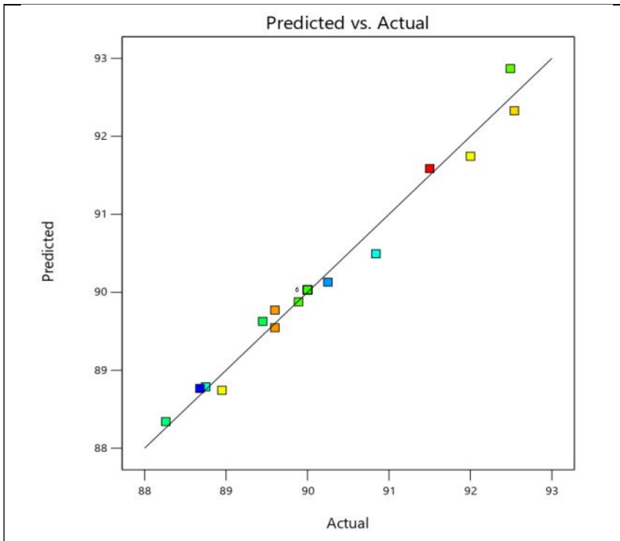

Fig. 8: Graphical presentation of actual and predicated value of harvesting efficiency

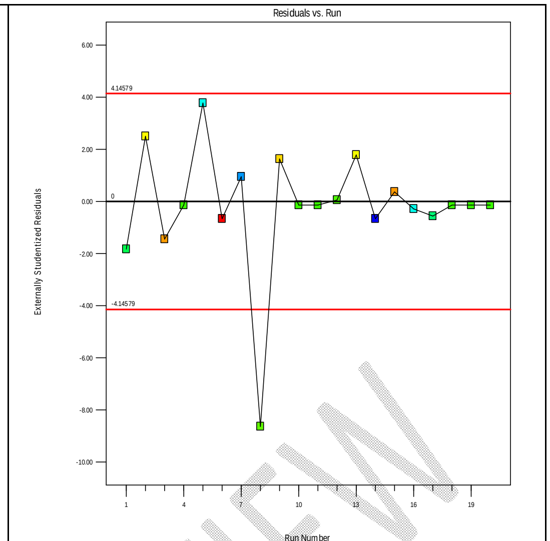

Fig. 9: Graphical presentation of residual and time of harvesting efficiency

4. Conclusions

The results showed that response surface method is well capable to predict data with negligible error and present the proper relationship between the independent variables (reel index, the cutting height of crop, horizontal distance of reel from cutter bar and vertical distance of reel from cutter bar) and header loss. The numerical optimization method was used to optimize the values of independent variables using Design Expert 13.0 software. The software predicted the optimum values of height of cut, cutter bar speed and reel speed as 30mm, 250 rpm and 12.5 rpm respectively. The predicted value for the dependent variable according the criteria selected during the numerical optimization for harvesting efficiency was 90%. The actual values found were more or less near to the predicted values suggested by the mentioned software.

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